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Towards Regionalisation of Soils in Northern Thailand and Consequences for Mapping Approaches and Upscaling Procedures

Zur Regionalisierung der Böden von Nordthailand und ihre Auswirkung auf mögliche Kartieransätze und Upscaling Verfahren

This thesis was accepted as a doctoral dissertation in fulfillment of the requirements for the degree “Doktor der Naturwissenschaften (Dr. rer. nat.)” by the Faculty of Natural Sciences at the University of Hohenheim on 15.09.2008.

Date of examination: 15.09.2008

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Diese Arbeit wurde von der Deutschen Forschuungsgemeinschaft in Rahmen des Sonderforschungsbereiches 564 The Uplands Program: Nachhaltige Landwirtschaft und Landentwicklung in Bergregionen Südostasiens, Teilprojekt B1 gefördert.

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Abbreviations

Al^{3+}	exchangeable aluminium [$cmol_c$ kg^{-1}]
BD	bulk density [g cm^{-3}]
BS	base saturation [%]
Ca^{2+}	exchangeable calcium [$cmol_c$ kg^{-1}]
C_{carb}	carbon content of calcium carbonate [g kg^{-1}]
CEC_{clay}	cation exchange capacity of the clay at pH 7 [$cmol_c$ kg^{-1}]
CEC_{soil}	cation exchange capacity of the soil at pH 7 [$cmol_c$ kg^{-1}]
C_{org}	organic carbon [g kg^{-1}]
C_t	total carbon [g kg^{-1}]
ECEC	effective cation exchange capacity of the soil at pH 7 [$cmol_c$ kg^{-1}]
Fe_d	the Fe fraction, extractable in dithionite [%m]
Fe_o	the Fe fraction, extractable in oxalate [%m]
K^+	exchangeable potassium [$cmol_c$ kg^{-1}]
K_{CAL}	calcium-acetate-lactate extractable potassium [mg kg^{-1}]
Mg^{2+}	exchangeable magnesium [$cmol_c$ kg^{-1}]
m asl	meters above mean sea level
M	moles per litre
ML	maximum likelihood
NA	not analysed or investigated
Na^+	exchangeable sodium [$cmol_c$ kg^{-1}]
NS	not significant
N_t	total nitrogen content [g kg^{-1}]
P_{CAL}	calcium-acetate-lactate extractable phosphorous [mg kg^{-1}]
Sibumasu	**Si**am, **Bu**rma, **Ma**laysia, **Su**matra
SOTER	World Soils and TERrain Digital Data Base (FAO 1995)
WRB	world reference base for soil resources

1. Introduction

North-western Thailand exceeds many other tropical regions in variability of elevations, vegetation, climate, land use, and petrography. In the morphogenetic sense the landforms of Northern Thailand represent transitional features ranging from old continental blocks to the young alpine mountain chains (Kubiniok 1999).

North-western Thailand is nowadays the homeland of many different ethnic minorities and refugees from neighbouring countries (Schliesinger 2000). Traditionally, the cultural background of these minorities dwelling in the mountainous highlands mostly classified them as hunters or shifting cultivators (Kunstadter *et al.* 1978).

Due to dramatic population increases shifting cultivation has decreased rapidly (Ganjapapan 1998). Today, most of the people's livelihoods depend on an increasingly intensified agriculture. The intensification of cultivation, the extension of deforestation and devastating fire during the dry season causes many severe problems not only to the high, but also to the lowlands. The highlands are facing soil erosion, nutrient leaching, decreases of other natural resources (e.g. drinking water, forest products) and yields (Panomtaranichagul and Nareuban 2005), finally resulting in a deterioration of farmers livelihoods (Ashadi 1992). The lowlands face increased sediment accumulations (Penny and Kealhofer 2005) as well as water pollution and flooding (Panomtaranichagul 2006).

Solutions for these present problems comprise mainly the improvement of education to achieve an understanding of the environment and the shift from fully market oriented cultivation systems to site adapted cultivation systems, which are more sustainable and favour several crops to secure nutrition and stabilise income. The knowledge about the given soils, their properties, and distribution in the landscape is a prerequisite for the implementation of such site adapted and sustainable agricultural systems.

1.1 Problem statement and objectives

Up to now, information on highland soils of Northern Thailand was quite sparse, though some studies of different comprehensiveness and foci were available. Hendricks (1981) investigated soil vegetation relations at three locations in Chiang Mai and Chiang Rai province. Hansen (1991) focused on soil formation and soil properties in a mountainous watershed in Chiang Mai province. Van Keer (1992) investigated the soils of seven different research sites within North-western Thailand. Weltner (1996) focused on soils, landform genesis and land suitability in the Doi Inthanon area. Kirsch (1998) studied the soil and relief genesis of soils in the Nam Mae Chan watershed. Anongrak (2003) investigated a soil catena in the Doi Inthanon area under consideration of vegetation and land use.

Reasons for the rather low data density are mainly terrain inaccessibility, steep slopes, remoteness from research centres and also political reasons like declaration of conservation areas and use by ethnic minorities.

A great share of the highlands has been considered unsuitable for agricultural production in land suitability surveys and was hence ignored in soil surveys (Hendricks 1981). Most of the soil cover has been classified as an undifferentiated "slope complex" *(*Vijarnsorn and Eswaran 2002).

Due to continuously increasing population (National Statistic Office Thailand 2007) and extension of agricultural land, the spatial variability of highland soils and their properties cannot be ignored any longer, but have to be systematically investigated in order to enable sound land use planning and to develop future options for the highland population.

The present study was conducted within the framework of the SFB 564 (special research program), which was implemented in 2000 in order to address the major problems faced by highland areas. This program is primarily investigating agricultural systems in the highlands of Northern Thailand and Northern Vietnam focussing on the development of innovations in order to improve the present living standards and to achieve a higher degree of agricultural sustainability, facilitating a perspective for the livelihoods of coming generations (Heidhues *et al.* 2007). To achieve this aim, understanding the environment and its interactions is a precondition. Thereby, knowledge of soil and soil properties plays a significant role.

From this the following objectives have been derived:

- Identification of the key factors of soil formation and distribution in North-western Thailand in order to enable predictive mapping.

- Investigation of different soil mapping approaches regarding their suitability for specific areas and scales.

- Assessment of the potential of local (soil) knowledge for soil mapping and land use planning.

2. General description of the region

2.2 Physiography

Northern Thailand is characterised by mountain ranges, generally trending in a north-south direction with slight curves (see Figure 2-1).

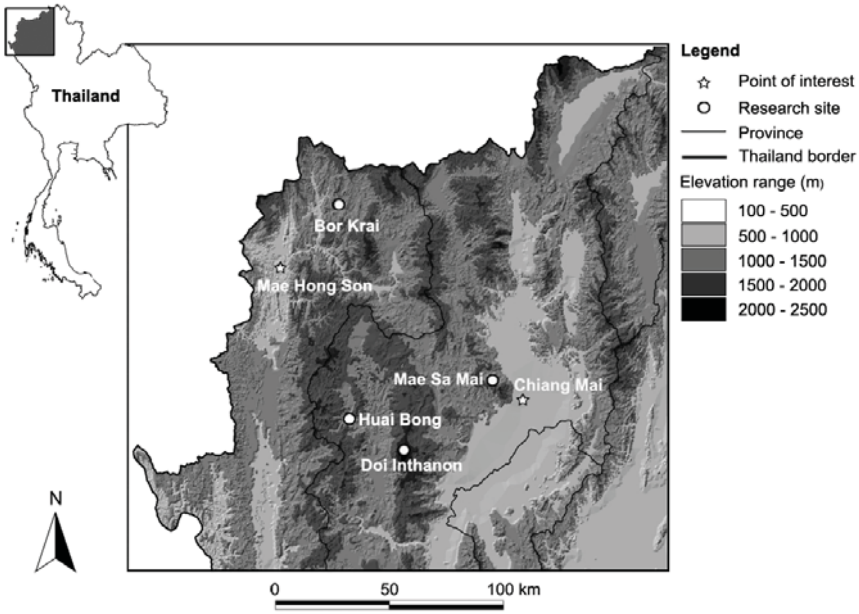

Figure 2-1: Physiography and research sites in North-western Thailand (topography based on Royal Thai Survey Department (1976))

"Doi Inthanon", the highest mountain in Thailand, with an elevation of 2565m above mean sea level (m asl) is an integral part of North-western Thailand. Between the main mountain ranges several basins exist, like the ones at Chiang Mai (Wattananikorn *et al.* 1995), Pai or Fang (Morely *et al.* 2001). With respect to this area, elevations higher than 500m asl, are called highlands (Vlassak *et al.* 1992). Lower foothill zones, basins and valleys are defined as uplands (Buddee 1985).

Further descriptions within the present study are restricted to the highlands. Morphogenetically, the landforms of Northern Thailand range from stable and largely flat relief of old continent blocks to young mobile alpine mountain chains (Kubiniok 1999).

While in the tropical zone old continental blocks are largely dominated by superficial denudation processes with insignificant linear incision and landforms showing little structural control (Büdel 1965), the high mountains are dominated by linear erosion, mass movements, and structural landforms controlled by endogenic dynamics (Löffler 1977). The intramountain basins of Northern Thailand show features that are transitional between these two extremes. Remnants of a tropical erosion surface survive as elevated, relict land surfaces in the summit regions of the mountain ranges and as old terraces surrounding the intramountain basins. The major part of the mountainous relief, however, is characterised by V-shaped valleys separating sharp crested ridges with steep side slopes (Kubiniok 1999). The region remains tectonically active since the collision between India and Asia, indicated by occurrences of hot springs, frequent earthquakes, and the above mentioned V-shaped valleys. In this transition zone between Himalaya and the tropical lowlands sloping land is predominant.

2.2 Climate

Northern Thailand is divided in two different climate types concerning elevation ranges. The lower elevations with a temperature of the coolest month over 18°C belong to the tropical humid climate, “Aw”-type [A = tropical rainy climates; w = dry during the period of low sun angle and wet during the period of high sun angle]. The higher elevations with an average temperature in the coolest month below 18°C belong to the humid mesothermal climate zone, “Caw”-type [C = humid mesothermal; aw = dry winters] (Köppen 1923, Trewartha 1968, Landon 1991).

Three different seasons can be distinguished in Northern Thailand. The rainy season begins with the onset of the southwestern monsoon in May or June and continues until mid-October. Approximately 90% of the total annual precipitation falls during this period. During the rainy season the southwest – to west monsoon transports warm-humid air masses from the Indian and Pacific Ocean, while a low pressure cell is dominating the Asian landmass, causing heavy convective rain showers. In this period the intertropical convergence zone is moving northwards over Thailand in May and southwards in September (Eelaart 1974).

In the following cool dry season lasting from November until February, the Asian landmass is under the influence of a high pressure cell. During this period, the northeast monsoon brings cool dry air masses which cause night time and early morning temperatures occasionally to drop to the freezing point at high elevations (>2000m asl). During this season very little rainfall occurs, while air humidity remains relatively high.

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The hot and dry season usually begins approximately in February and continues until May delivering warm winds from the south causing a temperature increase. During this time, precipitation is quite rare, as Thailand and especially its northern part are located in the "rain shadow" of western mountain ranges (Eelaart 1974). Intermittent rain showers may arrive approximately end of April lasting until the start of the monsoon season (Hendricks 1981).

Climate data for the highlands are rare as most of the climate stations are located in lowland and in valley position. Hence, the variability of the adiabatic lapse rate is unknown making sensible interpolations almost impossible.

2.3 Geology, petrography and landscape history

Northern Thailand can be subdivided into several tectonostratigraphic terranes with each terrane having its own history. The research sites for this study belong to the former Sibumasu terrane (name derived from **Si**am, **Bu**rma, **Ma**laysia, **Su**matra), which was positioned in the southern hemisphere as part of NW-Australian Gondwana until Early Perm (see Figure 2-2).
With the opening of the Meso-Tethys the Sibumasu terrane was separated from Gondwana (Wakita and Metcalfe 2005).
During the Permian age the continuous spreading of the Meso-Tethian Ocean enlarged the distance between the Sibumasu terrane and Gondwana. At the same time, the Paleotethys between the Sibumasu and Indochina terrane was in process of closing by subduction below the Indochina terrane. Behind the subduction zone the "Nan-Uttaradit back arc basin" developed and led to the separation of the Siamo from the Indochina terrane. At the end of the Triassic with the closure of the "Nan-Uttaradit back arc basin" and the Paleotethys, the Sibumasu, Siamo and South China/Indochina terranes were amalgamated. The collision of those terranes caused a folding of the continental margin deposits and widespread granitoid intrusions, known as the Indosinian orogeny (Charusir 1993).
In the Cretaceous the Meso-Tethys between the West Burma terrane and the eastern part of the Sibumasu terrane closed. The resulting suture corresponds with the border area between Thailand and Burma (Myanmar).

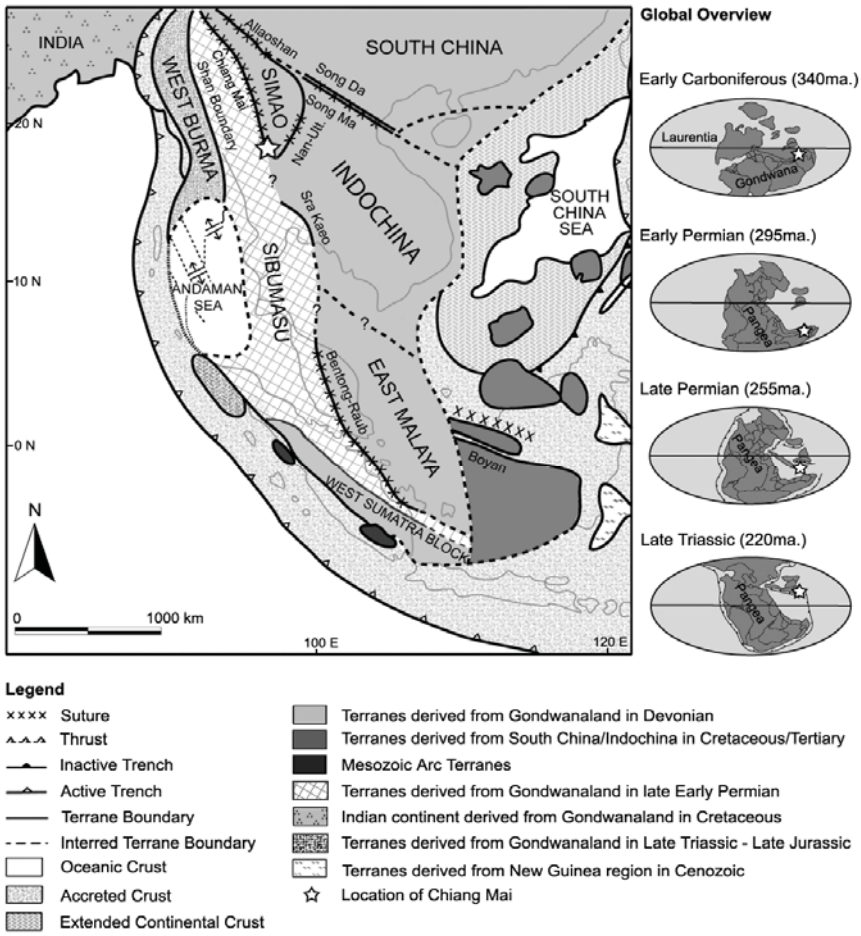

Figure 2-2: Geology of N-Thailand (adapted from Wakita & Metcalfe 2005).

The sequence of the former Sibumasu terrane consists of Precambrian paragneiss and marble, Paleozoic and Mesozoic sandstones, conglomerates, chert, shale, limestone, granites and basalts.

The collision of the Indian and Asian Plates in Tertiary caused the formation of basins along the old suture zones. Most are fault-bounded rifted basins, which were possibly initiated by strike-slip faults often showing NW-SE and NE-SW trends.

The development of Tertiary basins in Thailand commenced with narrow, rapidly subsiding rift grabens with fault-controlled lacustrine sedimentation followed by alluvial deposits.

Some of these Tertiary basins in Thailand have a petroleum potential (Lawwongngam and Philip 1993). The development of the present relief goes along with an uplift starting at the Pliocene/Pleistocene boundary.

Quaternary uplifts are expressed by fluvial deposits above the present valley floor as seen for example in Huay Bong (Schuler *et al.* 2005). Present tectonic activities are linked with hydrothermal activity (Sasada *et al.* 1987).

2.4 Vegetation

The actual **vegetation** of North-western Thailand is in a depleted state. Due to commercial exploitation and population growth the forest dramatically decreased in Northern Thailand from about 69% in 1961 to 43% in 1998, which corresponds to a loss of 43218km^2 (Wannitikul 2005). Maxwell (2004) even considered the remaining land covered with forest to be only about 15% and steadily declining. In the intervention zone of this project little primary forest is conserved (Maxwell and Elliot 2001).

Up to 1000m elevation the forest consists of various deciduous and evergreen tree species and bamboo. Evergreen trees are common on elevations above 1000m asl and wet areas close to streams.

Deciduous trees are widespread under the drier conditions below 1000m asl. Bamboos are a feature in often fire disturbed sites (Maxwell and Elliot 2001). Vegetation zones in dependence of the elevation, which could be assumed as the regional potential vegetation types, are described more detailed for the Doi Inthanon area by Weltner (1996).

Pampasit (1994) found a clear relationship between different plant associations in a dry dipterocarp forest and soil properties. The *Shorea siamensis* Miq. var. *siamensis* (Dipterocarpaceae) association was found on shallow (<50cm), coarse textured Entisols (Leptosols) with abundant rock fragments. The *Shorea obtusa* Wall. ex Bl. (Dipterocarpaceae) association was located on an Inceptisol (Cambisol) with a soil depth between 50 and 80cm.

The *Dipterocarpus obtusifolius* Teijsm. ex Miq. var. *obtusifolius* (Dipterocarpaceae) and *Dipterocarpus tuberculatus* Roxb. (Dipterocarpaceae) associations were associated with Ultisols (Acrisols, Luvisols) with a depth of at least 100cm. The soils of those associations can be distinguished by their different textures and rock fragment contents.

2.5 Ethnic groups and land use systems

Ethnic minorities, e.g. Hmong, Akha, Lahu, Lisu, Karen, and Shan predominantly inhabit the highlands, while the Thai majority lives in the more fertile lowlands and the valley floors (Hendricks 1981). Agriculture in many parts of the highlands is subject to several restrictions, as for example the use of machines is mostly difficult. Swidden farming remains a common practice. In this zone upland rice, maize and vegetables are cultivated during rainy season. The upper boundary of upland rice cultivation lies around 1200m asl (Hansen 1991). Cabbage is normally restricted to highlands (Martin 1984), its lower boundary lying around 1000m asl (personal observations). Before its eradication during the 1980s, opium was the most valuable cash crop of the ethnic minorities in the highlands and was cultivated during dry season (Renard 2001). According to Hansen (1991) opium favours climatic conditions occuring above 1000m asl. Farmers also mentioned the high opium suitability for soils derived from limestone (personal communication with farmers of Bor Krai). Nowadays opium is replaced by less valuable cash crops, such as vegetables and fruit trees.

Each ethnic group has its own farming system, which influences the soil properties in different ways. The farming systems of the Hmong and the Karen are extreme cases in means of agricultural sustainability.

While the traditional Karen farming system features a short cultivation period followed by a long fallow period the traditional Hmong farming system is characterised by a long cultivation period and a very short fallow period.

The idea of the Karen system is to preserve the soil and other natural resources, while the Hmong intend to exploit the resources until either soil depletion or weed infestation render farming no longer profitable (Schmidt-Vogt 1999). The vegetation of the Karen village areas is accordingly characterised by high species diversity; in contrast the vegetational environment of Hmong villages consists mainly of *Imperata* grass and weeds.

Actually, the farming systems of the Lahu, Karen, and Akha depend mainly on the subsistence-oriented cultivation of rain fed upland rice and maize. Hmong and Lisu systems are more market oriented and often mixed with cabbage, carrot or fruit tree cultivation.

In the valley bottoms paddy rice cultivation is widespread and predominantly done by the Thai-majority and in lesser proportions by the Shan and Karen minorities.

As response to population pressures, the opium ban, forest protection policies, and increasing wealth differences between people from the lowland and upland, the traditional highland farming systems could not be maintained.

Consequently these were substituted by unsustainable cultivation techniques resulting in a dramatic increase of soil erosion, nutrient depletion and application of fertilizers, herbicides and pesticides.

Due to a lack of agricultural extension services to farmers and hence professional knowledge an overuse of agrochemicals is very common (Nath *et al.* 1999). The only extension is provided by traders, who focus more on their economic welfare than on environmental issues.

The long-term impacts of this development are not fully predictable, but dramatic increases of pesticides (Reichenberger *et al.* 2002) and sediment loads (Kubiniok 1999) in freshwaters are already documented. Moreover, the pollution of streams flowing into lowland villages caused already intense protests among the Thai majority (Renard 2001).

2.6 Soils

In order to assure a standardisation, the "World reference base for soil resources" WRB (FAO 1998) soil classification system was applied. Only in those cases, where reviewed data do not ensure a clear differentiation of reference soil groups, mixed soil group names are applied, like Luvisol/Alisol.

According to the FAO world soil map (FAO 2003) based on the World Reference Base for Soil Resources (WRB) at a scale of 1:25 million, Northern Thailand is dominated by Acrisols, Alisols, and Plinthosols. At a larger scale of 1:1.2 million on the "General Soil Map of Thailand" (Vijarnsorn and Eswaran 2002) the same area features mainly the so called uniform "slope complex" lacking soil group differentiation, followed by Alfisols (Luvisols), Ultisols (Acrisols, Alisols), Oxisols (Ferralsols, Plinthosols), and Inceptisols (Cambisols, Gleysols, Anthrosols). The term "slope complex" was applied for all areas with slopes exceeding 35%, which are more difficult to access than the already mapped lowland areas. At a smaller scale no coherent soil map of Northern Thailand exists. At watershed and subcatchment scale soil mapping of different areas was carried out. Soil mapping of the Mae Chan watershed in Mae Chan district, Chiang Rai province at a scale of 1:200,000 (Kirsch 1996) revealed, that Cambisols and Nitisols dominate upstream and at the highest elevations.

The existence of the Nitisols could not be verified by the data given. Luvisols and Acrisols are widespread in the central part and at mid-slope position. Nevertheless, the available data are in most cases insufficient to differentiate between Luvisols and Acrisols. A minor occurrence of probably Luvisols was found on basic volcanite in the lower part of the watershed. Fluvisols and Gleysols prevail in the valley bottom and in depressions.

Soil investigation data of the Sap Poeng – San Pa Yang area in Mae Taeng district, Chiang Mai province at a scale of around 1:60,000 (Yemefack 1995) indicate for granite and gneiss areas, that Luvisols dominate below 500m asl, somewhere above 500m asl Luvisols pass over into Acrisols. Elevations above 1000m asl are dominated by Cambisols followed by Acrisols. Despite this, Acrisols and Cambisols dominate below 700m asl on quarzitic phyllite and slate, while parts consisting of marble are mainly covered with Phaeozems. In the alluvial terraces between 320 and 340m asl Stagnic Luvisols prevail.

For the soil maps of Doi Pui and Doi Luang in Chiang Rai province and the soil map of Mae Sanaam in Chiang Mai province at scale of 1:15,000, Hendricks (1981) used individual soil units. Unfortunately, these findings are almost impossible to convert into international soil classifications. Nevertheless, his transect and soil profile descriptions according to "Soil Taxonomy" (Soil Survey Staff 1951, 1967, 1975) give a valuable impression of the soil variability at this scale. On a transect of 3km length at Doi Pui sandstones and conglomerates on slopes between 450 and 800m asl mostly Acrisols are developed. At around 300m asl shales are covered with Acrisols and Alisols. At 800m asl a Ferralic Cambisol was found. On alluvial deposits at around 300m asl Stagnic Luvisols were found. Another transect at Doi Luang with a length of 4.5km showed that on slopes of granite, granodiorite, and quartz veins mainly Acrisols and Alisols are developed.

The data are insufficient to confirm the existence of Alisols according to the WRB 1998 classification. The terrace is dominated by Luvisols and Acrisols. Recent alluvial deposits are covered with Gleysols and Fluvisols, the latter found along Mae Chan stream. On a 1km long transect at Mae Sanaam between 950m asl and 1087m asl granite and migmatite developed into Acrisols, Cambisols, and Leptosols. Due to the low amount of samples it is unclear which soil type dominates. On a complex of granite, gneiss, and schist one Luvisol was found. The alluvial deposits at 950m asl are characterised by Fluvisols.

Soil investigations restricted to transect lines and single points were carried out by Okawa *et al.* (1975), Anongrak (1989, 2003), Hansen (1991), Vlassak (1992), Pampasit (1994), Weltner (1996), Kubiniok (1999), Sereke (2002), and Tinoco-Ordónez (2003).

Due to the diversity of approaches at this scale only major findings are reported here. Kubiniok (1999) investigated soils along long-distance cross sections giving a good impression of the regional soil variability. One cross section of more than 70km between 450 and 1200m asl elevation in the Phrao – Phayao region revealed Ferralsols, Acrisols, Cambisols, and Gleysols on slate, siltstone, limestone, granite, sandstone, gravel, and sand.

At another cross section between Mae Sariang and Hot with a distance of 75km Ferralsols, Acrisols, Cambisols, and Lithosols (Leptosols) were found on granite, gneiss, metamorphic rocks, gravel, and sand. A third cross section in the Mae Moh and Chok Nai area along a distance of 30km between 250 and 600m asl showed Ferralsols, Cambisols, and Gleysols on rhyolithe, andesite, limestone, shale, basalt, claystone, siltstone, gravel, and sand. These findings suggest that on regional scales parental material is not the major factor for soil development.

Based on transect investigations at field scale in the Doi Inthanon area Weltner (1996) defined several soil associations (A, B1, B2, C1, C2, D). Soil association "A" consists mainly of Cambisols under a fibric humus layer. This soil association occurs above 1600m asl. Soil association "B" consists of Acrisols, Nitisols, and Ferralsols on geomorphologically stable relief units. In this association Ferralsols dominate on crests, foot slopes, and plateaus. The slopes are dominated by Acrisols. Soil association "C" is dominated by Arenosols and occurs between 700 and 1800m asl and is mainly related to instable areas, characterised by land slides and debris avalanches. Soil association "D", which is characterised by Acrisols and Arenosols, is located below 700m asl, where regolith and similar substrates are widespread. These areas underwent periods of either strong erosion, physical weathering or rather slow mass dislocation. These results indicate that relief is the major soil forming factor in Northern Thailand.

Recent soil formation is dominated by retranslocation and development of iron oxides as well as clay illuviation, especially on granitic rocks. There, due to the high portion of quartz and feldspar grains of the regolith, soils are permeable and facilitate the downward movement of fine particles. The low pedogenic iron content also facilitates peptisation of clay minerals (Kubiniok 1999). The character of the weathering front depends on the various rock types. In basalts, sandstones, siltstones, and shale, weathering mainly proceeds along cracks and fractures and the transition between soil weathering horizon and bedrock is sharp. On coarse crystalline rock, however, the regolith can be more than 10m thick. The uplift rate of an area determines the ratio between soil development and denudation. For granite areas Kubiniok (1999) found with decreasing uplift rates a sequence from exposed bedrock over Leptosols and Acrisols to Ferralsols. Soil degradation by erosion is higher at lower elevations, where the litter layer is less dense (Hansen 1991, Kubiniok 1999). There, soil erosion is intensified by removal of the litter mainly by fire, but also by termites (Hansen 1991). Hansen (1991) observed that Inceptisols (Cambisols) occur at steeper slope segments than the Ultisols (Acrisols). This might be ascribed to greater erosion rates. According to Kubiniok (1999) the age of the oldest soils trace back to Upper Cretaceous to Miocene for some Ferralsols.

This estimation is based on the assumption that the soil age goes along with relief genesis. Therefore, the widespread Acrisols and Cambisols have to be dated as Plio-Pleistocene. In this case Kubiniok (1999) assumed that weathering onset is identical with the formation of one dated basalt and corresponds to the formation of Acrisols and Cambisols on it. He concluded that the Acrisols and Cambisols of Northern Thailand have developed under the present seasonal humid climate while the Ferralsols for which a Miocene age is postulated, were formed under humid tropical conditions. The assumption for the minimum age of the Ferralsols is based on dated basalts. The Ferralsols were only found on basalts form Upper Miocene and older.

Soil properties are often related to the parental material. Cambisols on siltstone and shale are often too shallow for agricultural use and the nutrient stock is less favorable compared to other Cambisols, while Cambisols and Acrisols on crystalline rock have more favorable characteristics. They are often developed on deep regolith and have a sandy loam texture in the upper horizon which ensures both good root penetration and water infiltration (Hansen 1991, Kubiniok 1999). Deep Cambisols on basic rock are best suited for agricultural use; however those soils are not common in the intervention zone of this project. Soils on sandstone are often characterised by extremely low values for CEC and available nutrients.

At elevations above 1000m asl the thickness of the Ah-horizon, brownish soil colours, organic matter content and CEC increase (Hansen 1991, Weltner 1996, Kubiniok 1999) faster than below 1000m asl. This corresponds with the assumed boundary between A- and C-climates and the corresponding one between deciduous and evergreen forests. For the Mae Chan watershed Kirsch (1998) mentioned a similar transition zone between 850 to 950m asl. There Ali- and Acrisols below the transition zone were characterised by several illuviation layers, lower weathering intensity, and higher soil moisture fluctuations in the topsoil (Kirsch 1998). The latter is responsible for the prevailing of clay eluviation-illuviation at lower elevations (Eswaran and Sys 1979, Hansen 1991). Soil on basaltic rock shows a lack of clay mobilisation due to high base saturation and high total clay content (Kubiniok 1999).

In conclusion, according to the literature the soil variability of Northern Thailand is mainly a result of relief development and long-term climatic change during the Tertiary and Quaternary (Weltner 1996, Kubiniok 1999). Elevation, climate, vegetation, and human impacts are considered as additional factors for soil formation (Weltner 1996).

3. Material & Methods

3.1 The mapped areas

In order to achieve a more systematic approach to map highland soil and property variability three sites were chosen based on differences in petrography (see Figure 2-1 and Table 3-1). According to the geological map of Northern Thailand 1:250, 000 (German Geological Mission, 1979) the chosen units (granite, sandstone, and limestone) represent the dominant ones in Northern Thailand. The three areas together include nearly the complete petrographic diversity of North-western Thailand. Topics investigated were petrography, spatial organisation of soils and variability of their physical, and chemical properties, as well as indigenous soil knowledge.

Table 3-1: Research sites

Research site	**Mae Sa Mai**	**Huay Bong**	**Bor Krai**
Province	Chiang Mai	Chiang Mai	Mae Hong Son
District	Mae Rim	Mae Chaem	Pang Ma Pha
Area [km^2]	10.5	6.8	8.5
Elevation range [m asl]	616 - 1540	700 - 1060	550 – 1020
Petrography (predominant)	Migmatite (granite, gneiss)	Sandstone	Limestone
Annual mean temp. [°C]	22.5	20.7*	19.8
Annual mean precipitation [mm]	1517	1071*	1197
Ethnic group	Hmong	Karen	Lahu
Farming system	Commercialised	Subsistence	Subsistence
Main crops	Lychee, cabbage	Rainfed rice, maize	Rainfed rice, maize

* Wat Chan weather station– 930m asl, distance to Huay Bong approximately 38km.

3.1.1 Mae Sa Mai granite and gneiss area

This area is located in Mae Rim district, Chiang Mai province, and covers 10.5km^2. It extends from N 18° 51’ 01’’ to 53’ 55’’ and from E 98° 50’ 44’’ to 52’ 20’’ (see Figure 3-1).

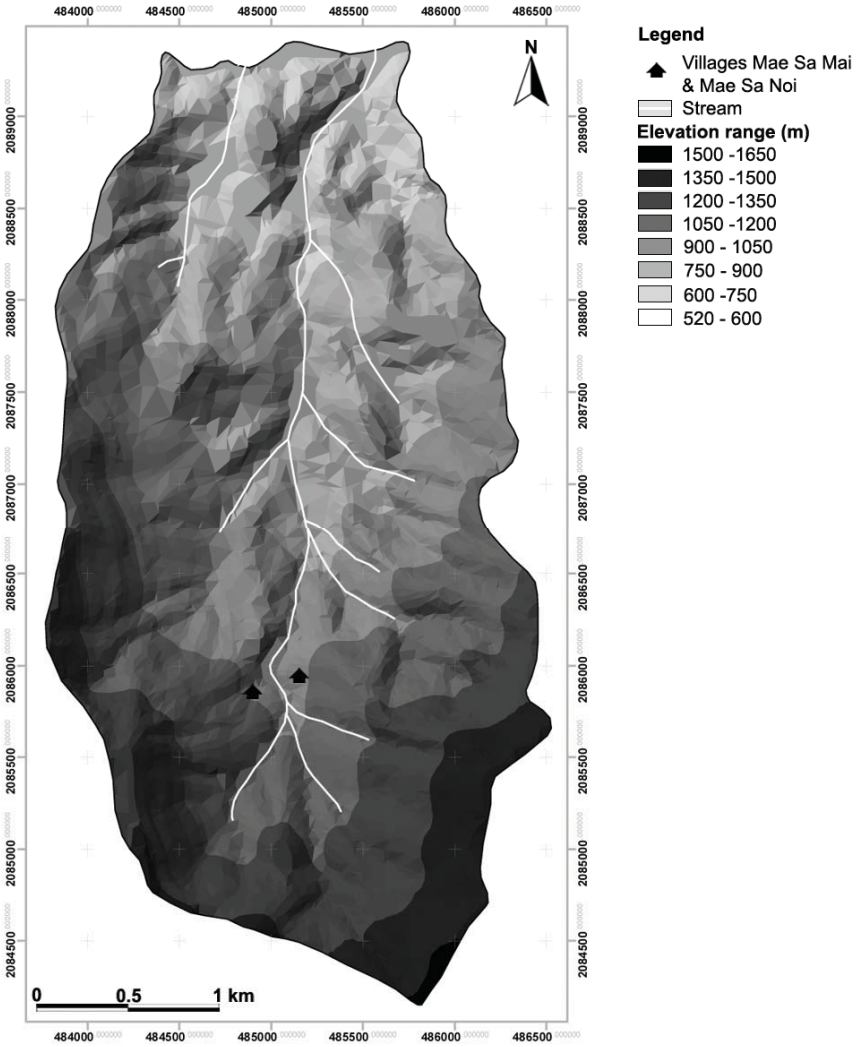

Figure 3-1: Physiography of the Mae Sa Mai area (topography based on Royal Thai Survey Department (1976)).

According to the geological map of Northern Thailand (German Geological Mission, 1979) the petrography of the area consists to 87% migmatites from Palaeozoic granites and 13% Precambrian paragneiss. The Mae Sa Mai subcatchment is characterised by steep slopes, which are dissected by V-shaped valleys.

At middle slope position isolated hills occur, representing remnants of former crests. The elevation ranges from 616m asl up to 1540m asl.

The lowest point is located at the north-eastern boundary of the area, where the Mae Sa Noi creek joins Mae Sa stream. The highest point is found on a mountain peak at the southern boundary. The average elevation of the area is approximately 1000m asl. The average annual precipitation measured for 2001/2002 and 2004 at 820m asl was 1419mm accompanied by an average mean temperature of 21.7°C. For 2005 an average discharge of 11l s^{-1} km^{-2} was measured within the lower part of the Mae Sa Noi catchment (SFB 564 database – unpublished data) which corresponds to 347l m^{-2} a^{-1} runoff and percolation. Almost half of the area is covered with forest with the primary forest on the eastern side degraded, but still intact. Deciduous trees and bamboo dominate the forest below 1000m asl; above it consists mainly of evergreen trees, some pine trees, and bamboo. Along the streams evergreen trees occur. There is no evidence about human activities in this area before 1965.

The two Hmong villages Mae Sa Mai and Mae Sa Noi are situated in this subcatchment. Nowadays, the subcatchment is influenced by Hmong people in the upper part and by the activities of Thai people (Queen Sirikit Botanical Garden and single households) in the lower part. The Hmong originated from the mountainous southern provinces of China. The movement of the Hmong into Northern Thailand has started 1885 (Cooper 1995). In 1965 the Hmong village in the study area was founded under the name Mae Sa Noi at a higher elevation than the present village.

In 1975 the villagers moved to the present position due to water scarcity, and the name was changed to Mae Sa Mai (Maxwell personal communication). In 2004 the village was subdivided into Mae Sa Mai and Mae Sa Noi. Nowadays both villages have together more than 2000 inhabitants (Sangkapitux *et al.* 1999).

Traditionally, the Hmong farming system consisted of swidden farming, mainly growing maize, opium, and upland rice. During the 1970s opium was cultivated as cash crop, maize for stock feed, and mainly rainfed rice for subsistence (Irwin 1976). Since the 1980s various cash crops were introduced. Nowadays lychee orchards dominate the cultivation area. Only a very small area is covered with mango, “Chinese” peach, or coffee plantations. The plantation of fruit trees went along with irrigation activities. Some areas have been reforested with pine trees and some *Eucalyptus sp.* during the 1990s and with native trees on ridges since 1998 (Maxwell personal communication). Due to pressure by the Royal Forest Department a protected forest area has been established in the south-eastern part of the subcatchment (Sangkapitux *et al.* 1999).

3.1.2 Huay Bong sandstone area

This research area is in Mae Chaem district, Chiang Mai province, and covers around 6.8km^2. It extends from N 18° 42' 31'' to 44' 22'' and from E 98° 14' 34'' to 15' 60'' (see Figure 3-2).

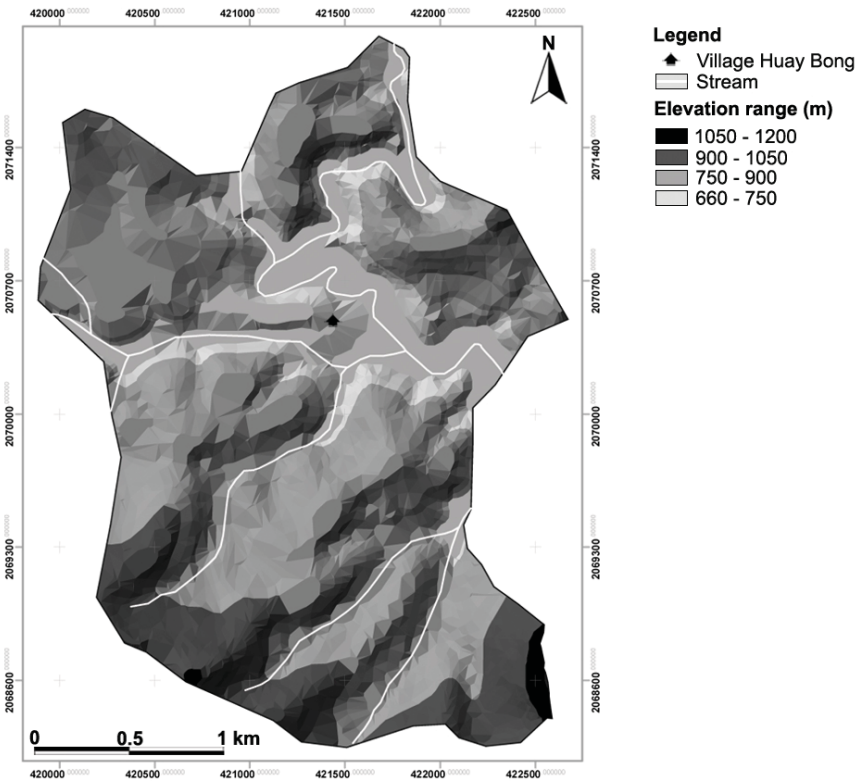

Figure 3-2: Physiography of Huay Bong area (topography based on Royal Thai Survey Department (1976))

According to the geological map of Northern Thailand 1:250,000 (German Geological Mission, 1979) the petrography of the area consists of 97% Upper Carboniferous conglomerate, sandstone, and shale; 2% Quaternary gravel and sand and minor areas of Devonian/Carboniferous shale, chert, limestone, sandstone, and greywacke.

Climatic data for Huay Bong are not available. Within a 40km distance the climatic stations at Wat Chan, Mae Hae, and Doi Inthanon are located and their data were available for this study.

Wat Chan station (Royal project 2007) is the only one at the same elevation range of the Huay Bong area. This station is located N 19° 04' 00''/ E98° 17' 45'' at 930m asl approximately 38km NNE of Huay Bong. Climate measurements between 2002 and 2005 showed an annual mean precipitation of 1071mm and an annual mean temperature of 20.7°C. The Huay Bong area ranges from 700 up to 1060m asl. The lowest point is located in the Mae Yot valley at the eastern boundary of the area. The highest point is a mountain peak in the southeastern corner of the area. The average elevation is 810m asl. The southern part of the study area is dominated by mountains which are dissected by SW to NE trending valleys. To the north the mountains are limited by the broad valley of the Mae Yot River. This broad part of the Mae Yot River is trending from NW to SE. Its broad valley bottom ends upstream and downstream at narrow breakthroughs. The incised meandering of the Mae Yot valley in the NE of the area is one indicator of the uplift of the area. The northern part of the area is mountainous, while the north-western part is characterised by a much gentler surface.

The forest consists of deciduous dipterocarp trees and bamboo covering around 60% of the area. Along the larger streams, evergreen trees exist. The first evidence of human influence in the area is given by a tomb in a cave and temple ruins, which are, according to the local people, several hundred years old. Around 500 years ago, Sgaw Karen settled in the Huai Paku village close to the research area. In the 1960's Huay Bong village was founded (personal communication with the villagers).

Cropping includes paddy rice in the valley floors and upland rice and maize at higher elevations. During the last twenty years, cash crops like mango, tomato and lychee were introduced.

The trend is leading towards intensification of the farming system resulting in permanent cultivation, especially since maize can be sold profitable to a company.

3.1.3 Bor Krai limestone area

This area is in Pang Ma Pha district, Mae Hong Son province, and covers 8.5km^2. It extends from N 19° 32' 41'' to 34' 10'' and from E 98° 11' 38'' to 14' 20'' (see Figure 3-3).

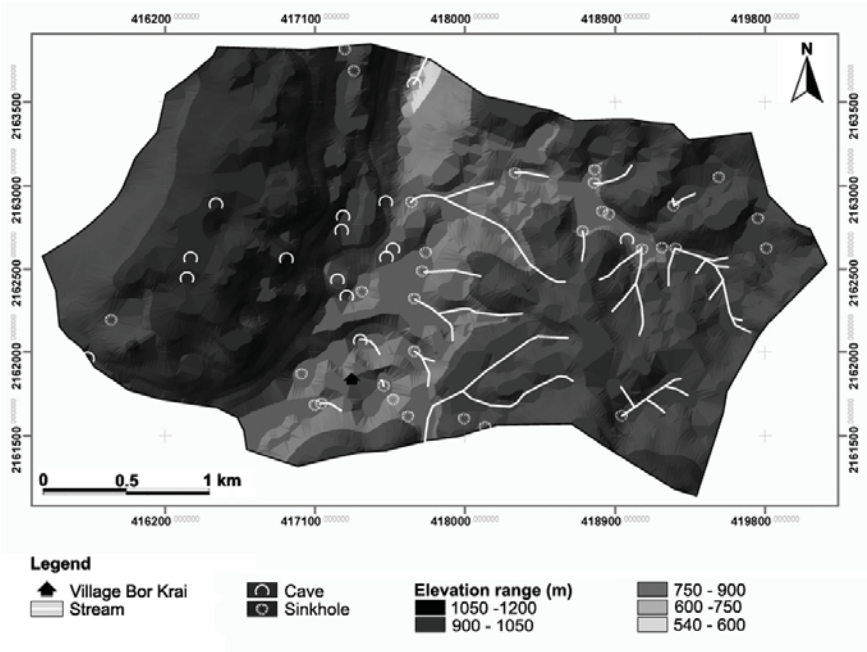

Figure 3-3: Physiography of the Bor Krai karst area (topography based on Royal Thai Survey Department (1976))

The elevation ranges from 550m to 1020m asl with a mean elevation of 810m asl. The lowest point is located in a deep karst depression at the northern boundary of the area. The highest points belong to a mountain chain of limestone in the western part. According to the geological map of Northern Thailand at a scale of 1:250,000 (German Geological Mission, 1979), the petrography of the area consists to 100% of Permian limestone. Climatic measurements for 2004 and 2005 at 800m asl show a mean precipitation of 1197mm and a mean temperature of 19.8°C. During December, the night temperature sometimes drops below 5°C. The western and eastern parts of the area are characterised by steep, often cone-shaped mountains, consisting of mostly massive limestone with karst depressions in between. In the central part of the area smooth hills prevail.

The forest consists of deciduous dipterocarp trees and bamboo, covering approximately 60% of the whole area. Human activities can be traced back to 9,000 to 12,500 years ago. For this time, the first human burials in Pang Ma Pha were reported (Sidisunthorn *et al.* 2006).

Additional prehistoric rock paintings and rock shelters were found in the area. In the Bronze Age, (2300-1600 year BP) coffins were placed in several caves. During the Second World War, the Japanese Army cut parts of the forest mainly for road construction (Bechstedt and Legsomboon 2006, Schuler *et al.* 2006c). In 1963, the Black Lahu (Lahu Na) people moved from Jabo village into the area for pig breeding. In 1974 Bor Krai was founded with 4 households and 28 individuals. The population increased to 60 households with 241 individuals in 2004 (personal communication with villagers). This increase went along with intensive destruction of the forest, extension of agricultural land, and reduction of the fallow period to 3 years. Before 1985, rice mixed with pumpkins, cucumbers, and beans were cultivated in the rainy season. In the dry season, opium was planted.

During the 1980s, several kinds of fruit trees and coffee were unsuccessfully introduced. Today, the rainfed farming system is dominated by cultivation of upland rice, intercropped with pumpkins, cucumbers, beans, and maize (personal communication with villagers).

3.2 Mapping

Digitised topographic, geological, and land use maps; aerial photographs as well as LANDSAT and SPOT images were available as baseline information for the field surveys. A topographic map, compiled by the Royal Thai Survey Department (1976), has a scale of 1:50,000 and contour lines with 20m intervals. These maps were geo-referenced and digitised for use as a base map. The geological map has a scale of 1:250,000 and was compiled by the German Geological Mission (1979). The aerial photographs have a scale of 1:15,000 and were provided by the Military Map Department. The LANDSAT 7 ETM+ image was provided by 'Global Land Cover Facility - GLCF' (GLFC 2007). This image was taken on 5th March 2000. The SPOT 5 images were provided by 'Geo-Informatic and Space Technology agency – GISTDA' (GISTDA 2007). The SPOT 5 image covering the area of Mae Sa Mai was taken on 6th November 2006, the image for Huay Bong was taken on 22nd February 2007, and the image for Bor Krai was made on 1st December 2006. The LANDSAT 7 image consists of 8 different bands, while the SPOT 5 image consists of 4 different bands (see Table 3-2).

During the field trips, a hand-held Garmin GPS III was used to obtain coordinates of the observation points. The evaluation of the field and laboratory data was carried out with the following software: MS Access 2003, ArcView 3.3, and ArcGIS 9.1.

Table 3-2: Properties of available Satellite images

Satellite		Resolution [m]	Range [µm]	Detection/Application
LANDSAT 7 ETM+	Band 1	30	Visible (blue): 0.45 – 0.52	water bodies; soil/vegetation discrimination; forest types; cultural features
	Band 2	30	Visible (green): 0.52 – 0.60	vegetation discrimination, vigour assessment; cultural features
	Band 3	30	Visible (red): 0.63 – 0.69	plant species; cultural features
	Band 4	30	Near Infrared: 0.76 – 0.90	vegetation types, vigour, biomass content; water bodies; soil moisture discrimination
	Band 5	30	Near Infrared: 1.55 – 1.75	vegetation moisture; soil moisture; differentiation of snow from clouds
	Band 6	60	Thermal: 10.40 – 12.50	vegetation stress; soil moisture; thermal differences
	Band 7	30	Mid Infrared: 2.08 – 2.35	minerals and rock types; vegetation moisture
	Band 8	15	Panchromatic: 0.52 - 0.90	provide higher spatial resolution
SPOT 5	Band 1	10	Visible (green): 0.50-0.59	recommended for use in combination with other bands because of low contrast and sensitivity to haze
	Band 2	10	Visible (red): 0.61-0.68	roads, bare soil, discrimination between vegetated and non-vegetated areas
	Band 3	10	Near Infrared: 0.78-0.89	vegetation biomass, water-vegetation discrimination
	Band 4	2.5	Panchromatic: 0,49-0,69	provide higher spatial resolution

According to Lillesand and Kiefer (2000), Mimas (2007).

3.2.1 Reference soil map

For all research areas reference soil maps with a scale of approximately 1:10,000 were created. The purpose of reference soil mapping was to obtain a "best guess" and to set a standard for other mapping approaches. Therefore, a maximum amount of information was included in these maps. All reference soil maps contain information from soil catenas, sampling points along local trails and for areas of low point density or high soil variability, reference profiles, LANDSAT and SPOT images, and topographic information. The mean sampling distance was around 200m.

The 'soil catena' concept was first introduced by Milne (1935) for a soil survey in East Africa and has been applied since to many areas worldwide. The theory proposes the existence of a regular repetition of soils in a certain sequence of soil profiles in association with a given topography (Milne 1935). Within this study, the catena concept was applied for different parental materials and land use types. Soils were investigated along transect lines, covering different geomorphic units, parental materials, and land use types; facilitating the detection of rules for soil distribution (Schlichting *et al.* 1995). Due to the rugged, steep and partly inaccessible landscape of the area this was mainly done along local trails. It was impossible to apply the boundary mapping according to Ostendorf (1955). For Europe, the conceptual soil mapping is another common approach, which is based on interpretation of map units revealed by intersection of geology, topography, land use and other soil forming factors. For each unit a certain soil type is assumed. Afterwards, the concept soil map has to be revised by ground checks until a sufficient amount of correspondence between assumption and reality is achieved (Holland 1996). In Northern Thailand this approach is hardly feasible because information about geology, topography, land use and land use history is available only in very different resolutions.

Due to the envisaged mapping scale a SOTER mapping (Van Engelen and Wen 1995) was also not feasible. SOTER maps consist of hierarchical terrain units which are linked with a data base. The lowest level (soil component) consists of soil profiles with corresponding soil horizons, but does not include vector information about their distribution. Assigned to the SOTER concept, each research area would correspond with only one terrain unit only. The application of the SOTER concept was restricted to the database at profile and horizon level. Reference soil profiles were described according to WRB and SOTER (FAO 1998, 2001; Jahn *et al.* 2006). Finally, the reference soil maps were created based on expert knowledge using ArcGIS software.

The reference soil map for the **Mae Sa Mai** area is based on information from soil catenas, sampling points along local trails, and previous investigations (Khamyong and Manjuti 1997; Laorpanssakul, 2000; Manajuti *et al.* 2004; Spohrer 2007).

Additional sampling points were taken for areas of low sampling point density or high soil variability. Aerial photographs, LANDSAT and SPOT images were used to delineate Anthrosols, Regosols, Leptosols, and water bodies. The area of Anthrosols corresponds with those of former paddy fields, where ground checks revealed this soil type. Regosols correspond mainly to construction sites within the Botanical Garden. Leptosols are characterised by a dense forest at the location of marble outcrops. Topographic information was used for orientation in the field and to facilitate the delineation of soil types in the map. In total, 14 reference profiles and 186 auger points were evaluated (see Figure 9-1).

For the **Huay Bong** area the reference soil map is based on information from soil catenas, sampling points along local trails, and sampling points taken for areas of low sampling point density or high soil variability and topographic information. LANDSAT and SPOT images were mainly used to delineate Cambisols along the valley bottoms.

In this case the cultivation area of the valley bottoms (mainly paddy fields) corresponds with the occurrence of Cambisols. In total, 10 reference profiles and 169 auger points were processed (see Figure 9-2).

The reference soil map for the **Bor Krai** area is a compilation of previous investigations (Tinoco-Ordónez 2003, Sereke 2002, Vlassak *et al.* 1992), information from soil catenas, investigations along local trails, topographic information, field observations, indigenous soil surveys and additional sampling points taken for areas of low sampling point density or high soil variability mapping, and information gained for the randomised grid based mapping approach (see Chapter 3.2.3). LANDSAT and SPOT images were used to delineate the most prominent limestone outcrops. In total, 24 reference profiles and 359 auger points were evaluated (see Figure 9-3).

3.2.2 Maximum likelihood mapping

Detailed soil mapping and field surveys for such a huge region as North-western Thailand are nowadays too expensive and time consuming. Hence, alternative mapping approaches have to be developed, among which the maximum likelihood method is preferable. The maximum likelihood approach is based on the Bayes' theorem of decision making (Milton and Arnold 1995). Normally, satellite image interpretation using the maximum likelihood approach is applied for land-cover classification (Huang *et al.* 2007) and monitoring of land-use changes (Shalaby and Tatsei 2007). Soil related application of maximum likelihood based satellite image interpretation are reported for soil salinity mapping in North-eastern Thailand (Katawatin and Kotrapat 2005), and peat land mapping in Finland (Haapanen and Tokola 2007). Both studies revealed maps with a promising accuracy of more than 80%.

In order to test this method in the context of the present study, soil maps were established for all three research areas.

The used secondary raster data were elevation, slope, curvature, aspect, LANDSAT 7 (bands 1-8), and SPOT 5 (bands 1-4). Maximum likelihood maps were created along the scheme in Figure 3-4.

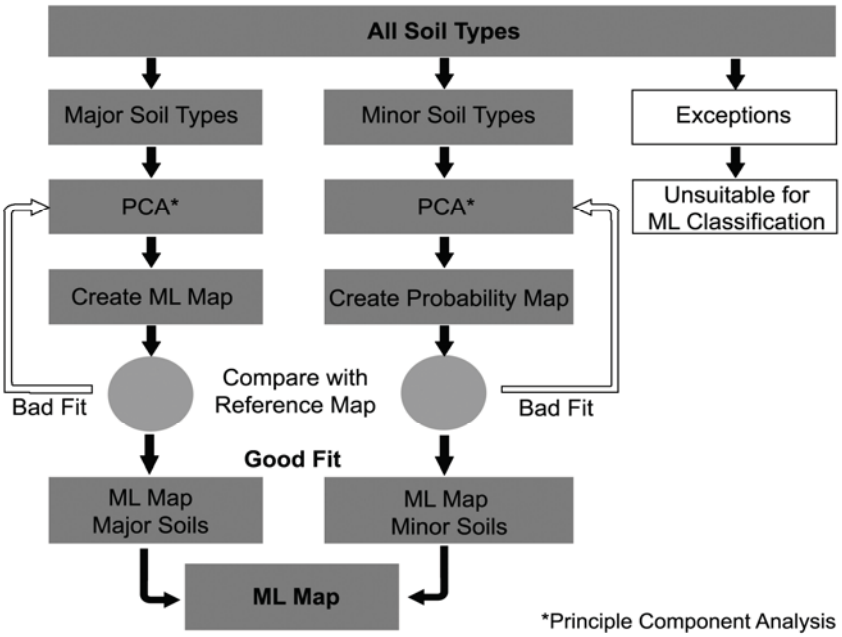

Figure 3-4: Flow chart for soil mapping according to the maximum likelihood method

First, soil types were sorted according to their abundance within an area. Soil types occurring in more than 15% of all samples build up the group “major soil types”. The less frequent soil types, representing between 2 and 15% of all samples were grouped as “minor soil types”. Exceptional soil types representing less than 2% of all samples were excluded from the maximum likelihood mapping since their abundance is not sufficient to calculate a covariance matrix (the calculation of the covariance matrices requires at least 5 different sampling points).

The second step comprised a PCA for both groups using the software PAST 1.69. The aim of the PCA was to select the raster data with the highest explanation value for the given soil data. In a next step the maximum likelihood approach was applied for all sampling points of the major soil types within the area.

This step was implemented using the ArcGIS 9.1 software. Several solutions of the factor analysis consisting of different shares of the respective raster data were compared with the reference soil map. The solution with the highest accordance was selected. The same approach was applied for all sampling points of the minor soil types.

For Mae Sa Mai the major soil types are Acrisols and Cambisols. For compiling the maximum likelihood map of the major soils all secondary information was used, because only in that way the highest correlation with the reference soil map could be achieved. Regosols and Leptosols were identified as minor soil types. The best fit for the Regosols with the reference soil map was achieved by generating a probability map including all secondary data and selecting all areas with more than 90% probability for Regosol occurrence. For Leptosols the best fit was revealed by excluding slope, curvature, aspect, all SPOT bands, and LANDSAT band 4 from the secondary data. Finally, only those areas were selected where the Leptosol showed a probability of more than 90%. All other soil types were considered as exceptions. The final maximum likelihood map was compiled by overlaying the maximum likelihood map of the major soils with the map of the areas, where the minor soil types show a probability of more than 90%.

For the Huay Bong area, Luvisols and Cambisols were identified as the major soil types. The respective maximum likelihood map was created by using all secondary information. Leptosols and Regosols were identified as minor soil types.

For both minor soil types, probability maps were generated by excluding elevation, slope, curvature, and aspect from the secondary data, as suggested by the factor analysis. The final maximum likelihood map was compiled by overlaying the maximum likelihood map of the major soil types with the areas, where the minor soil types show a probability of more than 95%.

For the Bor Krai area Acrisols, Cambisols, and Luvisols were identified as the major soil types. Here again, all secondary information was used to create the respective maximum likelihood map. Leptosols and limestone were identified as “minor (soil) types”. The probability map for the Leptosols was generated by excluding elevation, slope, curvature, aspect, SPOT band 1, and LANDSAT bands 4 and 8 from the secondary data. The probability for the limestone was calculated by using all secondary data. The final maximum likelihood map was created by overlaying the maximum likelihood map of the major soils with the map of the areas where the probability of Leptosols and limestone exceeds 98%.

In order to test the possibility of upscaling the soil mapping based on the maximum likelihood approach was extended from the Mae Sa Mai area (approximately 10.5km^2) to the whole Mae Sa watershed (approximately 138km^2) of which the Mae Sa Mai area is an integral part.

3.2.3 Grid based randomised mapping

For the Bor Krai area an additional randomised grid cell mapping approach was performed. The map of the research area was overlain by a grid of 15 squares with a length of 950m. Afterwards the grid was filled with randomised points until each cell contained at least three points (see Figure 3-5).

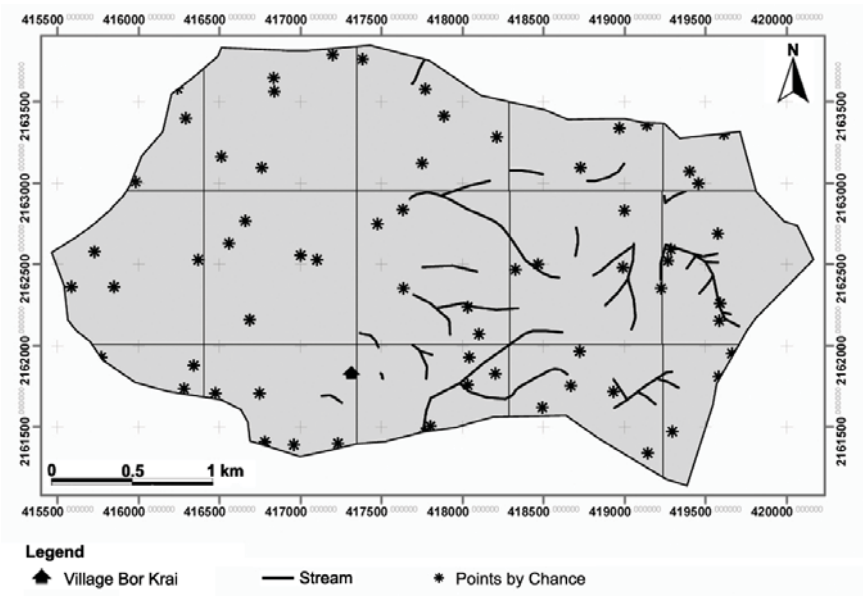

Figure 3-5: Randomised grid cell approach for the Bor Krai area

The sample points were located with a GPS. The deviation of the used GPS accounted for 4m in open areas and 15m in forest or scrub-fallow land. Either no signal could be received or the deviation was worse than 15m close to the steep rugged limestone rocks. In such cases the best approximation was taken.

3.2.4 Soil property mapping

In order to gain a spatial overview several soil properties were kriged with the ordinary kriging approach (McBratney *et al.* 2000). Kriging is a common interpolation technique based on least squares predictors. According to (Goovaaerts 1999) for the prediction of the variable Z at location x_o, $\{Z(z_o)]$, the estimator $Z^*(x_o)$ is defined as:

Equation 3.1:

$$Z^*(x_0) = \sum_{i=1}^{no} \lambda i Z(x_i)$$

here "n_o" represents the number of sample neighbours and the "λi" are weights found by solving the system of equations,

Equation 3.2:

$$\begin{cases} \sum^{n_0} \lambda_j \gamma(x_i, x_j) + \mu = \gamma(x_i, x_0), i = 1,...,n_0 \\ \sum_j^{n_0} \lambda_j = 1 \end{cases}$$

with λ (h) being the theoretical model for the variogram of the variable Z and being also a Larange multiplier (Reis *et al.* 2007).

This approach was performed for the soil pH (H_2O), soil colour value, soil colour chroma, and the A-horizon thickness. Soil property data was introduced into an Access-database and processed with ArcGIS 9.1.

3.2.5 Indigenous soil knowledge

Conventional soil mapping techniques are often time-consuming, costly, and do not always provide relevant data for local stakeholders. As a low cost alternative, which integrates other knowledge domains, Local soil knowledge from Mae Sa Mai, Huay Bong, and Bor Krai was elicited and compared with results obtained by classical soil science methods.

The evaluation of farmers' soil knowledge was based on a "Participatory Rural Appraisal" (PRA) approach (Chambers 1992). It included semi-structured interviews, field and key informant interviews, participatory mapping, and group discussions.

The survey was conducted during the dry season (October to May) in 2004/2005 in Bor Krai (Schuler *et al.* 2006) by a multidisciplinary group of scientists representing expertises in soil science, agricultural extension, farming systems, and rural sociology.

In Huay Bong local soil knowledge was elicited during August and September 2005 (Weiß 2006) and in Mae Sa Mai in November 2005.

In these three villages farmers with long-term practical experience were selected. These key informants were asked which soil types they distinguish and by which differentiating criteria. Soil classification was further refined during field walks with farmers. Soils on the sites chosen by the farmers were described according to local perceptions and the WRB and SOTER system (van Engelen and Wen 1995, FAO 1998 & 2001) and samples were taken. In the next step farmers were asked to rank different soil properties for the local soil types. The ranked soil properties comprised crop suitability, fertility, infiltration rate, available water capacity, erosion hazards, soil stickiness, and topsoil thickness.

Finally, local soil mapping was carried out using aerial photographs (in Mae Sa Mai), a 3D topographic model (in Huay Bong), and topographic maps (in Bor Krai) as communication tools.

3.2.6 Petrographic and geological mapping

In most cases soils derive from the underlying parent rock material. In order to detect relations between soils and parent rock material petrographic and geological mapping was performed. This was mainly done in combination with the soil mapping by determining the rock type at most sampling points. At sites with extraordinary petrography additional points were investigated. Thin sections of rock samples were produced and selected samples were taken for X-ray diffraction analysis. The rocks were classified according to Dunham (1962), Matthes (1996), and Tucker (1985). In nearly all cases the rock age was derived from available geological maps and literature. Only for the Huay Bong area fossil plant leaves were found facilitating the estimation of the age of one rock formation.

3.2.7 Database

All measured data were transformed into databases in order to support further evaluations, analyses, and to facilitate documentation. The software Access 2003 was used to create the databases. The climate data were transferred into a climate database. Field data of the geological and soil surveys were put into a separate database as well, which is mainly structured according to SOTER (SOils and TERaine Digital Databases) according to FAO (1995).

3.2.8 Data evaluation and processing

Data were analysed using the software PAST 1.69, SPSS 14.0 and ArcGIS 9.1.

In order to evaluate the relationship of some relevant soil properties (CEC_{clay}, base saturation, degree of clay illuviation) with other variables the Spearman correlation was applied, as some data were either ordinal data or did not fulfil the normality assumption (Quinn and Keough 2002).

3.3 Soil analysis

Laboratory analyses were conducted at Hohenheim and Chiang Mai Universities from 2003 to 2006. The soil samples were analysed according to several manuals (Klute 1986, VDLUFA 1996, 2001, Schlichting *et al.* 1995, Blume *et al.* 2006, Herrmann 2005).

3.3.1 Soil physics

Bulk density: At least three core samples of each soil horizon were taken to obtain the bulk density. The entire core samples were oven dried for 12 hours at 105ºC and weighed. Bulk density was calculated as the full-core oven dry soil weight divided by the soil core volume.

Infiltration rate: The infiltration rate for some soil profiles was measured using a disc permeameter. The measured infiltration rates together with texture derived parameter α according to Carsel and Parrish (1988) were used to compute the soil hydraulic conductivity according to Wooding (1968).

Moist colour: The moist colour was determined with a Munsell colour chart (Oyama and Takehara 1967) in the field.

Texture: After destruction of organic matter (for organic matter content >1%) samples were dispersed with 0.05M NH_4OH solution and sieved into the fractions coarse (2 – 0.63mm), middle (0.63 – 0.2mm) and fine sand (0.2 – 0.063mm). Coarse (63 – 20mm), middle (20 – 6.3mm), fine silt (6.3 – 2mm) and clay (< 2mm) were determined by sedimentation (Schlichting *et al.* 1995).

Water-dispersible clay: 20g of soil was dispersed in 200ml distilled water , shaken for 12h without any pre-treatment to remove cementing compounds and without use of a dispersing agent. The proportion of water dispersible clay to total clay can be used as a structure stability indicator (FAO 2006).

Water retention: In order to determine soil water retention function, water-holding capacity, and porosity undisturbed (by using soil cores) and disturbed soil samples were taken. The undisturbed soil samples were used to determine water retention at 1, 6.3, 31.6kPa. The soil in the cores was carefully saturated with deaerated water. The saturated samples were placed in a pressure plate extractor. The samples were equilibrated to the corresponding pressures and their gravimetric water content was determined. For 1500kPa disturbed samples were used. A sample of <2mm (sieved), air-dry soil was placed in a retainer ring mounted on a ceramic plate in a pressure plate extractor. The membrane was covered with water to wet the samples by capillarity. The samples were equilibrated at 1500kPa. The pressure was kept constant until equilibrium was obtained. The gravimetric water content was determined and the volumetric transformation was done by multiplying with the bulk density (Burt 2004).

3.3.2 Soil and water chemistry

Alkalinity (Bicarbonates): The alkalinity (bicarbonate) of the water samples was determined by hydrochloric acid titration (Clesceri *et al.* 1998).

Calcium-acetate-lactate (CAL) extractable P and K: Plant available phosphate was complexed by acetate-lactate and tinted blue with molybdate and analysed from the extract at a wavelength of 710nm with a Hitachi U-3300 spectrometer. Plant available potassium was replaced by calcium in the CAL-extract and delivered into the solution in which it was quantified at a wavelength of 767nm with a flame photometer Elex 6361 from Eppendorf (Herrmann 2005).

Carbonate carbon (C_{carb}): C_{carb} was determined using a carbonate detector (Woesthoff Carmhograph C12S). A surplus of phosphoric acid was added to the sample in order to release carbonate C as CO_2. The amount of CO_2 was conductometrically determined after a reaction with 0.1M NaOH solution (Herrmann 2005).

CAT extractable B and Zn: The contents of plant available boron and zinc were measured in the laboratory of the "Landesanstalt für landwirtschaftliche Chemie Hohenheim". Soluble boron and zinc were analysed with the CAT extraction method (VDLUFA 2002).

Dithionite extractable elements (Fe, Al, and Mn): To reduce the iron, samples were treated with dithionite in a neutral buffer solution. A citrate-complex kept the elements in solution. Finally, the elements were measured with an AAS. This extraction method detects theoretically pedogenic, crystalline (and organically) bound Fe-, Al-, and Mn-oxides (Herrmann 2005).

Exchangeable acidity: The samples were treated with 1M KCl solution in order to exchange the acid cations (H + Al). The amount of exchanged acid cations was determined by titration with 0.05 M NaOH (Herrmann 2005, FAO 2006).

Exchangeable cations (Ca, Mg, K, and Na): Exchangeable cations were extracted with NH_4-acetate at pH 7. Mg was measured with an AAS while for Ca, K, and Na a flame photometer was used (Herrmann 2005).

Hot water extractable Mo: The content of plant available molybdenum was measured in the laboratory of the "Landesanstalt für landwirtschaftliche Chemie Hohenheim". The soluble molybdenum was extracted with hot water. The extract was treated with perchloric acid, nitric acid, and hydrofluoric acid in order to remove contaminants and silicic acid.

Afterwards the extract was transferred into a coloured complex. Colouring was carried out with toluene-3, 4-dithiol. Finally, the extinction was measured at 660nm with an emission spectrometer including inductive coupled plasma (ICP-OES) and compared with a calibration function (VDLUFA 1996).

Oxalate extractable elements (Fe, Al, and Mn): Extraction of Fe, Al, and Mn with cold ammonium-oxalate was performed at pH 3, 20º C, in darkness (without UV radiation). The elements were measured with an AAS. This extraction method detects X-ray amorphous oxides, e.g. organically bound Fe, Ferrihydrite-Fe, as well as Fe from allophane (Herrmann 2005).

pH (H_2O): The pH (H_2O) was determined in a supernatant solution of a 1:2.5 soil-water mixture (FAO 1995). The measurement was carried out with a WTW pH/mV Hand-Held Meter pH 330.

pH (KCl): The pH (KCl) was determined in the supernatant solution of a 1:2.5 soil- 1 M KCl mixture (FAO 1995). The measurement was carried out with a WTW pH/mV Hand-Held Meter pH 330.

Potential cation exchange capacity (CEC): The soil was treated with Na-acetate in order to exchange all cations. Afterwards the sample was cleaned with ethanol. To extract Na-cations, samples were treated with NH_4-acetate. The Na concentration was measured in propane activated flame photometer at 589nm (Schlichting *et al.* 1995).

Sampling and pre-treatment: Soil samples were taken from soil profiles and from reference points. Disturbed samples were taken from each horizon. Each sample covers all features of the respective horizon. The samples were dried, carefully ground, crushed, and sieved. The fractions coarser than 2mm diameter (skeleton) were separated and weighed, while the soil fraction finer than 2mm diameter was weighed and used for further analysis. As a first step, air-dry moisture was determined in order to recalculate to oven-dry basis. A reference soil sample was included into each set of analysis to check the precision of the analysis in the laboratory. At least two replicates were also carried out for all analyses.

Total carbon (Ct) and total nitrogen (Nt): The content of Ct and Nt was determined with a C/N analyser (LECO CN-2000). For samples without carbonate the soil organic matter (SOM) content was calculated by multiplying C_{org} with the factor 1.724 (Schlichting *et al.* 1995).

Total hardness: The total hardness of the water samples was determined by ethylenediaminetetraacetic (EDTA) titration (Clesceri *et al.* 1998).

3.3.3 Mineralogy

X-ray diffraction (XRD) was done with a "Siemens D500" powder diffractometer (Michigan Tech 2007). Powder samples were used for bulk samples and oriented specimens for clay mineral determination. The latter includes saturation with K and Mg. For further analysis Mg-samples were treated with glycerol and K-samples were heated to 400 and 600ºC, respectively. Semi-quantitative analysis of the clay fraction included the use of the software package Diffrac AT 3.3 (Siemens). Quantitative mineral composition of the bulk samples was determined using the Rietveld software SEIFERT AutoQuan. X-ray fluorescence (XRF) for total element analysis was performed with a Siemens SRS 200 instrument. Scanning electron microscopy (SEM) was carried out with a LEO 420 instrument with an attached Röntec Edwin-NT-EDX (energy dispersive X-ray spectrometry).

4. Results

4.1 Petrography

The petrographic mapping at all three study sites revealed a clearly higher petrographic variability than indicated on the available geological maps.

4.1.1 Mae Sa Mai

The Mae Sa Mai area roughly consists of 90% migmatite, 9% marble, and to approximately 1% freshwater limestone (Figure 4-1).

The predominant migmatite can be subdivided into a granite dominated migmatite (20% of the area) and a paragneiss dominated one (70% of the area). The paragneiss and granite were dated by the German Geological Mission (1979) as Precambrian and Palaeozoic, respectively. Within the paragneiss bodies of marble and (very small) quartzite were found. While the paragneiss dominates the central and northern part of the subcatchment, granite is merely found in the northern part. Paragneiss bodies of variable sizes are preserved within the granite. Paragneiss and granite have as common minerals microcline, muscovite, and orthoclase. Additionally, the granite contains albite and anorthite. The quartz content of the paragneiss is around 6% higher than in the granite. This indicates reduced weathering rates for paragneiss in comparison to granite.

Table 4-1 Rock composition [%] of the Mae Sa Mai area (X-ray diffraction analysis)

	Freshwater limestone (N=1)	**Granite (N=2)**	**Marble (N=1)**	**Paragneiss (N=2)**	**Quartzite (N=1)**
Biotite	0	0	0	2 ± 3	0
Calcite	99	0	100	0	0
Gibbsite	0	3 ± 4	0	0	0
Kaolinite	0	0	0	9 ± 12	0
Microcline	0	37 ± 1	0	26 ± 12	0
Muscovite	0	4 ± 6	0	3 ± 5	0
Orthoclase	0	2 ± 2	0	21 ± 30	0
Plagioclase (Albite)	0	19 ± 6	0	0	0
Plagioclase (Anorthite)	0	7 ± 9	0	0	0
Quartz	1	28 ± 6	0	35 ± 43	100
Vermiculite	0	0	0	4 ± 6	0

With respect to geomorphology the weak granites are found in valleys, like the Mae Sa valley in the north, while stronger paragneiss builds up the surrounding mountain ranges.

Granites are often covered with a thick and highly weathered regolith. Despite this, the regolith on paragneiss is mostly shallow and not so intensively weathered. Higher percolation rates for the upper part of granite can be assumed. The different clay mineral contents also show the different weathering intensities. Kaolinite and vermiculite were developed in paragneiss and gibbsite in granite (see Table 4-1).

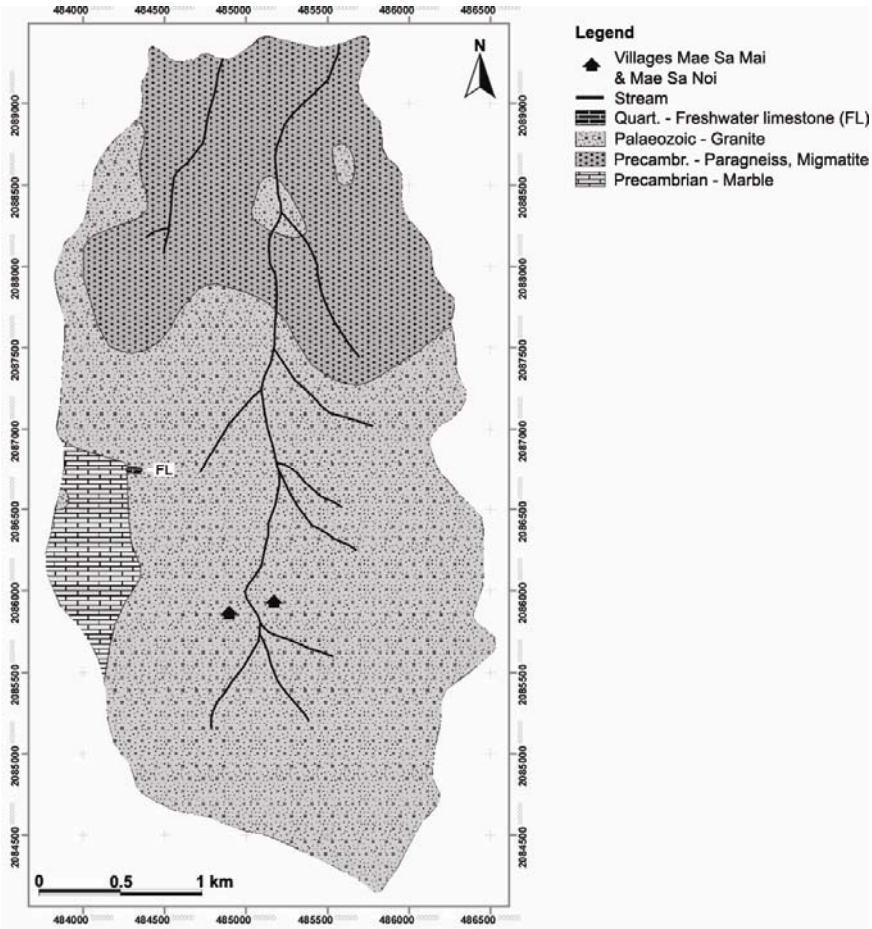

Figure 4-1: Geological map of the Mae Sa Mai area

In the western part of the watershed marble was found in the paragneiss with body sizes ranging from little veins up to a thickness of more than 10 meters. This marble shows clear karst features such as karren and caves. At one site, freshwater limestone is precipitated below a karst spring in the paragneiss-marble contact. The Quaternary freshwater limestone also showed clear karst features in the form of a cave with speleothems. Many prints of leaves and branches are preserved in the freshwater limestone. The marble and freshwater limestone consists to more than 98% of calcite.

4.1.2 Huay Bong

The petrography of Huay Bong (Figure 4-2) is dominated by Carboniferous sediments (sandstone 53%, shale 12%, breccias and conglomerates 10%, marl 6%, claystone 3 %). Additionally, 8% Tertiary sandstone and coal, 7% Quaternary alluvial deposits, and less than 1% Pleistocene conglomerates occur. The Carboniferous sandstone with its intercalations of marl, claystone, breccias, and conglomerate prevails in mountainous areas. This sandstone is composed of 98% quartz and 2% kaolinite. Carboniferous shale exists in the north-eastern and the south-eastern parts. In the north-western part Tertiary sandstone with coal intercalations built up the underground of gently sloping land. Pleistocene conglomerates occur approximately 70m above the Mae Yot River in the eastern part, indicating an uplift of the area. The valley floors of the streams consist of Holocene fluvial deposits. The Carboniferous sequence is in part heavily disturbed by several ancient tectonic events. The Tertiary sandstone contains geodes with plant fossils like *Alnus sp.* (Betulacea) and *Ficus sp.* (Moracea), (Late Oligocene) (see Figures 9-4 and 9-5). The Tertiary sequence belongs to a rift basin which might be caused by strike slip tectonics. The Pleistocene conglomerates above the Mae Yot River, a hot spring around 3 km south of the village, and many Holocene landslides along the river vividly display the still ongoing tectonical activity.

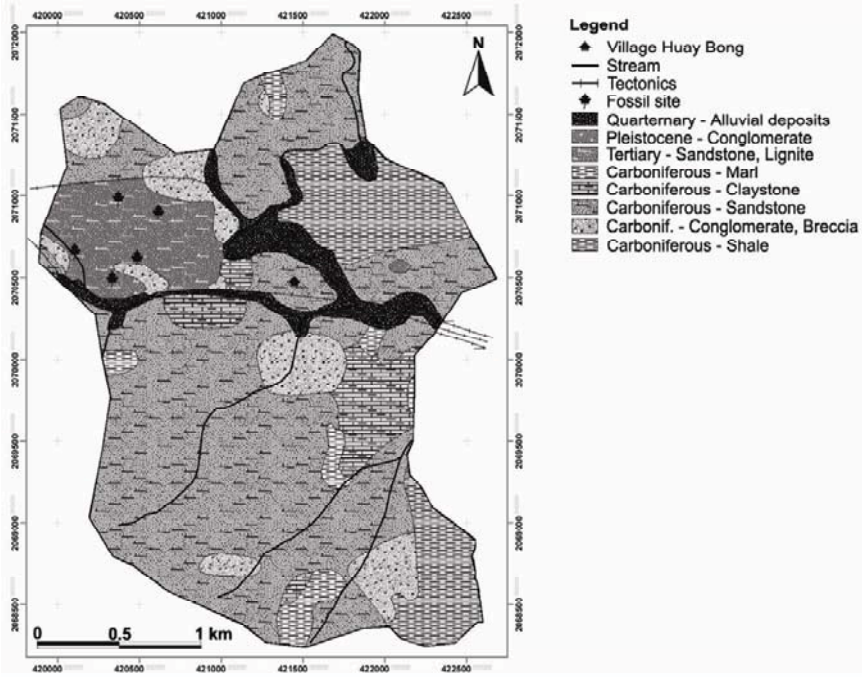

Figure 4-2: Geological map of the Huay Bong area

4.1.3 Bor Krai

The Bor Krai area consists in petrographic terms of 60% limestone and 39% claystone, siltstone, and sandstone. The remaining 1% comprises alluvial deposits, dolomite, freshwater limestone, iron ore, and latite (Figure 4-3). The limestone builds up a steep SW-NE directed mountain chain at the western part of the research area. Further mountains consisting of limestone are positioned at the southern, western, and eastern boundaries. The limestone is crystalline (sparitic), mostly massive, and only occasional layering is detectable. Veins of ironstone and bauxite were found in the limestone.

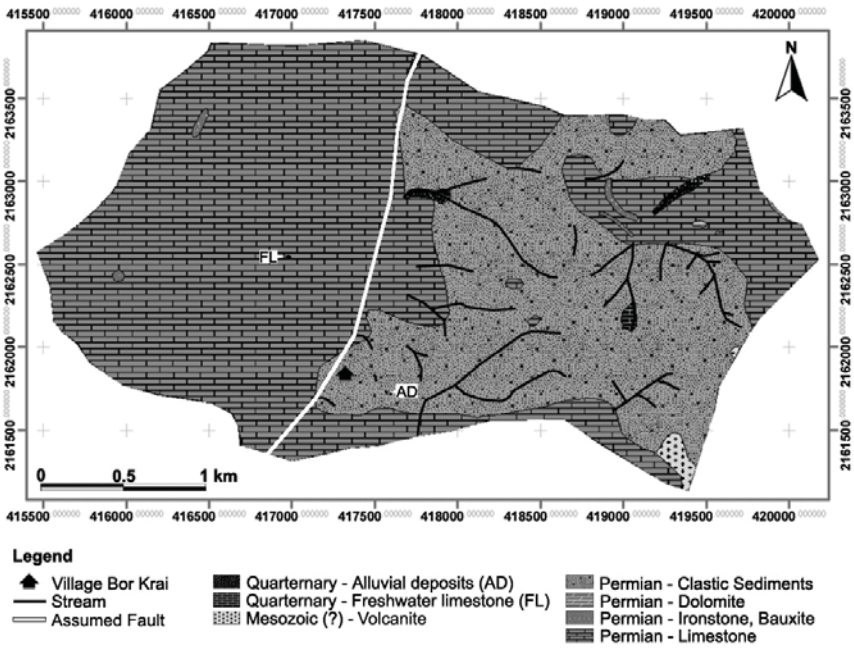

Figure 4-3: Geological map of the Bor Krai limestone area

Usually the limestone in the Bor Krai area consists of more than 97% of calcite and <3% quartz. In the vicinity of ironstone and bauxite outcrops ankerite is also added to its composition. In the locations below the mountain ranges some limestone is covered with claystone. Along the eastern part of the western mountain range the presence of a fault can be assumed, which caused a downward displacement of the eastern part (see Figures 4-3, 4-24 and 4-25). In that way the younger claystone is still preserved. All claystones investigated contain quartz and kaolinite. At some locations layers of siltstone and sandstone are interlacing into the claystone. This claystone shows a yellow weathering colour. Only at few places along the creeks fresh, dark grey coloured claystone was found. The composition of the claystone shows a high variability ranging from marly claystone to pure claystone (see Table 4-2).

The claystone cover is furrowed with small valleys, all ending in a sinkhole except one stream showing a surface discharge during rainy season. At some locations the claystone cover is scarified and groundwater from the limestone aquifer below emerges. Such karst springs supply the village Bor Krai with drinking water and water for domestic use.

The water from the karst springs contains high amounts of $CaCO_3$, with a total hardness of 150mg l^{-1} and an alkalinity (bicarbonate) of 320mg l^{-1} leading to the precipitation of freshwater limestone below. Volcanites were found in the southeastern part of the research area and in the Mae Lana Cave. X-ray diffraction revealed that this volcanite consists to 91% of plagioclase (albite, anorthite, and labradorite), 7% hematite, and 2% quartz. According to the TAS classification (Matthes 1996, Le Maitre *et al.* 2002) this volcanite plots into the field of a trachyte and according to the QAPF classification (Matthes 1996) it is classified as a latite. Due to the alteration of the rock samples certain doubt for these classifications exists. The volcanite outcrop within the Mae Lana cave (Figure 4-24) definitively shows a relationship to the iron ore and a volcanite stock with a diameter of approximately 50m was found. This stock is surrounded by iron ore which contains slickensides. With increasing distance from the stock, the massive iron ore passes over into limestone with iron ore veins, decreasing in size. The ironstone consists of a dark reddish matrix containing white coloured veins. Within the iron stone domain bauxite was found. The ironstone consists mainly of goethite followed by kaolinite and hematite. The bauxite consists of diaspore, hematite, gibbsite; goethite, kaolinite, ankerite, and boehmite (Table 4-2).

Table 4-2: Rock composition [%] of the Bor Krai area (X-ray diffraction analysis)

	Latite (N=1)	**Bauxite (N=1)**	**Iron ore (N=1)**	**Sandstone (N=1)**	**Claystone (N=3)**	**Limestone (N=3)**
Ankerite	0	7	0	0	0	5 ± 9
Bayerite	0	0	0	0	0	0
Boehmite	0	4	0	0	0	0
Calcite	0	0	0	0	4 ± 6	93 ± 9
Christobalithe	3	0	0	0	0	0
Diaspore	0	38	0	0	0	0
Gibbsite	0	16	0	0	0	0
Goethite	0	11	63	0	0	0
Hematite	7	18	3	0	0	0
Illite	0	0	0	0	7 ± 12	0
Kaolinite	0	7	33	0	27 ± 22	0
Muscovite	0	0	0	3	10 ± 9	0
Plagioclase (Albite)	50	0	0	0	0	0
Plagioclase (Anorthite)	13	0	0	0	0	0
Plagioclase (Labradorite)	27	0	0	0	0	0
Plagioclase (Oligoclase)	0	0	0	0	4 ± 7	0
Quartz	0	0	0	97	42 ± 17	2 ± 1
Vermiculite	0	0	0	0	3 ± 3	0

4.2 Soils and soil properties

The investigations within this study revealed the dominance of clay illuviation as soil forming process for the mountainous areas of North-western Thailand. Accordingly, most soils were classified as Luvisols and Acrisols. Cambisols were found to be the third common soil type. Other soil types are by far less prominent (Tables 4-3 and 4-4). The three major soil types are mainly distinguished by the degree of clay illuviation, CEC_{clay}, and base saturation. The degree of clay illuviation differentiates between Cambisols and Luvisols and Acrisols. Cambisols are characterised by a lack or a minor degree of clay illuviation. Luvisols and Acrisols show a distinct clay illuviation. Acrisols are characterised by an Argic horizon of less the 24cmol (+) kg^{-1} clay in some parts and a base saturation of less than 50% base saturation in the major part between 25 and 100cm. Luvisols have an Argic horizon with a cation exchange capacity equal to or greater than 24cmol (+) kg^{-1} clay (FAO 1998, 2001). Other soil groups, which are also based on clay illuviation (like Alisols and Lixisols), were not found in the three research sites.

Henceforth, the term ‘regional scale’ is applied to the whole of North-western Thailand including the three research areas.

Table 4-3: WRB 1998 soil types of the three investigation areas according sample frequency [%]

Mae Sa Mai	%	Huay Bong	%	Bor Krai	%
Profondi-Humic Acrisol	32	Dystri-Profondic Luvisol	31	Dystri-Humic Cambisol	10
Dystri-Humic Cambisol	21	Dystri-Humic Cambisol	8	Ferri-Profondic Luvisol	9
Humi-Ferralic Cambisol	12	Chromi-Dystric Cambisol	5	Rhodi-Profondic Luvisol	8
Humi-Umbric Acrisol	6	Dystri-Skeletic Regosol	4	Chromi-Profondic Luvisol	8
Hyperdystric-Humic Acrisol	5	Eutri-Humic Cambisol	4	Profondi-Humic Acrisol	8
Hyperdystric-Profondic Acrisol	4	Dystri-Hyperskeletic Leptosol	3	Profondi-Endostagnic Luvisol	5
Chromi-Dystric Cambisol	3	Ferri-Profondic Luvisol	3	Cutani-Profondic Luvisol	4
Humi-Abruptic Acrisol	1	Profondi-Stagnic Luvisol	3	Chromi-Ferric Luvisol	4
Humi-Leptic Acrisol	1	Dystri-Endoskeletic Luvisol	2	Humi-Leptic Cambisol	3
Dystri-Ferralic Cambisol	1	Profondi-Endostagnic Luvisol	2	Humi-Umbric Acrisol	3
Dystri-Humic Gleysol	1	Skeleti-Leptic Regosol	2	Humi-Endostagnic Cambisol	2
Humi-Mollic Leptosol	1	Dystri-Leptic Cambisol	2	Chromi-Leptic Luvisol	2
		Dystri-Skeletic Cambisol	2	Rhodi-Leptic Luvisol	2
		Skeleti-Humic Cambisol	2	Dystri-Leptic Cambisol	2
		Chromi-Dystric Luvisol	2	Chromi-Dystric Cambisol	1
		Dystric-Leptic Luvisol	2	Calcari-Humic Leptosol	1
		Profondi-Abruptic Luvisol	2	Humi-Mollic Leptosol	1
		Dystri-Stagnic Cambisol	1	Chromi-Cutanic Luvisol	1
		Rhodi-Dystric Cambisol	1	Humi-Leptic Acrisol	1
		Skeleti-Leptic Cambisol	1	Cutani-Profondic Luvisol	1
		Dystri-Humic Fluvisol	1		
		Dystri-Stagnic Luvisol	1		
		Endoskeleti-Profondic Luvisol	1		
		Skeleti-Humic Regosol	1		

Table 4-4: WRB 1998 soil types of the main lithology according sample frequency [%]

Granite, Gneiss	**%**	**Breccia, Conglomerate, Sandstone**	**%**	**Limestone**	**%**
Profondi-Humic Acrisol	33	Dystri-Profondic Luvisol	32	Rhodi-Profondic Luvisol	14
Dystri-Humic Cambisol	25	Dystri-Humic Cambisol	8	Profondi-Humic Acrisol	12
Humi-Ferralic Cambisol	9	Chromi-Dystric Cambisol	5	Dystri-Humic Cambisol	12
Humi-Umbric Acrisol	7	Ferri-Profondic Luvisol	5	Chromi-Profondic Luvisol	8
Hyperdystri-Humic Acrisol	5	Eutri-Humic Cambisol	4	Humi-Umbric Acrisol	5
Hyperdystri-Profondic Acrisol	3	Profondi-Endostagnic Luvisol	4	Humi-Leptic Cambisol	5
Chromi-Dystric Cambisol	3	Profondi-Stagnic Luvisol	4	Profondi-Endostagnic Luvisol	4
Humi-Leptic Cambisol	3	Dystri-Skeletic Regosol	4	Rhodic-Leptic Luvisol	4
Humi-Abruptic Acrisol	1	Skeleti-Leptic Regosol	4	Cutani-Profondic Luvisol	3
Humi-Leptic Acrisol	1	Dystri-Endoskeletic Luvisol	3	Humi-Endostagnic Cambisol	2
Dystri-Ferralic Cambisol	1	Profondi-Abruptic Luvisol	3	Calcari-Humic Leptosol	2
		Dystri-Leptic Cambisol	2	Chromi-Leptic Luvisol	2
		Dystri-Stagnic Cambisol	2	Humi-Leptic Acrisol	2
		Skeleti-Leptic Cambisol	2	Dystri-Leptic Cambisol	2
		Dystri-Hyperskeletic Leptosol	2	Humi-Mollic Leptosol	2
		Dystri-Stagnic Luvisol	2	Humi-Endostagnic Acrisol	1
		Endoskeleti-Profondic Luvisol	2	Calcari-Lithic Leptosol	1
				Humi-Lithic Leptosol	1

The **degree of clay illuviation** can be expressed by the clay ratio of the subsoil to topsoil. In this study the relative degree of clay illuviation was calculated by dividing the average clay content between 40 and 60cm by the average clay content between 0 and 20cm, which means that the higher the ratio the higher the degree of clay illuviation. This calculated degree of clay illuviation shows a positive correlation with the soil colour chroma at regional scale (NW Thailand). Correlations with the clay content were proven for the regional scale, the Bor Krai area, for Cambisols and soils from gneiss and granite. Negative correlations with elevation were detected for soils originating from granite (see Tables 4-5, 4-6 and 4-7).

The $\mathbf{CEC_{clay}}$ correlates positively with the bulk density at regional scale and for the topsoil of the Bor Krai area. Negative correlations with the $CaCO_3$ rock content were found for the Bor Krai area. Negative correlations with the elevation were calculated for soils from claystone and limestone. Negative correlations with the curvature were also detected for soils from limestone (see Tables 4-5, 4-6 and 4-7).

The **base saturation** correlates negatively with the soil colour chroma at regional scale and also for the Mae Sa Mai area. Positive correlations with the pH (H_2O) were calculated at all scales and the major soil types. The same correlations were found for soils from granite, claystone and limestone. Negative correlations with the elevation were found at regional scale, for Huay Bong and for soils from gneiss and granite. For soils from claystone a negative correlation with the curvature was detected (see Tables 4-5, 4-6 and 4-7).

Table 4-5: Spearman correlation coefficient ($p<0.01$) for relevant soil properties in different regions

Soil depth	Variable	Mae Sa Mai (N<=33)	Huay Bong (N<=10)	Bor Krai (N<=25)	NW-Thailand (N<=136)
0-20 cm	**Clay illuviation**[1]	NS	NS	NS	chroma (0.4)
	CEC_{clay}	NS	NS	bulk density (0.9), $CaCO_3$ (rock)[2] (-0.5)	bulk density (0.4)
	Base saturation	chroma (-0.5), pH (H_2O) (0.8)	NS	pH (H_2O) (0.7)	elevation (-0.4), pH (H_2O) (0.7)
40-60 cm	**Clay illuviation**[1]	NS	NS	clay content (0.5)	chroma (0.4), clay content (0.4)
	CEC_{clay}	NS	NS	$CaCO_3$ (rock) (-0.7)	bulk density (0.5), elevation (-0.3)
	Base saturation	chroma (-0.6)	elevation (-0.9), pH (H_2O) (0.9)	pH (H_2O) (0.7)	chroma (-0.3), elevation (-0.4), pH (H_2O) (0.6)
80-100 cm	**Clay illuviation**[1]	NS	NS	clay content (0.5)	chroma (0.3), clay content (0.4)
	CEC_{clay}	NS	NS	$CaCO_3$ (rock) (-0.6)	bulk density (0.4), elevation (-0.3)
	Base saturation	NS	NS	pH (H_2O) (0.7)	chroma (-0.3), elevation (-0.3), pH (H_2O) (0.7)

[1] clay illuviation: average clay content between 40 and 60cm divided through the average clay content between 0 and 20cm
[2] $CaCO_3$: content of parental rock
[3] NS: not significant

Table 4-6: Spearman correlation coefficient ($p<0.01$) for relevant soil properties of the main soil types

Soil depth	Variable	Acrisols (N<=33)	Cambisols (N<=10)	Luvisols (N<=25)
0-20 cm	**Clay illuviation**[1]	NS	NS	NS
	CEC_{clay}	NS	NS	NS
	Base saturation	pH (H_2O) (0.7)	pH (H_2O) (0.8)	pH (H_2O) (0.8)
40-60 cm	**Clay illuviation**[1]	NS	clay content (0.5)	NS
	CEC_{clay}	NS	NS	NS
	Base saturation	pH (H_2O) (0.6)	pH (H_2O) (0.8)	pH (H_2O) (0.6)
80-100 cm	**Clay illuviation**[1]	NS	NS	NS
	CEC_{clay}	NS	NS	NS
	Base saturation	NS	pH (H_2O) (0.8)	pH (H_2O) (0.7)

[1] clay illuviation: average clay content between 40 and 60cm divided through the average clay content between 0 and 20cm
[2] NS: not significant

Table 4-7: Spearman correlation coefficient ($p<0.01$) for relevant soil properties in different regions of the main rock types

Soil depth	Variable	Gneiss (N<=10)	Granite (N<=44)	Claystone (N<=13)	Limestone (N<=9)
0-20 cm	**Clay illuviation**[1]	clay content (-0.8)	elevation (-0.6)	NS	NS
	CEC_{clay}	NS	NS	elevation (-0.6)	curvature (-0.7), elevation (-0.8)
	Base saturation	elevation (-0.8)	elevation (-0.4), pH (H_2O) (0.6)	pH (H_2O) (0.8)	pH (H_2O) (0.9)
40-60 cm	**Clay illuviation**[1]	NS	elevation (-0.6) CEC_{soil} (-0.3) clay content (0.5)	NS	clay content (0.9)
	CEC_{clay}	NS	NS	NS	curvature (-0.8), elevation (-0.8)
	Base saturation	elevation (-0.7)	NS	curvature (-0.8), pH (H_2O) (0.8)	pH (H_2O) (0.8)
80-100 cm	**Clay illuviation**[1]	NS	elevation (-0.6) CEC_{clay} (-0.4) clay content (0.5)	NS	clay content (0.9)
	CEC_{clay}	NS	NS	NS	curvature (-0.8), elevation (-0.8)
	Base saturation	NS	elevation (-0.4)	Curvature[2] (-0.8)	NS

[1] clay illuviation: average clay content between 40 and 60cm divided through the average clay content between 0 and 20cm
[2] curvature: values extracted form the curvature output raster of ArcGIS 9.1 – used values ranging from 4 = concave to -4 = convex; 0 = linear
[3] NS: not significant

The topsoils (where preserved) in all three study sites are commonly dark coloured, indicating an incomplete decomposition of **organic matter**. Unlike suggestions in previous studies (Hansen 1991, Kubiniok 1999), the organic carbon (C_{org}) concentration of the topsoil does not correlate with the elevation at regional scale (see Figure 4-4). All applied regression equations delivered no significant r^2 values (see Equations 4-1, 4-2, 4-3 and 4-4). Due to an insufficiency of data correlation to other factors like human impact, slope inclination, curvature, vegetation, termite activity, and parent rock.

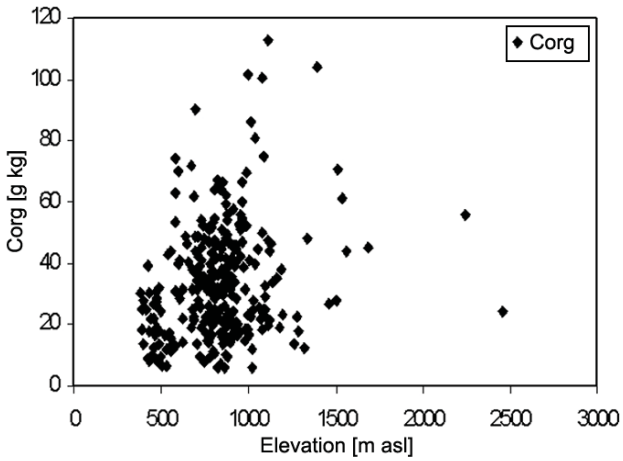

Figure 4-4: C_{org} of the upper 20cm from soils of whole North-western Thailand according to elevation

Equation 4-1: Linear function of C_{org} [g kg^{-1}] according to elevation [m asl]

$$E(Corg) = 22.024 + 0.014\,(elevation) \qquad r^2=0.035$$

Equation 4-2: Exponential function of C_{org} [g kg^{-1}] according to elevation [m asl]

$$E(Corg) = 19.616\, e^{0.0005\,(elevation)} \qquad r^2=0.039$$

Equation 4-3: S function of C_{org} [g kg^{-1}] according to elevation [m asl]

$$E(Corg) = e^{(3.925 + \frac{-434.057}{(elevation)})} \qquad r^2=0.068$$

Equation 4-4: Quadratic function of C_{org} [g kg^{-1}] according to elev. [m asl]

$$E(Corg) = 9.264 + 0.040\,(elevation) + (-0.00001)(elevation)^2 \qquad r^2=0.047$$

4.2.1 Mae Sa Mai

The soil cover in the Mae Sa Mai area is dominated by Acrisols covering about 70% of the surface, while the remaining 25% are represented by Cambisols, Anthrosols, Chernozems, Gleysols, Leptosols, and Regosols (Figure 4-5).

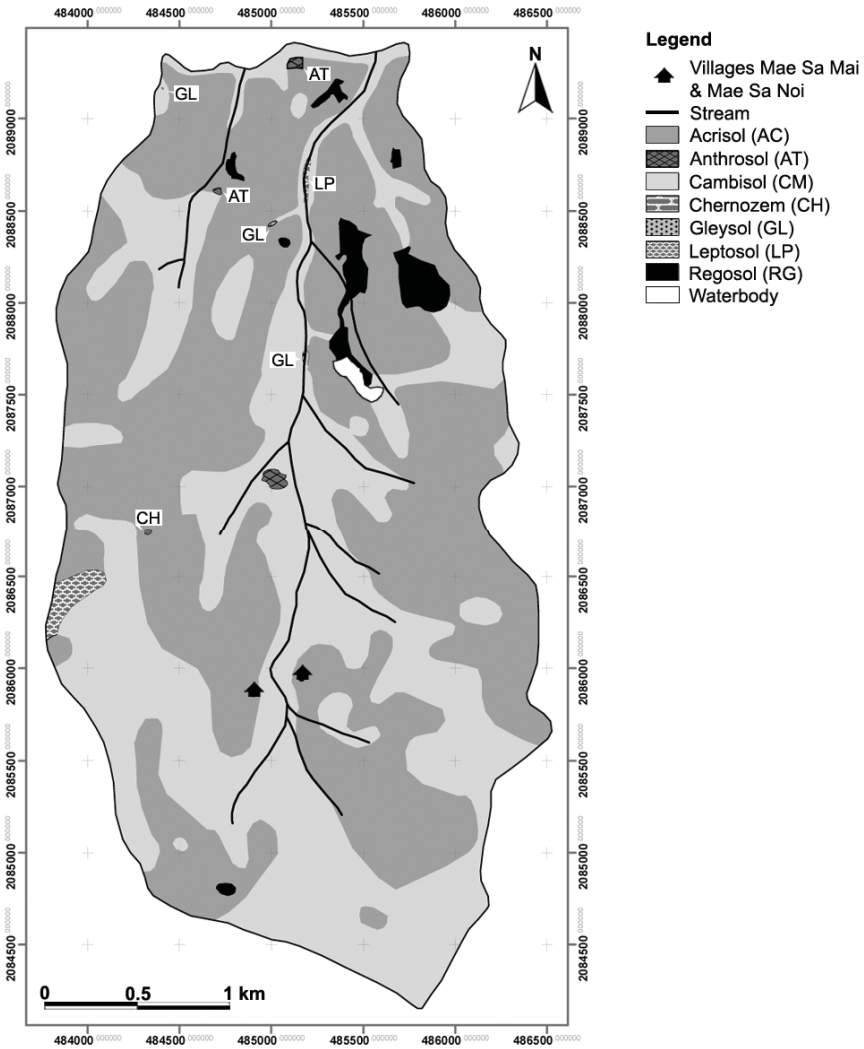

Figure 4-5: Soil map according to WRB classification of the Mae Sa Mai area

The **soil pH** (H_2O) in the Mae Sa Mai area generally decreases from the topsoil to lower subsoil. The lower slopes often show higher pH values than the higher areas. Lowest values were found in the village area, the Botanical Garden and places of intensive land use (Figure 4-6).

The soil **colour value** increases with soil depth. Higher values occur at places with enhanced erosion rates. Such zones were found close to the villages, in the vicinity of canyons, and in the Botanical Garden. The soil colour value distribution of the subsoil trends in a north-south direction with increasing values towards the east (see Figure 4-7). The reason for this might be found in local climate differences due to different expositures.

The soil **colour chroma** behaves similarly as the soil colour value. The chroma increases with soil depth. The chroma of the subsoil also trends in a north-south direction with increasing values towards the east (see Figure 4-8).

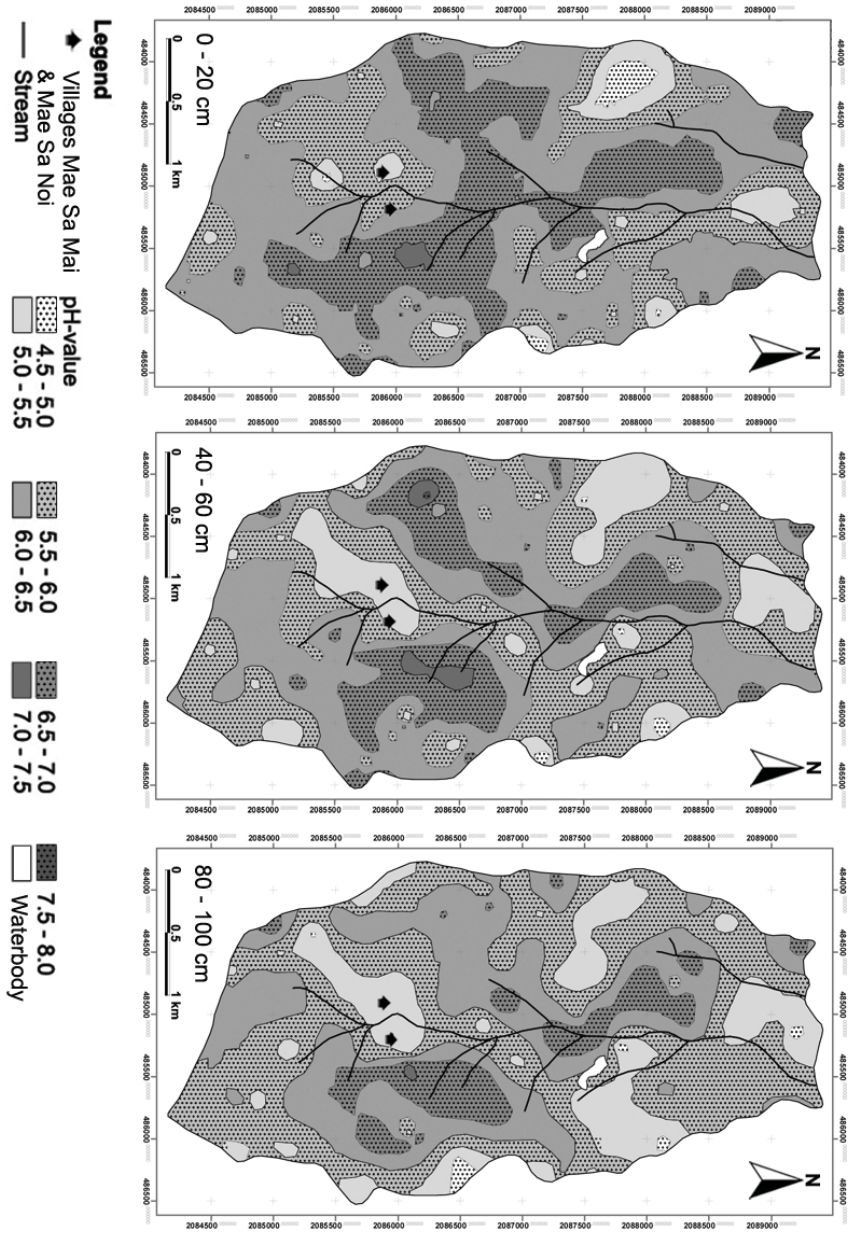

Figure 4-6: Soil pH distribution at different depths in the Mae Sa Mai area

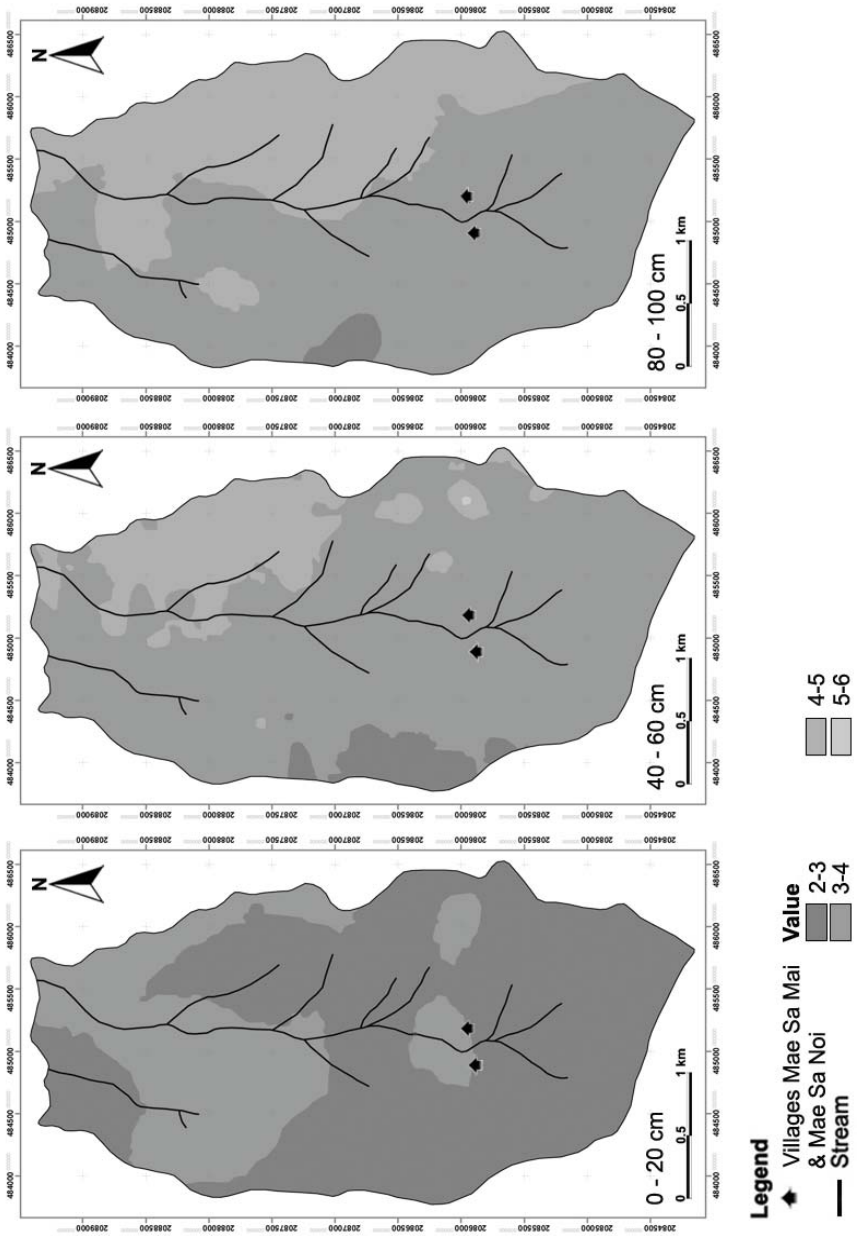

Figure 4-7: Soil colour value distribution at different depths in the Mae Sa Mai area

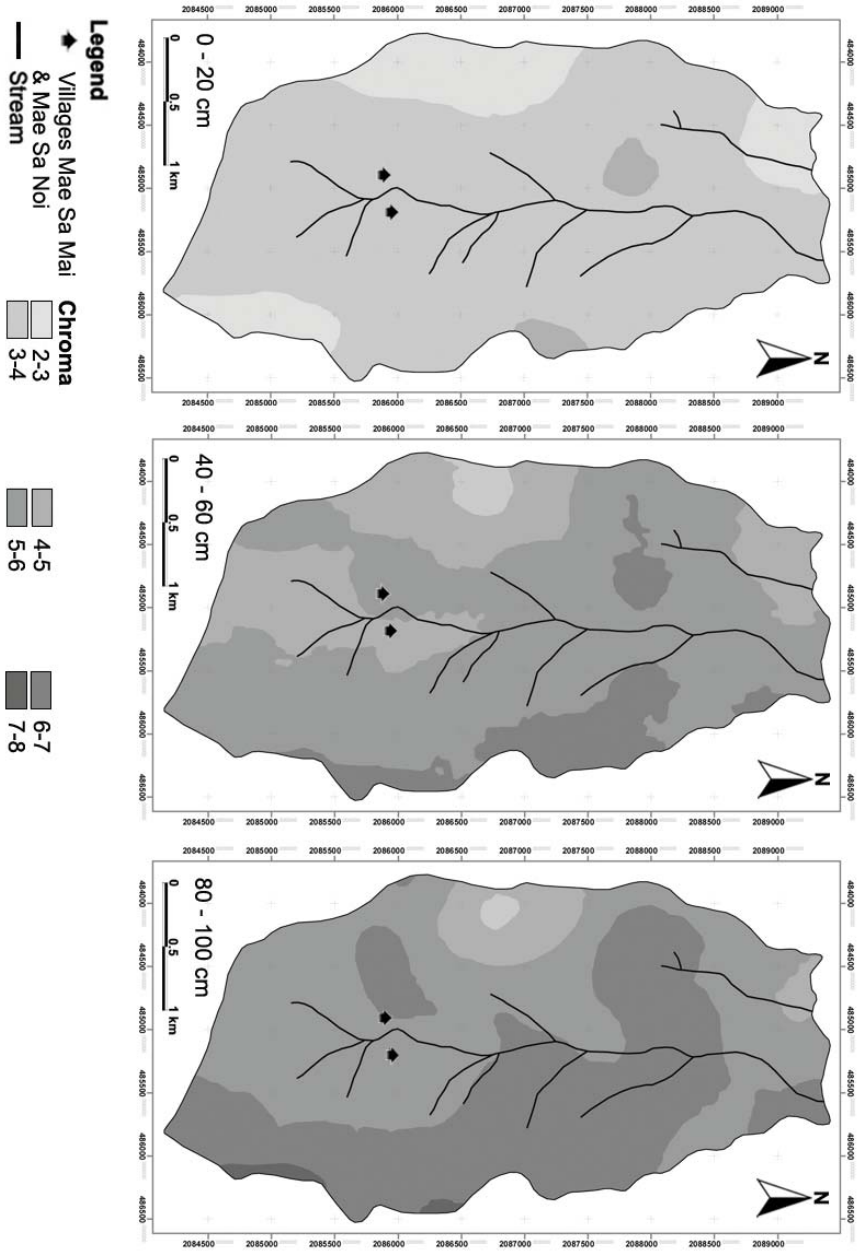

Figure 4-8: Soil chroma distribution at different depths in the Mae Sa Mai area

In general the **A-horizon thickness** increases with elevation (see Figure 4-9). Apart from this trend, thickness generally tends to be reduced at places with increased erosion rates, like the Botanical Garden or in the vicinity of canyons, while exceptional thick A-horizons were found in local depressions.

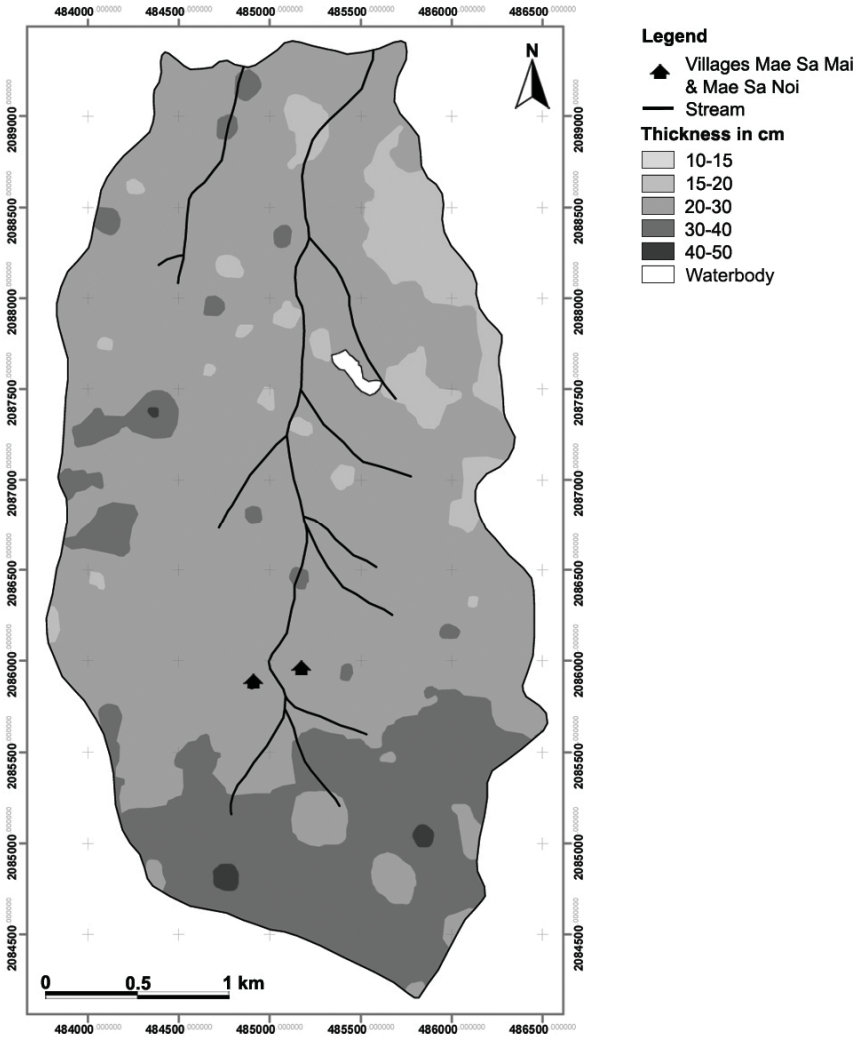

Figure 4-9: A-horizon thickness in the Mae Sa Mai area

Acrisols dominate the slopes in the central and northern part of the subcatchment. Most of them are classified as Profondi-Humic Acrisols (see Table 4-3). The upper boundary of Acrisol occurrence lies generally around 1300m asl (see Figure 4-11). In the Mae Sa watershed Acrisols are mostly used for production of lychee and vegetables. The latter is only possible by fertilizer application. At burial sites and inaccessible areas the Acrisols are still covered with forest and shrubs. Most Acrisols showed reddish soil colours. Often mica is preserved throughout the whole soil profile. Most topsoils have a clay loamy texture with a granular structure. The transition to subsoil is mostly clear and smooth. The subsoil has a clayey texture and shows a subangular blocky structure. For the topsoil the sand fraction dominates followed by clay and silt. Despite this, the clay fraction prevails in the subsoil, followed by silt and sand (see Table 4-11). Termite holes and channels are common in the upper 100cm. All Acrisols are lacking a prominent eluvial horizon (E-horizon). In the following, rating of C_{org}, N_t, P_{CAL}, K_{CAL}, pH (H2O), CEC_{soil}, base saturation (BS), exchangeable Na^+, K^+, Ca^{2+}, Mg^{2+} and bulk density are according to Table 4-8.

The average bulk density is low at 1.1±0.1g cm^{-3} (N=8) for the topsoil and medium at 1.3±-0.1g cm^{-3} for the subsoil. The soil water content is near saturation at h=-3.75cm and ranges from 46.9%vol for the topsoil to 43.8%vol for the subsoil. The soil water content at pF 4.2 ranges from 14%vol for the topsoil to 20%vol for the subsoil. The saturated hydraulic conductivity ranges from 1.04cm d^{-1} for the topsoil to 0.4 cmd^{-1} for the subsoil (Spohrer 2007). While Acrisols on granite often show a soil thickness of more than 5m, those on paragneiss and marble are often less than 3m thick.

The C_{org} concentration of most Acrisols decreases from medium values for the topsoil to very low values for the subsoil.

The average N_t concentration for the topsoil is low and very low for the subsoil.

The plant available phosphorous concentration (P_{CAL}) of the topsoil is medium and low for the subsoil.

The plant available potassium concentration (K_{CAL}) is high for the topsoil and low for the subsoil.

The average pH (H_2O) within 1m soil depth is medium.

The average CEC_{soil} is decreasing from medium values for the topsoil and low values for the subsoil.

The base saturation of the topsoil is medium and low for the subsoil. The main part of the base saturation derives from Ca cations followed by Mg and K. Na cations were not detected (see Table 4-10).

Table 4-8: Relative rating of soil properties according to Landon (1991) and Schlichting *et al.* (1995)

	Very low	**Low**	**Medium**	**High**	**Very high**
C_{org} [g kg^{-1}]	<10	10-20	20-40	40-80	>80
N_t [g kg^{-1}]	<1	1-2	2-5	5-10	>10
P_{CAL} [mg kg^{-1}]	-	<5	5-15	>15	-
K_{CAL} [mg kg^{-1}]	-	<75	75-150	150-300	>300
pH*	-	<5.5	5.5-7.0	7.0-8.5	>8.5
CEC_{soil} [$cmol_c kg^{-1}$]	<5	5-15	15-25	25-40	>40
BS [%]	<5	5-20	20-50	50-80	>80
Na^+ [$cmol_c kg^{-1}$]	-	-	-	>1	-
K^+ [$cmol_c kg^{-1}$]	-	<0.2	-	>0.6	-
Ca^{2+} [$cmol_c kg^{-1}$]	-	<4	-	>10	-
Mg^{2+} [$cmol_c kg^{-1}$]	-	<0.5	-	>4	-
Bulk density [g cm^{-3}]	<0.80	0.80-1.25	1.25-1.50	1.50-1.75	>1.75

The oxalate extractable iron (Fe_o) of the topsoil is 0.17±0.02%m and the dithionite extractable iron (Fe_d) is 2.27±0.30%m with an average Fe_o-Fe_d ratio of 0.077 (n=6). The Fe_o concentration of the subsoil is 0.13±0.17%m and the Fed concentration is 3.02±0.36%m with an average Fe_o-Fe_d ratio of 0.044 (n=16) (Spohrer 2007).
The Rietveld analysis of Acrisols from granite revealed clearly increased shares of gibbsite and kaolinite and decreased amounts of quartz for the subsoil (see Table 4-9).

Table 4-9: Quantitative mineralogical composition of top- and subsoil horizons of soils developed from granite in the Mae Sa Mai area according to Rietveld analysis (Herrmann et al. 2007)

Profile*	Soil type (WRB)	Depth [cm]	[%]					
			Clay	Gibbsite	Kaolinite	Muscovite	Orthoclase	Quartz
1494	Acrisol	0-25	35	0.8	37.0	8	4	50
		>140	40	1.3	50.8	9	2	37
1495	Acrisol	0-12	46	2.7	24.0	14	2	56
		75-100	57	3.5	54.5	7	1	34
1496	Cambisol	0-10	39	2.3	20.5	13	7	57
		75-95	46	4.8	43.8	10	6	36
1497	Acrisol	0-20	30	0.8	18.8	16	8	56
		20-35	40	2.2	20.5	18	8	52

Anthrosols (Regi-Hydragric Anthrosols) were found at locations of former paddy rice fields. Presently, most Anthrosols are used for the cultivation of vegetables. Their anthraquic horizons mainly consist of homogenised greyish topsoil of clay loam with weak subangular blocky structure. Due to the practice by Hmong farmers of preparing their plots only with a hoe, a plough pan is not developed. The transition to the hydragric horizon below is abrupt. The hydragric horizons commonly consist of clay loam with a weak subangular blocky structure and is characterised by Fe-, Mn-concretions with a maximum concentration at the top of the horizon.

Cambisols prevail at the highest areas in the north of the subcatchment and along the creeks, which are mostly N-S directed. They are often covered with forest for mainly two reasons: the first group of Cambisols is often restricted to very steep sloping land which is not accessible and hence not suitable for any agricultural practice and the second group occurs at the highest parts of the watershed, where the increased moisture hampers forest destruction by fire. Among both groups, Dystri-Humic Cambisols prevail, followed by Humi-Ferralic Cambisol (see Table 4-3). On accessible slopes Cambisols are used for lychee production. Above 1300m asl Cambisols are brownish and often shallow (< 50cm). Under relative undisturbed conditions a thick layer of undecomposed litter is developed. Towards lower positions, Cambisols represent more and more disturbed sites with increasingly reddish colours. Mica can often be found throughout the whole soil profile.

Most Cambisols are characterised by a very homogenous texture throughout the entire soil profile, ranging from clay loam to sandy clay loam. The average bulk density of the topsoil is low 1.1±0.1g cm^{-3} (n=7), and medium 1.3±0.1g cm^{-3} for the subsoil.
Cambisols at lower elevations can be described as truncated Acrisols. Hence, their soil water content and hydraulic conductivity should correspond to the values determined for the subsoil of the Acrisols (Spohrer 2007). The soil thickness here can exceed 3m.
The C_{org} concentration shows a decreasing trend from medium values for the topsoil to very low values for the subsoil.
The N_t concentration decreases from low values for the topsoil to very low values for the subsoil.
The plant available phosphorous concentration of the topsoil is medium and low for the subsoil.
The plant available potassium shows a decreasing trend from very high concentrations for the topsoil to high values for the lower subsoil.
The average pH (H_2O) within 1m soil depth is neutral to slightly acidic (5.5-7.0).
The average cation exchange capacity of the topsoil is high and medium for the subsoil.
The base saturation is medium within 1m soil depth. The main part of the base saturation derives from Ca, followed by Mg and K. Na cations are negligible (see Table 4-10).
The mineral composition of a single Cambisol is congruent to that of Acrisols derived from granite. The amount of gibbsite within the subsoil exceeds other investigated soils in the area (see Table 4-9).

A little patch (<1ha) of **Chernozem** (Glossi-Calcic Chernozem) was found covering freshwater limestone. Due to the surface rockiness and inaccessibility this location's forest cover is mostly preserved. The topsoil texture is loam or sandy clay. The subsoil shows a silty loamy and sandy loamy texture. Within 54cm depth the dark A-horizon has a strong granular structure and finely dispersed secondary carbonate is common. Due to the strong structure and high porosity a low bulk density of less than 1g cm^{-3} can be assumed. Below an abrupt transition freshwater limestone builds an R-Horizon.

Within the central and lower part of the Mae Sa Mai area patches of **Gleysols** were found. Most of them are classified as Dystri-Humic Gleysols. They are mainly located in the vicinity of springs or along the streams, where the groundwater level is close to the surface. Due to the high groundwater level Gleysols are commonly not used for cultivation. Depending on human activities Gleysols are either covered with forest or grass. The Gleysols detected showed different textures and organic matter distributions, ranging from very homogenous textured profiles to very inhomogeneous ones.

The textures found comprises sandy loam, loam, sandy clay loam, and clay loam. Some Gleysols within the forest with a high litter accumulation showed very high organic matter contents. Due to the high water content the structure was mostly coherent. The soil thickness can exceed 200cm.
The Gleysols investigated showed very high C_{org} concentration for the topsoil and a high C_{org} concentration for the upper subsoil.
The N_t concentration of the topsoil is high and medium for the upper subsoil.
The pH (H_2O) within 1m soil depth is medium.
The cation exchange capacity of the topsoil and upper subsoil is very high.
The base saturation is high for the throughout the upper 60cm. The main contribution to the base saturation derives from Ca followed by Mg (see Table 4-10). The exceptional high values of Ca and Mg can be explained by the marble karst, influencing the surface water and groundwater chemistry in the area below it.

Leptosols are restricted to the vicinity of marble outcrops and to the canyon of the Mae Sa Mai stream in the north (see Figures 4-10 and 4-11). Most of them are classified as Humi-Mollic Leptosols. Due to the shallowness and the inaccessibility all Leptosols are covered with forest. The soils have mostly a clay loamy texture with a crumbly or subangular blocky structure, comparable to the topsoil of the Acrisols. The bulk density and hydraulic conductivity should correspond to the latter.

Regosols (Anthropic Regosols) were found on terraces and in the Botanical Garden with its recent anthropogenic landscape (see Figure 4-10), which is mostly used as sites for greenhouses. In the greenhouses sweet pepper and flowers are cultivated in flower pots. Soil outcrops along the street indicate that before human intervention took place the recent location of the Regosols mostly hosted Acrisols. In most cases the soil profile starts with the former C-horizon of the removed Acrisols. For this reason, most Regosols show a relative coarse texture ranging from clay loam to loam, sandy clay and sand either massive or in single grains.

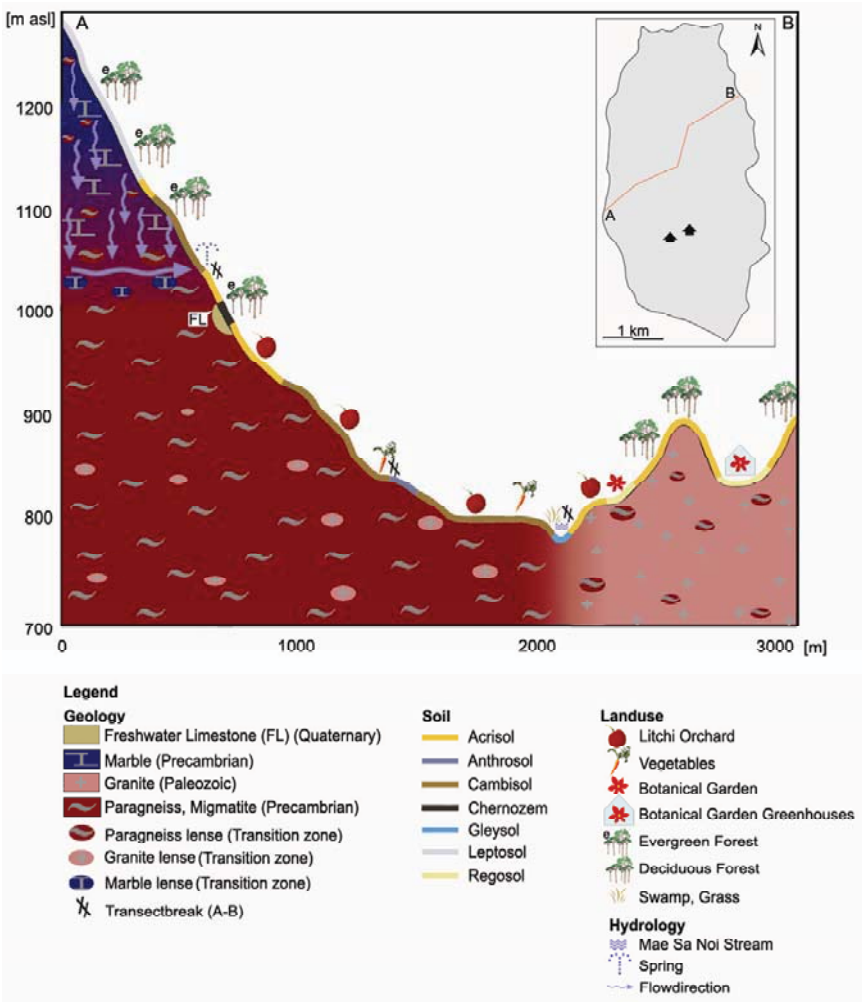

Figure 4-10: Transect through the Mae Sa Mai area

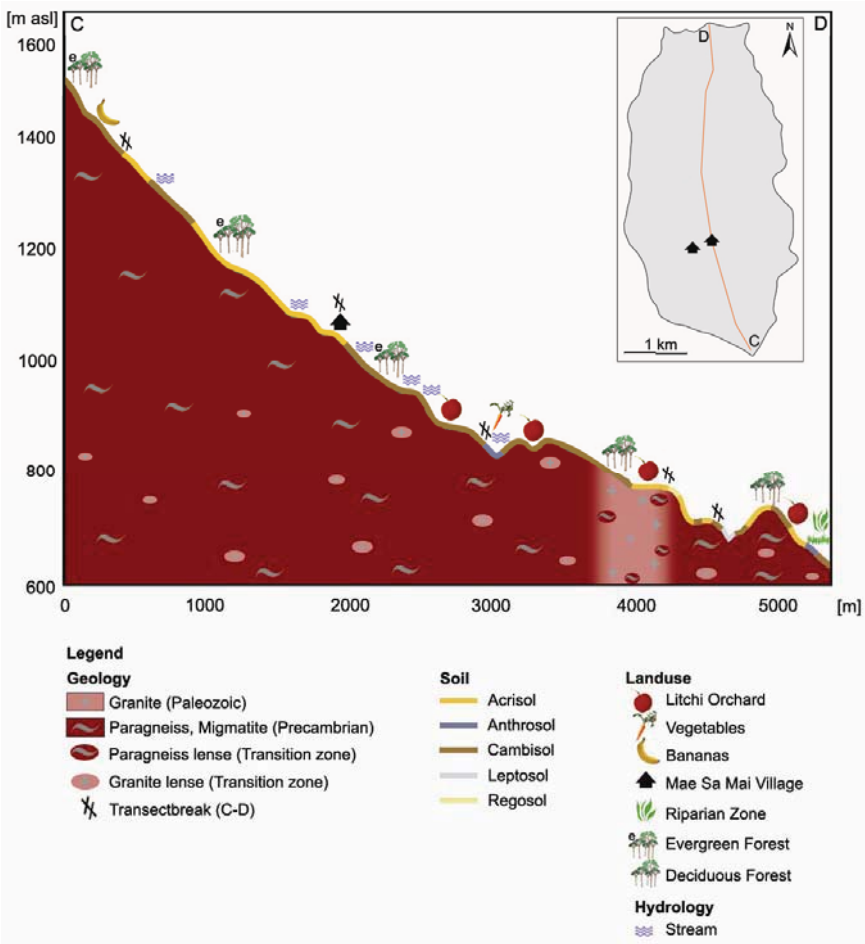

Figure 4-10: Transect through the Mae Sa Mai area

Table 4-10: Soil chemical properties of major soil groups in the Mae Sa Mai area
(Continuation on next page)

Depth		Acrisols N=7	Cambisols N=5	Gleysols N=1	Leptosols N=1	Regosols N=2
0.0 - 0.2 m	C_{org} [g kg^{-1}]	28.6 ± 9.0	26.3 ± 10.0	90.4	NA	NA
	N_t [g kg^{-1}]	1.8 ± 0.6	2.0 ± 0.7	7.9	NA	NA
	P_{CAL} [mg kg^{-1}]	6.5 ± 5.4	5.9 ± 5.6	NA	NA	NA
	K_{CAL} [mg kg^{-1}]	266 ± 170	640 ± 314	NA	NA	NA
	pH*	6.2 ± 0.6 N=88	6.2 ± 0.5 N=65	6.4 ± 0.5 N=2	5.8	6.4 -6.5
	CEC_{soil} [$cmol_c kg^{-1}$]	19.1 ± 4.4	25.6 ± 5.7	60.9	NA	NA
	BS [%]	28.6 ± 14.1	33.0 ± 17.3	59.2	NA	NA
	Na^+ [$cmol_c kg^{-1}$]	0.0 ± 0.0	0.0 ± 0.1	0.4	NA	NA
	K^+ [$cmol_c kg^{-1}$]	0.8 ± 0.4	0.9 ± 0.4	0.4	NA	NA
	Ca^{2+} [$cmol_c kg^{-1}$]	3.7 ± 2.7	6.1 ± 5.0	30.2	NA	NA
	Mg^{2+} [$cmol_c kg^{-1}$]	1.4 ± 1.0	1.8 ± 1.1	5.1	NA	NA
0.4 - 0.6 m	C_{org} [g kg^{-1}]	8.0 ± 2.8	9.8 ± 6.8	56.9	-	NA
	N_t [g kg^{-1}]	0.7 ± 0.3	0.8 ± 0.5	4.4	-	NA
	P_{CAL} [mg kg^{-1}]	1.1 ± 0.9	0.9 ± 1.1	NA	-	NA
	K_{CAL} [mg kg^{-1}]	58 ± 29	346 ± 179	NA	-	NA
	pH*	5.9 ± 0.7	6.1 ± 0.6	6.5 ± 0.1	-	6.3 – 6.6
	CEC_{soil} [$cmol_c kg^{-1}$]	11.6 ± 1.9	17.5 ± 4.0	41.2	-	NA
	BS [%]	11.8 ± 9.1	21.2 ± 16.6	64.7	-	NA
	Na^+ [$cmol_c kg^{-1}$]	0.0 ± 0.0	0.0 ± 0.0	0.4	-	NA
	K^+ [$cmol_c kg^{-1}$]	0.2 ± 0.1	0.4 ± 0.1	0.3	-	NA
	Ca^{2+} [$cmol_c kg^{-1}$]	0.4 ± 0.3	2.5 ± 3.0	22.1	-	NA
	Mg^{2+} [$cmol_c kg^{-1}$]	0.6 ± 0.7	0.7 ± 0.6	3.8	-	NA

Table 4-10: Soil chemical properties of major soil groups in the Mae Sa Mai area (Continuation)

Depth		Acrisols N=7	Cambisols N=5	Gleysols N=1	Leptosols N=1	Regosols N=2
0.8 - 1.0 m	C_{org} [g kg^{-1}]	5.3 ± 2.1	6.2 ± 4.5	NA	-	NA
	N_t [g kg^{-1}]	0.5 ± 0.2	0.5 ± 0.4	NA	-	NA
	P_{CAL} [mg kg^{-1}]	1.1 ± 0.9	0.9 ± 1.1	NA	-	NA
	K_{CAL} [mg kg^{-1}]	72 ± 36	276 ± 167	NA	-	NA
	pH*	5.7 ± 0.6 N=69	5.8 ± 0.6 N=49	NA	-	6.4 – 6.7
	CEC_{soil} [$cmol_c kg^{-1}$]	10. 0 ± 2.7	16.2 ± 4.0	NA	-	NA
	BS [%]	11.1 ± 3.9	20.1 ± 17.7	NA	-	NA
	Na^+ [$cmol_c kg^{-1}$]	0.0 ± 0.0	0.0 ± 0.0	NA	-	NA
	K^+ [$cmol_c kg^{-1}$]	0.2 ± 0.1	0.3 ± 0.1	NA	-	NA
	$Ca^{2=}$ [$cmol_c kg^{-1}$]	0.4 ± 0.2	2.1 ± 2.6	NA	-	NA
	Mg^{2+} [$cmol_c kg^{-1}$]	0.3 ± 0.2	0.6 ± 0.6	NA	-	NA

*N deviates from other analysis (Acrisols N=88; Cambisols N=65; Gleysols N=2; Leptosols N=1; Regosols N=1)

Table 4-11: Soil physical properties of major soil groups in the Mae Sa Mai area (Continuation on next page)

Depth		Acrisols	Cambisol	Gleysols	Leptosoll	Regosols
0.0-0.2 m	Sand [% m]	41.9 ± 5.7 N=9	42.2 ± 5.7 N=8	NA	NA	NA
	Silt [% m]	35.2 ± 14.7 N=9	20.2 ± 5.0 N=8	NA	NA	NA
	Clay [% m]	37.7 ± 6.2 N=9	37.6 ± 10.2 N=8	NA	NA	NA
	Bulk density [g cm^{-3}]	1.1 ± 0.2 N=9	1.1 ± 0.1 N=8	NA	NA	NA
	Ks [cm d^{-1}]	0.9 N=1	NA	NA	NA	NA
	Texture	clay loam	clay loam – sandy clay loam	sandy loam – clay loam	clay loam	high variability: clay loam – sand
	Structure	granular – subangular blocky	subangular blocky	coherent	granular – subangular blocky	single grains, massive

Table 4-11: Soil physical properties of major soil groups in the Mae Sa Mai area (Continuation)

Depth		Acrisols	Cambisol	Gleysols	Leptosols	Regosols
0.4-0.6 m	**Sand [% m]**	31.0 ± 5.2 N=8	40.4 ± 11.8 N=8	NA	-	NA
	Silt [% m]	37.4 ± 24.0 N=8	15.8 ± 5.2 N=8	NA	-	NA
	Clay [% m]	54.4 ± 6.0 N=8	43.9 ± 15.4 N=8	NA	-	NA
	Bulk density [g cm-^{3}]	1.2 ± 0.3 N=8	1.2 ± 0.1 N=8	NA	-	NA
	Ks [cm d^{-1}]	0.5 N=1	NA	NA	-	NA
	Texture	clay	clay loam – sandy clay loam	sandy loam – clay loam	-	high variability: clay loam – sand
	Structure	subangular blocky	subangular blocky	coherent	-	single grains, massive
0.8-1.0 m	**Sand [% m]**	31.6 ± 2.9 N=8	40.5 ± 12.7 N=8		-	NA
	Silt [% m]	35.8 ± 21.6 N=8	15.8 ± 4.9 N=8		-	NA
	Clay [% m]	53.2 ± 4.9 N=8	43.7 ± 15.9 N=8		-	NA
	Bulk density [g cm-^{3}]	1.3 ± 0.1 N=7	1.3 ± 0.1 N=8		-	NA
	Ks [cm d^{-1}]	NA	NA	NA	-	NA
	Texture	clay	clay loam – sandy clay loam	sandy loam – clay loam	-	high variability: clay loam – sand
	Structure	subangular blocky	subangular blocky	coherent	-	single grains, massive

4.2.2 Huay Bong

In contrast to Mae Sa Mai, Luvisols prevail (66%) in Huay Bong, followed by 24% Cambisols, 8% Regosols, 2% Leptosols, and less than 1% Fluvisols (Figure 4-12).

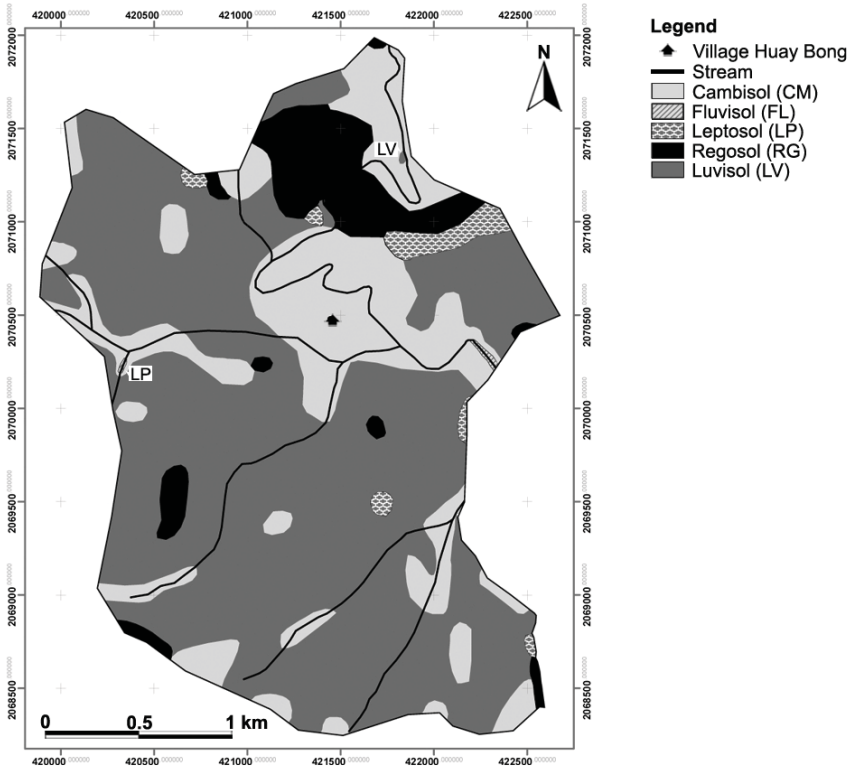

Figure 4-12: Soil map according to WRB classification of the Huay Bong area

In general, the **soil pH (H_2O)** decreases with soil depth. The highest pH values were found on lower slopes, in the valley bottoms, and in the vicinity of marl outcrops. The lowest pH values were found at sites with increased erosion rates and "acidic" parental material (Figure 4-13).

The **soil colour value** increases with the depth. This increase is slighter in the steep sloping northern part of the area than in the more gentle sloping part in the south (see Figure 4-14).

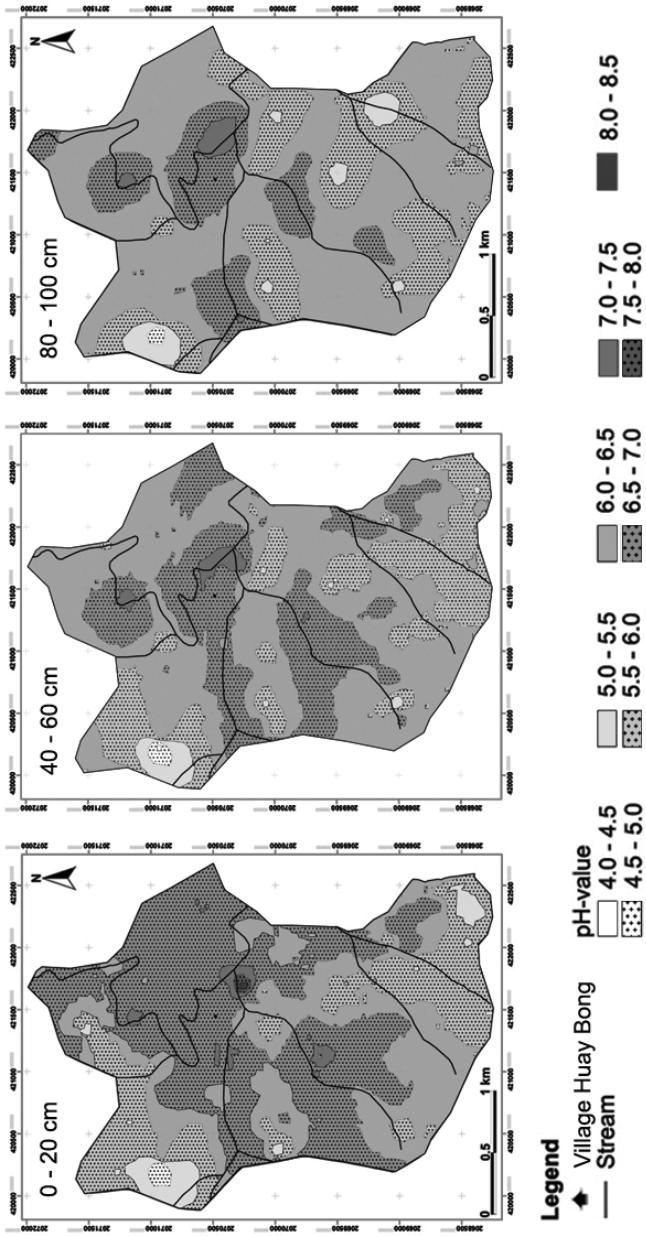

Figure 4-13: Soil pH distribution at different depths in the Huay Bong area

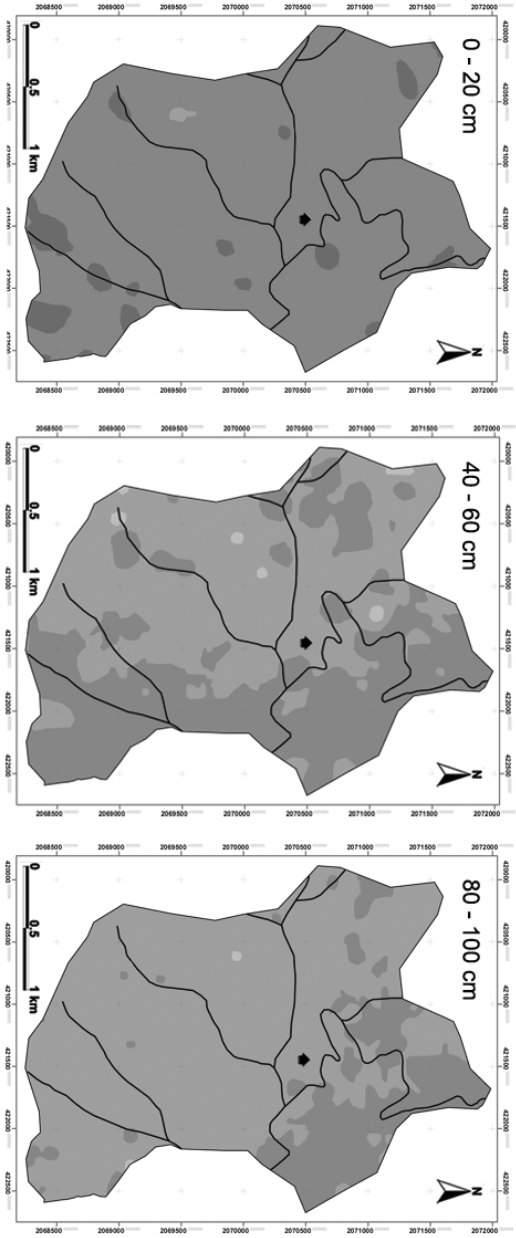

Figure 4-14: Soil colour value distribution at different depths in the Huay Bong area

A similar trend can be observed for the **soil colour chroma**. In general, the values also increase with soil depth. Exceptions are the steep sloping area close to the Mae Yot valley at the NE part of the area and Huay Bong valley in the west as well as some of the highest parts in the south (see Figure 4-15).

In the Huay Bong area the **A-horizon thickness** normally does not exceed 30cm. The lowest thickness was found in the northern part of the research area, where the steepest slopes occur. Shallow topsoil thickness was also observed on sloping land in the southern part of the research area. There many little streams have carved gullies into the landscape. The highest topsoil thickness was found in the valley bottoms and in the conservation forest in the SE part of the research area (Figure 4-16).

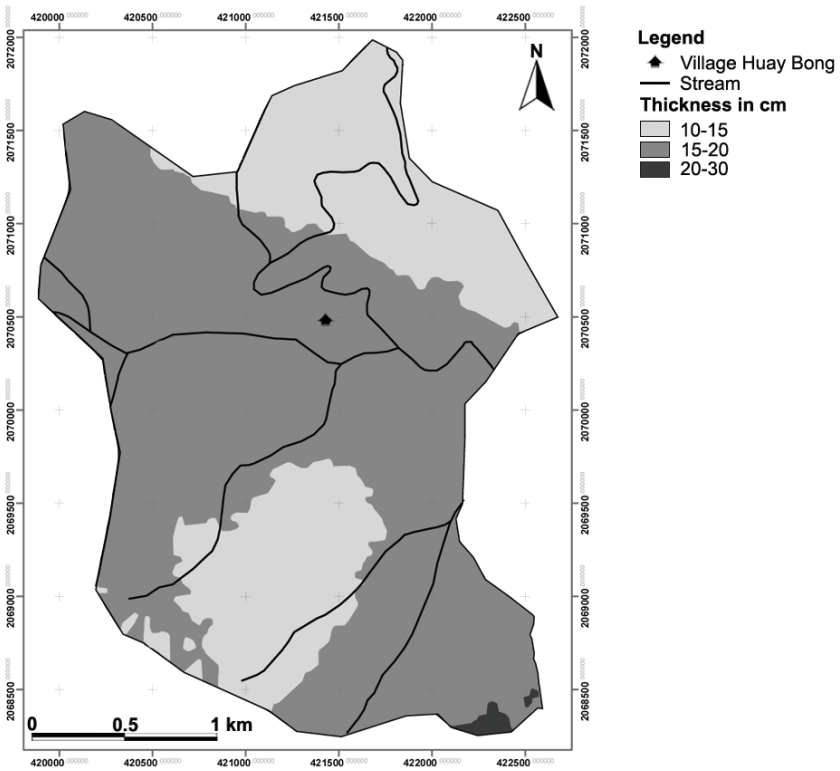

Figure 4-16: A-horizon thickness in the Huay Bong area

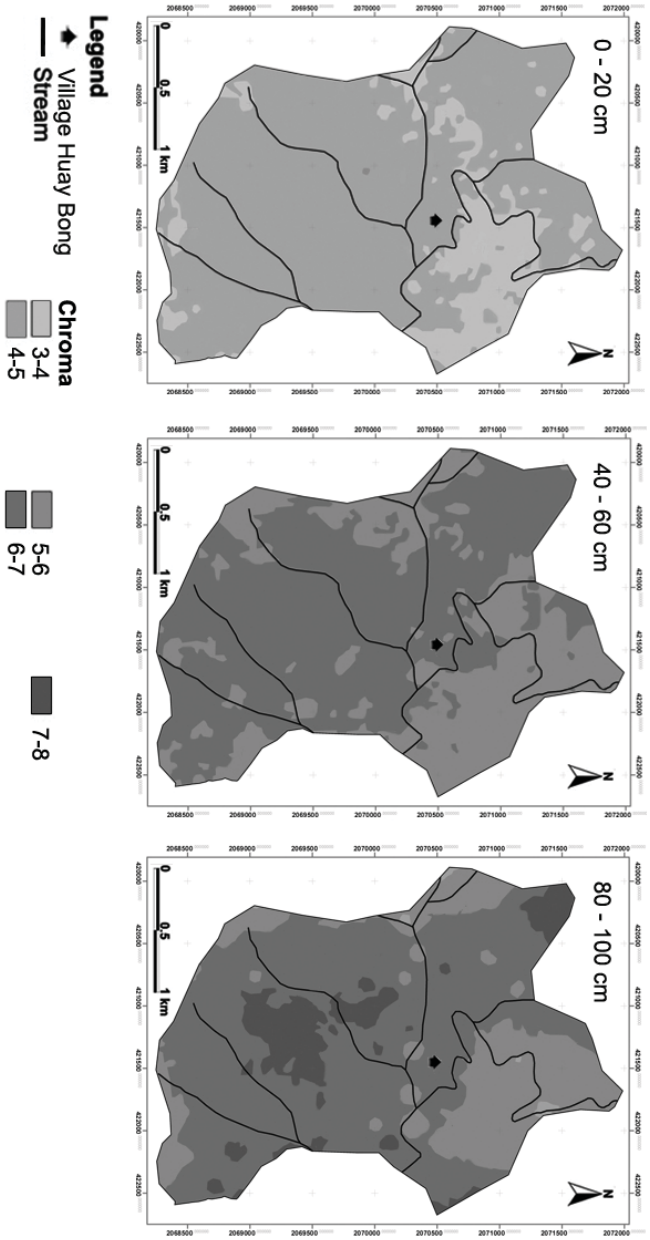

Figure 4-15: Soil colour chroma distribution of different depths in Huay Bong

Cambisols prevail in the valleys and on lower slopes as well as on steeper slopes (Figures 4-17, 4-18). Most of them are classified as Dystri-Humic Cambisols (Table 4-3). The Cambisols along the valley floors are mainly used for the cultivation of paddy rice and maize. Despite paddy rice cultivation, no Anthraquic horizon was observed, but sometimes stagnic properties were found. Close to the village mango orchards were established on Cambisols. In the valley bottom the A- and B-horizon texture commonly is clay loam or loam with a subangular blocky structure containing few coarse fragments. Towards the C-horizon the sand content increases resulting in a sandy clay loam texture with subangular blocky structure. The C-horizon consists mostly of gravel or conglomerate. The soil thickness normally ranges between 1 and 2m. On slopes the texture of the Cambisols depends on the parental material. Cambisols from sandstone mainly has a texture ranging from loam to clay loam with a granular structure for the topsoil to subangular blocky structure for the subsoil. Cambisols from claystone mainly show a less sandy texture ranging from silty clay to clay, with a granular structure for the topsoil and a subangular blocky to angular blocky structure for the subsoil. In both cases, the soil thickness (excluding the C-horizon) hardly exceeds 1m. Generally, the silt fraction prevails throughout 1m soil depth, followed by the clay fraction (see Table 4-13).

The C_{org} and N_t concentrations decrease from low values for the topsoil to very low values for the subsoil.

The P_{CAL} and K_{CAL} concentrations are decrease from medium values for the topsoil to low values for the subsoil.

The pH (H_2O), CECsoil, and base saturation, are medium throughout 1m soil depth. The main contribution to the base saturation derives from Ca followed by Mg, K, and Na. Ca and Mg can be traced back to the marl found in the area (Table 4-12).

The oxalate extractable iron (Fe_o) of the topsoil is 0.19±0.02%m and the dithionite extractable iron (Fe_d) is 3.67±0.08%m with an average Fe_o-Fe_d ration of 0.052 (n=2). The Fe_o concentration of the subsoil is 0.13±0.03%m and the Fed concentration amounts to 4.03±0.40%m with an average Fe_o-Fe_d ratio of 0.034 (n=6).

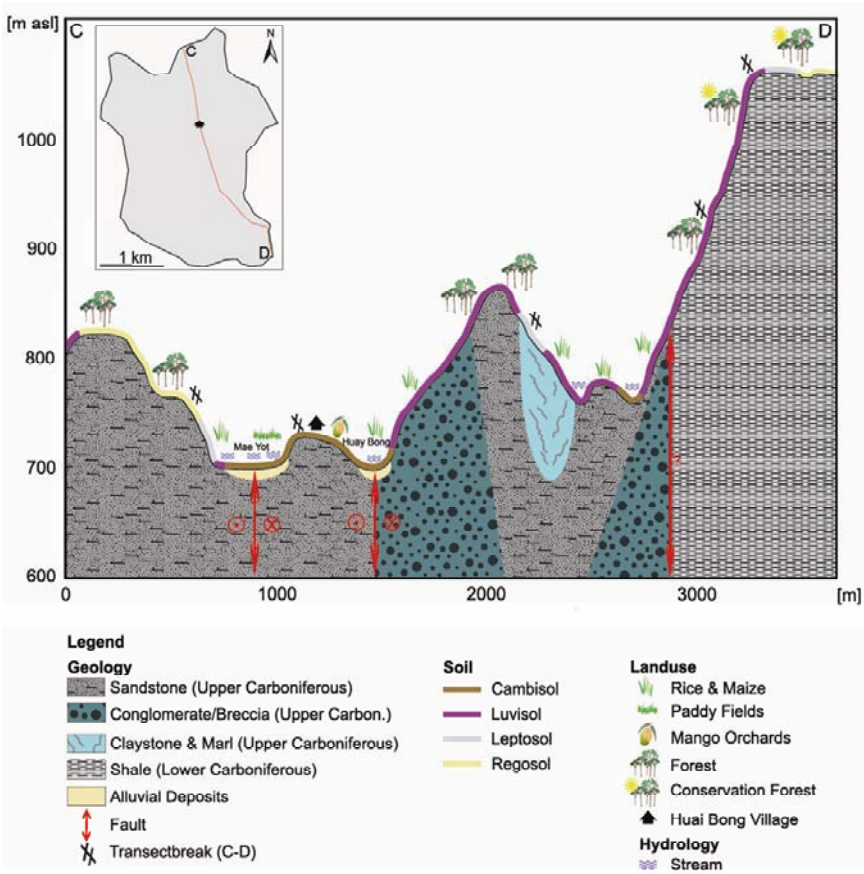

Figure 4-17: Transect through the Huay Bong area

One single **Fluvisol** (Dystri-Humic Fluvisol) was found at the lowest elevation in the study area. It occurs on both sides along the Mae Yot River and is covered with riparian vegetation. The texture is rather coarse comprising silt, silty loam, sandy clay and sandy clay loam. The soil thickness ranges between 1 and 2m. The pH (H_2O) of the investigated Fluvisols is medium throughout 1m soil depth.

Leptosols are common at crests and very steep slopes often in the vicinity of cliffs at several places in the area. Due to the steepness and shallowness and partly extreme high stone content, all Leptosols investigated are covered with forest. Most of them are classified as Dystri-Hyperskeletic Leptosols.

The texture ranges from clay loam, to loam and sandy clay. Subangular blocky structure prevails. All Luvisols investigated showed a medium topsoil pH (H_2O).

Luvisols (mostly Dystri-Profondic Luvisols) dominate sloping land (see Figures 4-17; 4-18). On steep sloping land they are covered with forest, while on gentler slopes maize and upland rice cultivation is common. Often a prominent eluvial horizon is developed within the soil profile. Luvisols from sandstone, breccia, and conglomerates show an A-horizon with a texture of sandy loam to sandy clay loam either coherent or in subangular blocky structure. The E-horizon consists of sandy clay loam to loam either subangular blocky structured or containing single grains. The Bt-horizon below is dominated by clay loam and clay with a subangular blocky structure. While the topsoil is dominated by the sand fraction, the clay fraction is clearly prevailing for the subsoil (see Table 4-13). The total soil thickness ranges between 1 and 2m. Luvisols from Carboniferous sandstone feature mostly abrupt clear horizon boundaries. In contrast, Luvisols from Tertiary sandstone show mainly gradual diffuse transitions. The soil thickness ranges between 1 and 2m.
The C_{org} concentration decreases from low values for the topsoil to very low values for the subsoil.
The $N_{t,}$ P_{CAL} concentrations are low throughout 1m soil depth.
The K_{CAL} concentration is medium for the topsoil and low for the subsoil.
The CEC_{soil} is low for the topsoil and medium for the subsoil.
The base saturation decreases from medium values for the topsoil is medium to low values for the subsoil (Table 4-12).

Regosols usually occur on the steepest slopes which are covered with rock debris. Most of them are classified as Dystri-Skeletic Regosols. Due to its inaccessibility, low fertility, high stone content preventing agricultural use all Regosols are covered with forest. Regosols originating from sandstone mostly have a texture of sandy loam and loam without structure (coherent). The soil thickness hardly exceeds 5cm. Regosols from claystone mainly show texture of silty clay and clay without structure (coherent). The variability of the sand and clay fraction (Table 4-13) is caused by different parental materials ranging from claystone to sandstone. The soil depth barely exceeds 40cm.
The investigation of the upper 20cm revealed low concentrations for C_{org}, P_{CAL} and K_{CAL}. The concentration of N_t is very low. Medium values are found for pH (H_2O), CEC_{soil} and base saturation. The high pH (H_2O) values for the subsoil can be traced back to one Regosol derived from alluvial deposits, containing marl in their rock debris (Table 4-12).

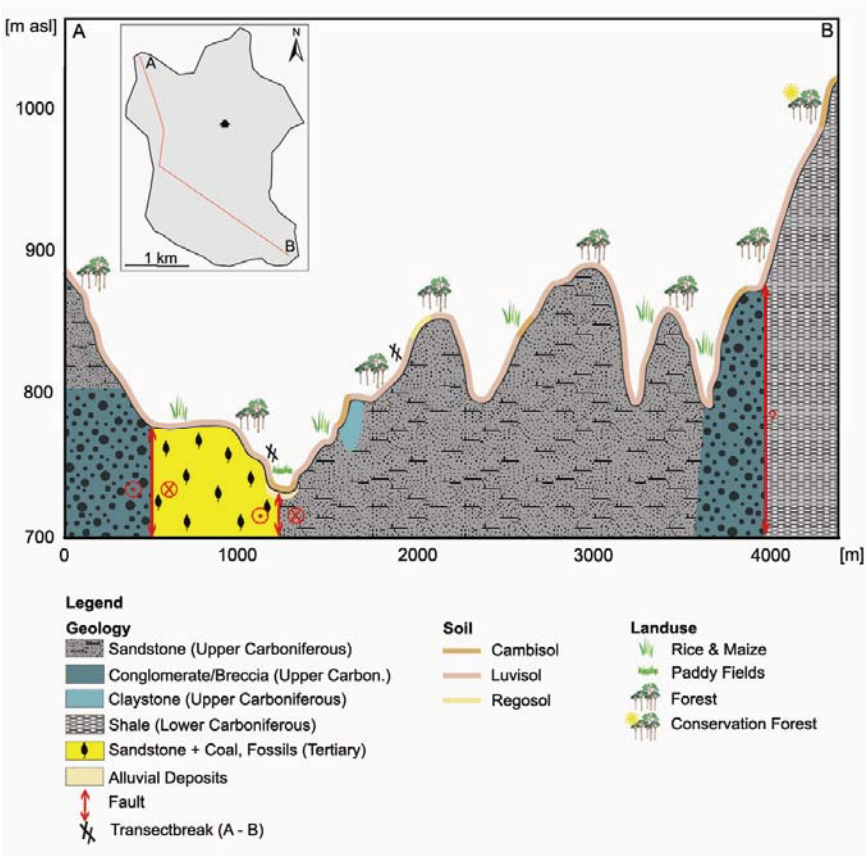

Figure 4-18: Transect through the Huay Bong area

Table 4-12: Chemical properties of major soil groups in the Huay Bong area
(Continuation on next page)

Depth		Cambisols N=3	Fluvisols N=2	Leptosols N=5	Luvisols N=4	Regosols N=3
0.0 - 0.2 m	C_{org} [g kg^{-1}]	14.7 ± 6.8	NA	NA	11.8 ± 4.2	13.3 ± 6.6
	N_t [g kg^{-1}]	1.1 ± 0.6	NA	NA	0.8 ± 0.4	0.8 ± 0.3
	P_{CAL} [mg kg^{-1}]	13.7 ± 20.0	NA	NA	3.9 ± 4.8	3.2 ± 2.3
	K_{CAL} [mg kg^{-1}]	136 ± 63	NA	NA	95 ± 87	67 ± 30
	pH	6.2 ± 1.8	6.7 - 6.9	6.4 ± 0.6	5.4 ± 0.7	6.5 ± 0.6
	CEC_{soil} [$cmol_c kg^{-1}$]	22.4 ± 5.7	NA	NA	13.2 ± 5.6	15.2 ± 7.5
	BS [%]	46.4 ± 21.0	NA	NA	20.9 ± 10.2	30.8 ± 22.7
	Na^+ [$cmol_c kg^{-1}$]	0.1 ± 0.1	NA	NA	0.0 ± 0.0	0.0 ± 0.0
	K^+ [$cmol_c kg^{-1}$]	0.6 ± 0.2	NA	NA	0.4 ± 0.3	0.4 ± 0.3
	Ca^{2+} [$cmol_c kg^{-1}$]	8.5 ± 6.3	NA	NA	1.3 ± 1.1	2.8 ± 3.3
	Mg^{2+} [$cmol_c kg^{-1}$]	2.0 ± 0.7	NA	NA	1.0± 0.5	0.9 ± 0.2
0.4 - 0.6 m	C_{org} [g kg^{-1}]	4.2 ± 1.7	NA	-	3.5 ± 0.9	NA
	N_t [g kg^{-1}]	0.5 ± 0.2	NA	-	0.5 ± 0.2	NA
	P_{CAL} [mg kg^{-1}]	0.4 ± 0.2	NA	-	0.2 ± 0.2	NA
	K_{CAL} [mg kg^{-1}]	73 ± 27	NA	-	49 ± 32	NA
	pH	6.0 ± 1.2	6.1 – 6.8	-	5.0 ± 0.5	7.0 ± 0.2
	CEC_{soil} [$cmol_c kg^{-1}$]	18.6 ± 8.4	NA	-	19.6 ± 5.2	NA
	BS [%]	39.8 ± 22.1	NA	-	8.6 ± 5.9	NA
	Na^+ [$cmol_c kg^{-1}$]	0.1 ± 0.1	NA	-	0.0 ± 0.0	NA
	K^+ [$cmol_c kg^{-1}$]	0.4 ± 0.0	NA	-	0.3 ± 0.1	NA
	Ca^{2+} [$cmol_c kg^{-1}$]	5.7 ± 4.9	NA	-	0.2 ± 0.1	NA
	Mg^{2+} [$cmol_c kg^{-1}$]	2.0 ± 1.4	NA	-	1.2 ± 1.2	NA

Table 4-12: Chemical properties of major soil groups in the Huay Bong area (Continuation)

Depth		Cambisols N=3	Fluvisols N=2	Leptosols N=5	Luvisols N=4	Regosols N=3
0.8 - 1.0 m	C_{org} [g kg^{-1}]	3.0 ± 0.6	NA	-	1.7 ± 0.8	NA
	N_t [g kg^{-1}]	0.4 ± 0.0	NA	-	0.5 ± 0.4	NA
	P_{CAL} [mg kg^{-1}]	0.6 ± 0.5	NA	-	0.2 ± 0.1	NA
	K_{CAL} [mg kg^{-1}]	58 ± 29	NA	-	34 ± 20	NA
	pH*	5.9 ± 0.9	5.6 – 7.0	-	5.1 ± 0.4	7.18 N=1
	CEC_{soil} [$cmol_c kg^{-1}$]	17.4 ± 8.8	NA	-	17.4 ± 4.1	NA
	BS [%]	47.5 ± 23.9	NA	-	7.4 ± 3.9	NA
	Na^+ [$cmol_c kg^{-1}$]	0.1 ± 0.0	NA	-	0.1 ± 0.0	NA
	K^+ [$cmol_c kg^{-1}$]	0.3 ± 0.0	NA	-	0.3 ± 0.1	NA
	Ca^{2+} [$cmol_c kg^{-1}$]	6.8 ± 6.9	NA	-	0.2 ± 0.1	NA
	Mg^{2+} [$cmol_c kg^{-1}$]	2.2 ± 1.8	NA	-	0.9 ± 0.7	NA

*N partially deviates from other analysis

Table 4-13: Physical properties of major soil groups in Huay Bong

Depth		Cambisols	Fluvisols	Leptosols	Luvisols	Regosols
0.0 - 0.2 m	**Sand [% m]**	23.2 ± 13.9 N=3	NA	NA	46.2 ± 16.8 N=4	44.3 ± 25.6 N=3
	Silt [% m]	44.5 ± 5.0 N=3	NA	NA	29.5 ± 5.4 N=4	29.4 ± 1.8 N=3
	Clay [% m]	32.3 ± 10.3 N=3	NA	NA	24.3 ± 16.8 N=4	25.4 ± 25.2 N=3
	Texture	loam – clay loam	silt – sandy clay loam	clay loam – sandy clay	sandy loam – sandy clay loam	high variability: sandy loam-clay
	Structure	subangular blocky	single grains, coherent	subangular blocky	coherent, subangular blocky	coherent
0.4 - 0.6 m	**Sand [% m]**	23.5 ± 15.3 N=3	NA	-	25.0 ± 13.4 N=4	NA
	Silt [% m]	39.5 ± 2.6 N=3	NA	-	24.8 ± 7.1 N=4	NA
	Clay [% m]	37.1 ± 13.4 N=3	NA	-	50.3 ± 10.2 N=4	NA
	Texture	loam – clay loam	silt – sandy clay loam	-	clay loam, clay	high variability: sandy loam-clay
	Structure	subangular blocky	single grains, coherent	-	subangular blocky	coherent
0.8 - 1.0 m	**Sand [% m]**	24.3 ± 19.4 N=3	NA	-	25.8 ± 15.9 N=4	NA
	Silt [% m]	38.8 ± 4.8 N=3	NA	-	27.9 ± 10.0 N=4	NA
	Clay [% m]	36.9 ± 14.9 N=3	NA	-	45.1 ± 10.0 N=4	NA
	Texture	loam – clay loam	silt – sandy clay loam	-	clay loam, clay	high variability: sandy loam-clay
	Structure	subangular blocky	single grains, coherent	-	subangular blocky	coherent

4.2.3 Bor Krai

Soil mapping revealed the soil variety of the Bor Krai area as 66% Luvisols, 20% Acrisols, 8% Cambisols, and 1% Leptosols Umbrisols, Ferralsols, Chernozems, and single rock outcrops each representing less than 0.1% (Figure 4-19).

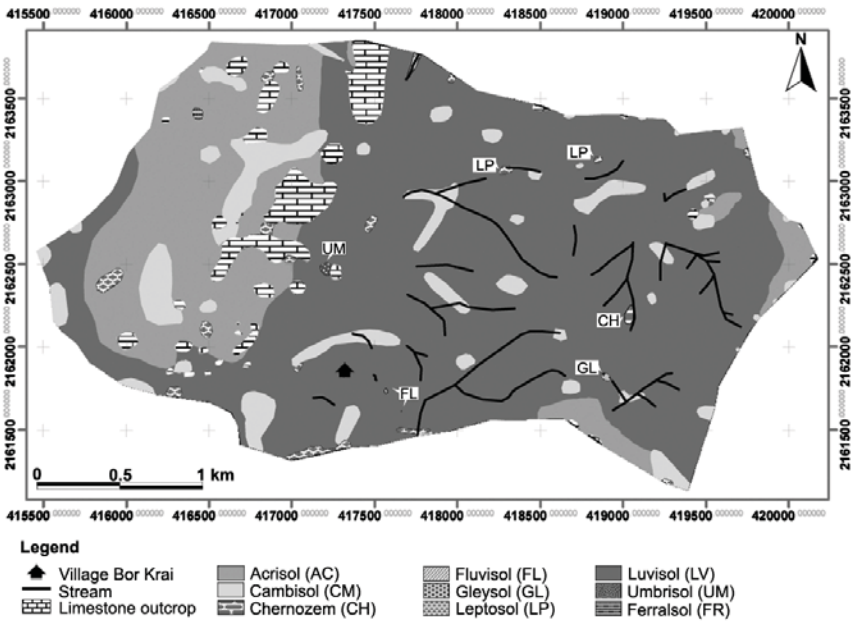

Figure 4-19: Soil map according to WRB classification of the Bor Krai area

In general, the **soil pH** (H_2O) decreases along with the soil depth. The lowest pH values were mostly found at locations, which are under intensive land use and affected by increased erosion rates, like the “pig camp”. This location resembles a village, but the huts are only used for storing tools and forage. Most of the pigs stay there in expectation of food. Exceptional high pH values were measured below karst springs and in the vicinity of sinkholes, where lime-rich backwater infiltrates the soil (see Figure 4-20).

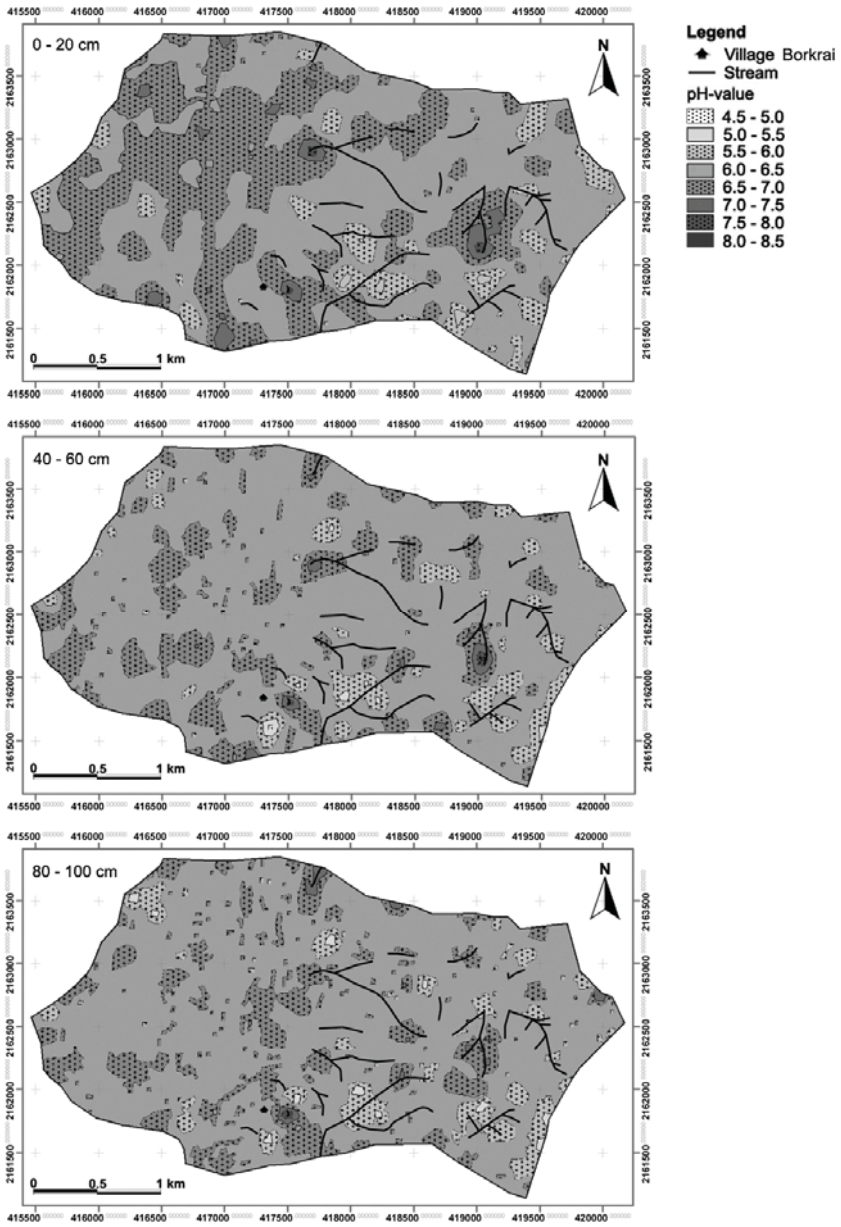

Figure 4-20: Soil pH distribution of different depths in the Bor Krai area

The Bor Krai area is the only study site where the parent rock material has a striking influence on soil colour. Luvisols and Acrisols from limestone and ironstone showed with over 63% soil colours with a **hue** of 2.5 YR or even more reddish. Luvisols from sandstone, siltstone and claystone showed with over 76% soil colours with a hue of 7.5 YR or more yellowish. The boundary between the "yellow soil" and the "red soil" is often very sharp (<10cm). The **soil colour value** of the subsoil corresponds with the parental material. Soils on limestone showed the lowest values, while the highest values were found on claystone (Figure 4-21).

In general, the **soil colour chroma** increases with soil depth (Figure 4-22). Like the subsoil value, the subsoil chroma is congruent to the parental material. Soils from limestone and iron ore in the area showed lower chroma than those from claystone, siltstone and sandstone.

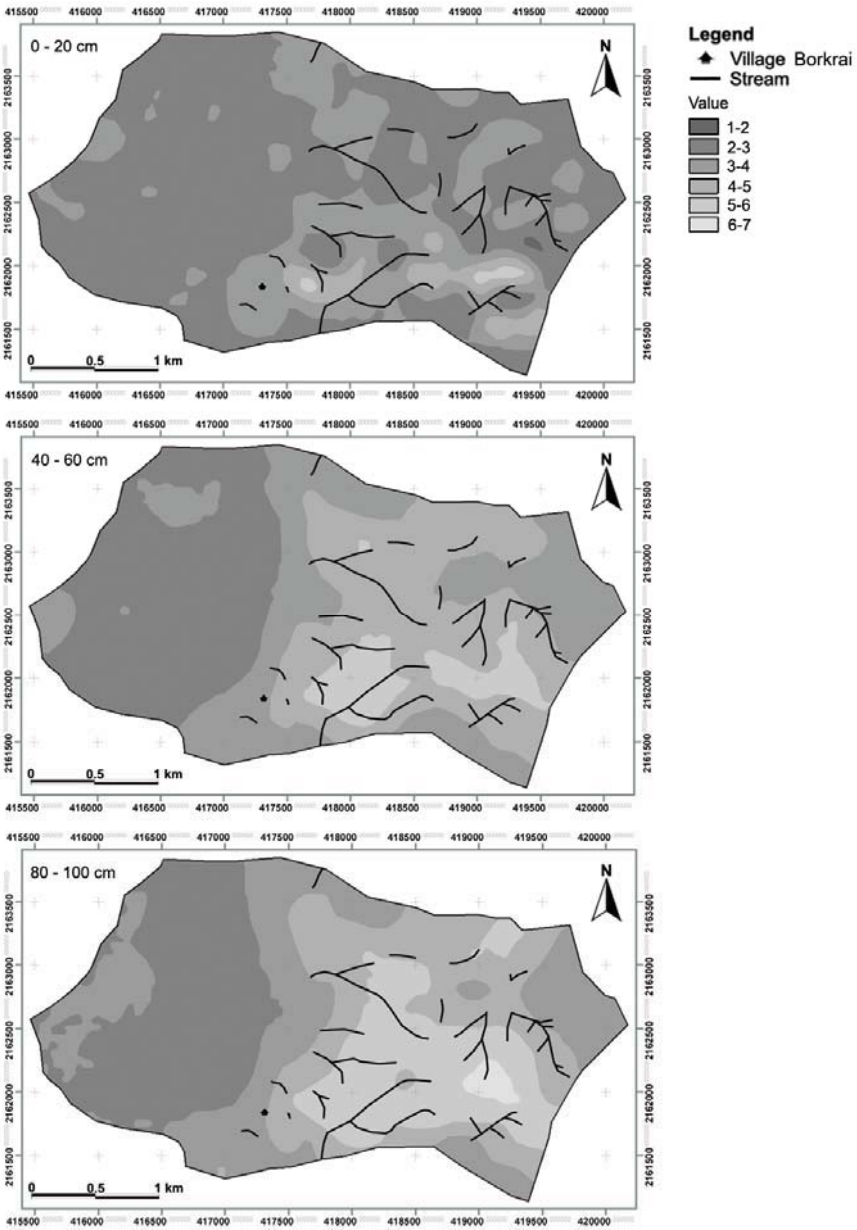

Figure 4-21: Soil colour value distribution for different depths in the Bor Krai area

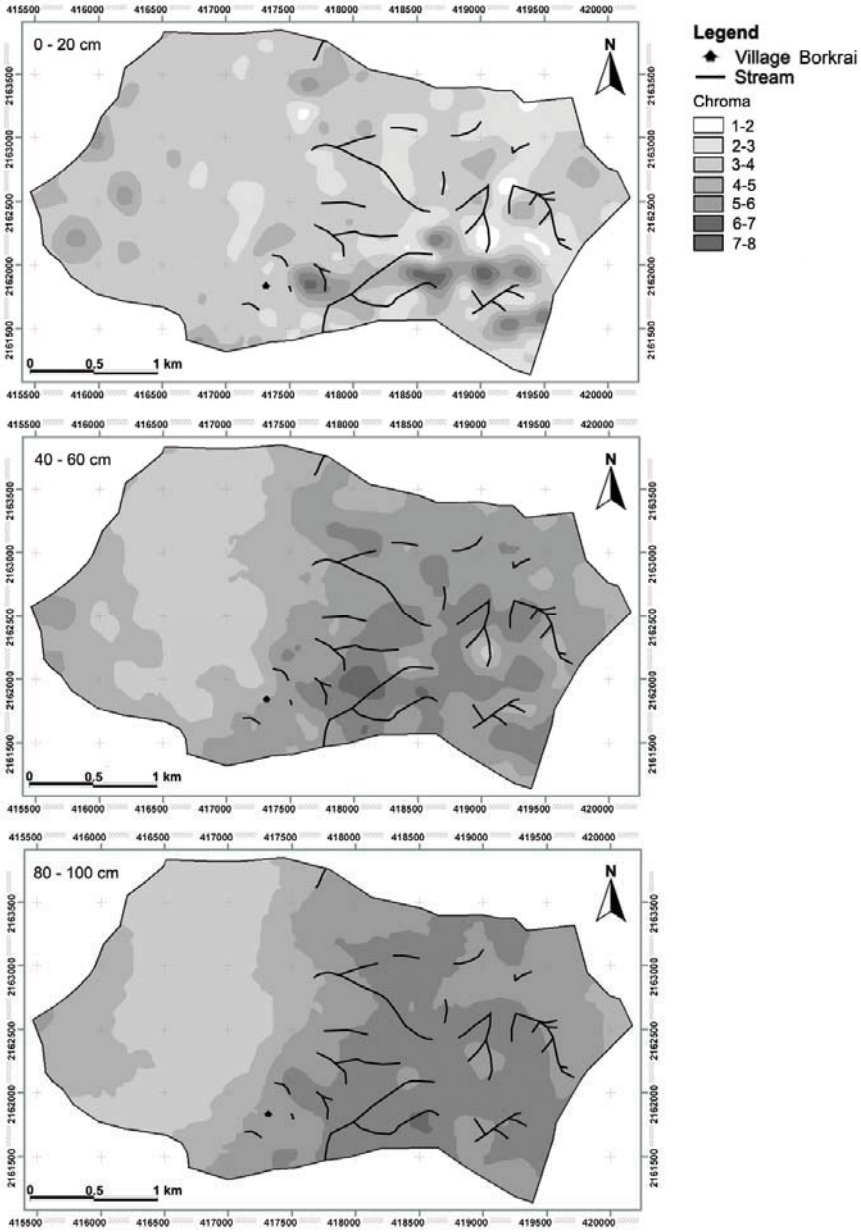

Figure 4-22: Soil colour chroma distribution for different depths in the Bor Krai area

The A-horizon thickness highly depends on the position in the landscape. The lowest A-horizon thickness was found on convex slopes, and the highest A-horizon thickness was found in karst depression without a sinkhole (Figure 4-23).

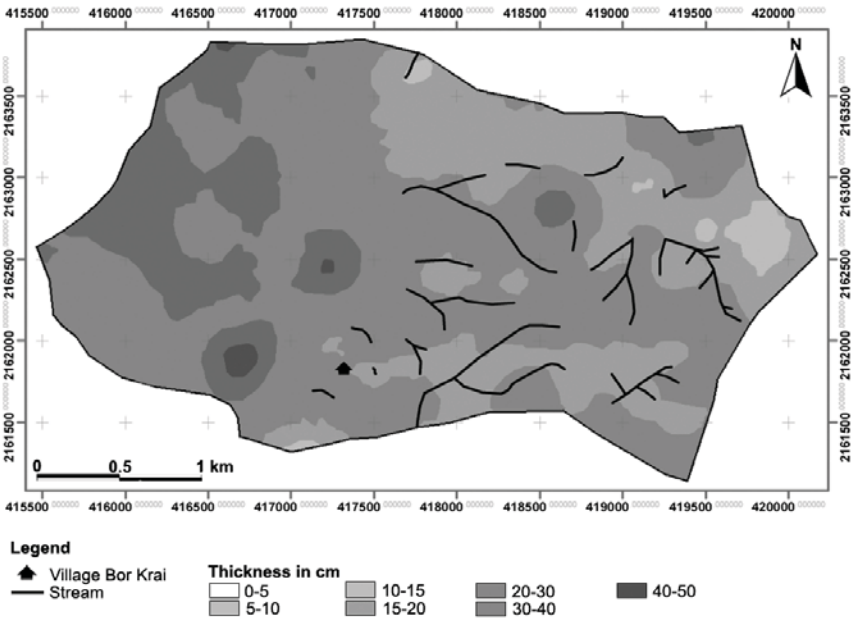

Figure 4-23: A-horizon thickness in the Bor Krai area

Acrisols prevail at higher landscape positions, below 800m asl Acrisols pass over to Luvisols (see Figures 4-24 and 4-25). Acrisols are mainly covered with deciduous forest while Luvisols are cultivated with rice and maize. In former times Acrisols were also used for poppy cultivation. Most Acrisols feature topsoil with a clay loam or clay texture showing a strong granular structure. The transition to the Argic horizon is mostly clear and a prominent E-horizon is missing. The Argic horizon commonly consists of clay loam and clay with a strong subangular blocky structure. Most of them are classified as Profondi-Humic Acrisols (Table 4-3).

The clay fraction dominates throughout 1m soil depth. In this range the clay fraction increases from around 57% for the topsoil to approximately 80% for the subsoil (Table 4-16A). Due to the strong pronounced soil structure the average bulk density of 0.8±0.1g cm^{-3} (n=7) is low to very low throughout the whole soil profile. The hydraulic conductivity of the topsoil is 77±27cm d^{-1} and 33±7cm d^{-1} for subsoil.

The soil thickness ranges from 25cm, where the limestone is close to the surface to several meters in karst pockets. For this reason Acrisols are often interlaced with Leptosols.

The C_{org} concentration decreases from medium values for the topsoil to low values for the subsoil.

The N_t concentration decreases from medium values for the topsoil to very low values for the lower subsoil.

The P_{CAL} and K_{CAL} values are low throughout the whole soil profile.

The CEC_{soil} decreases from high values for the topsoil to low values for the subsoil.

The base saturation is medium throughout 1m soil depth. The main contribution to the base saturation derives from Ca followed by Mg and K. Na can be ignored (Table 4-15A). Ca and Mg clearly originate from the limestone.

The oxalate extractable iron (Fe_o) of the topsoil is 0.17±0.04%m and the dithionite extractable iron (Fe_d) is 11.57±0.61%m with an average Feo-Fed ration of 0.015 (n=5). The Fe_o concentration of the subsoil is 0.22±0.04%m and the Fed concentration amounts to 12.52±0.84%m with an average Feo-Fed ratio of 0.018 (n=8).

In the vicinity of bauxite and iron ore outcrops the soil has exceptionally high amounts of gibbsite (Table 4-14).

Table 4-14: Bulk mineral composition of the subsoil horizons of an Acrisol in the vicinity of a bauxite outcrop in the Bor Krai area (Herrmann *et al.* 2007)

Depth [cm]	**[%]**							
	Muscovite	**Gibbsite**	**Hematite**	**Kaolinite**	**Verniculite**	**Quartz**	**Tridymite**	**Feldspars**
25-50	0	52	14	21	5	2	6	0
50-80	0	52	15	17	4	3	7	2
80-110	0	45	16	20	5	2	9	4
110-150	0	58	17	11***	7	5	0	2
>150	0	59	19	11***	6	4	0	1
LDR	54	0	4	12	0	0	26	5
Bauxite	0	65*	29**	29	7	0	0	0

*bayerite + boehmite + diaspore + gibbsite; ** hematite + goethite; ***nacrite suspected, LDR=limestone dissolution residue

Two kinds of **Cambisols** are present in the Bor Krai area. The first group prevails in depressions and on lower slopes, where deposition of eroded soil material occurs. The second group can be found on very convex slopes, which are subject to increased erosion rates. Cambisols in depressions are composed of colluvial deposits. The composition of the colluvial deposits depends on the degree of soil erosion from the slope above. In cases of minor soil erosion the colluvial deposits consist mainly of eroded topsoil material. In cases of severe soil erosion subsoil material is quite common. In the worst case material consists of the parental material. Most of the Cambisols are classified as Dystri-Humic Cambisols (Table 4-3). Cambisols in depressions are mainly used for cultivation of upland rice and maize. Cambisols on convex slopes close to the village are used for mango production. Those close to limestone outcrops were used until the 1990s for opium cultivation. At remote and inaccessible zones Cambisols are covered with forest. Cambisols on steep and convex slopes consist of clay loam and clay in the upper part and of coarser texture like silty clay in the lower part. Within 1m soil depth the textural composition of the Cambisols is very stable, and the clay fraction dominates followed by the silt fraction (Table 4-16A). Subangular blocky structure prevails throughout the whole soil profile. The presence of coarse fragments is clearly higher for Cambisols derived from claystone, than those from limestone.

Due to the high variability of Cambisols, this soil group shows the highest standard deviation for most of chemical parameters.

Generally, the C_{org} concentration decreases from medium values for the topsoil to very low values for the subsoil.

The N_t concentration of the topsoil is low and very low for the upper subsoil and low for the lower subsoil.

The P_{CAL} concentration decreases from high values for the topsoil to low values for the subsoil.

The K_{CAL} concentration is high for the topsoil and upper subsoil and medium for the lower subsoil.

The CEC_{soil} is high at least within 1m soil depth.

The pH (H_2O) and base saturation are medium throughout 1m soil depth. The main contribution derives from Ca followed by Mg and K. Exchangeable Na was not detected (Table 4-15A).

The oxalate extractable iron (Fe_o) of the topsoil is 0.44±0.10%m and the dithionite extractable iron (Fe_d) is 5.37±2.02%m with an average Fe_o-Fe_d ration of 0.095 (n=7). The Fe_o concentration of the subsoil is 0.32±0.15%m and the Fe_d concentration amounts to 5.32±2.18%m with an average Fe_o-Fe_d ratio of 0.078 (n=21).

Chernozems are restricted to the surroundings of karst springs and the area below the village's water reservoir. There, during the rainy season, carbonate-rich water seeps into the soil below and transformed it from a Cambisol into Chernozem in mere 10 years. Three kinds of Chernozems were found so far, namely Calci-Molliglossic Chernozems, Glossi-Calcic Chernozems, and Glossi-Luvic Chernozems. The main Chernozem occurrence is exclusively used for maize production. According to the local farmers, upland rice production is not feasible on Chernozems.

Most of the Chernozems investigated consist of a very dark thick topsoil (>50cm) with a silty clay texture and a strong granular structure in the upper part and a subangular blocky structure in the lower part. The clay fraction dominates slightly, followed by the silt fraction. Further characteristics of this topsoil are secondary carbonates and channels. The boundary to the underlying freshwater limestone is abrupt and irregular.

The soil thickness ranges between 40 and 70cm.

The investigation of one Chernozem location below the karst spring, which supplies the village with drinking water, revealed high C_{org}, N_t and pH (H_2O) values for the topsoil. The subsoil already consists of more than 95% of secondary carbonate and was, therefore, not analysed. The concentration of CEC_{soil} is high, P_{CAL} is medium and K_{CAL} is low.

The base saturation of the topsoil showed with 100% the maximum possible value. The contribution of Ca to base saturation is outstandingly high, followed by Mg and K. Exchangeable Na was not found (Table 4-15A).

The oxalate extractable iron (Fe_o) of the topsoil is 0.15±0.13%m and the dithionite extractable iron (Fe_d) is 0.80±0.16%m with an average Fe_o-Fe_d ration of 0.180 (n=3). This is the highest Fe_o-Fe_d ratio of all three study areas.

One **Ferralsol** patch (mostly Umbri-Gibbsic Ferralsols) was found approximately 100m below an ironstone and bauxite outcrop. The site was used for cultivation of rice and maize. At present, the site is fallow with young trees and might be cultivated again in the future. This Ferralsol has a topsoil of silty clay to clay with granular to subangular blocky structure. The subsoil consists of clay and has a moderate to strong subangular blocky structure. The clay fraction dominates throughout the whole soil profile, thereby the clay content increases from the upper topsoil until reaching its maximum at the lower subsoil. Below this the clay content remains very high down to at least 1.4m soil depth. The increase of clay content within the topsoil fulfilled almost the requirements of an Argic horizon (Table 9-28).

The bulk density of the topsoil is very low 0.7±0.1g cm^{-3} (n=3) and for the subsoil low 1.1±0.1g cm^{-3} (n=3).

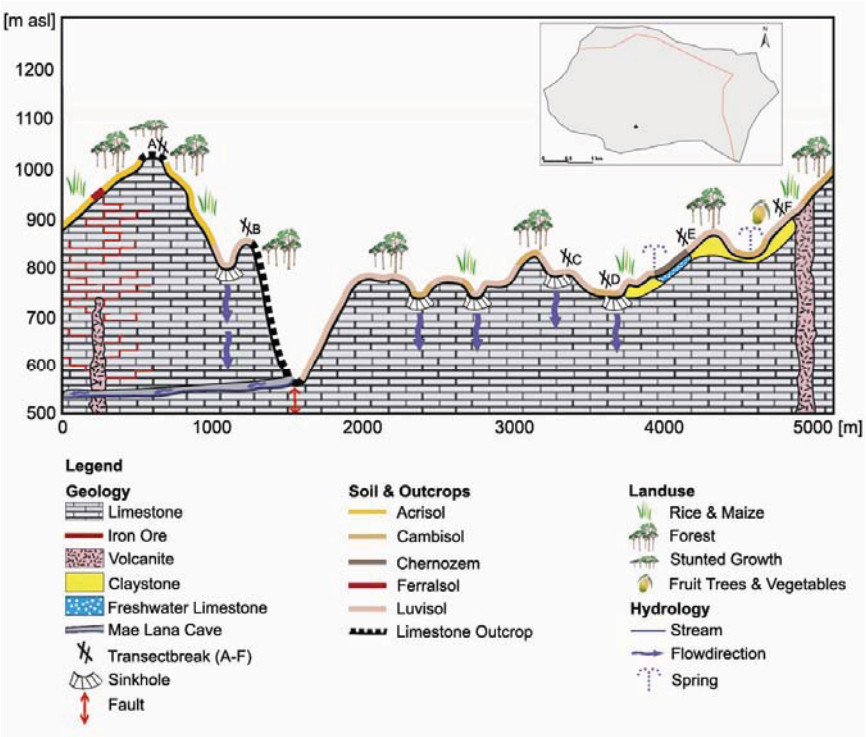

Figure 4-24: Transect (A-B) through the Bor Krai karst area

The hydraulic conductivity of the topsoil is 40±29cm d^{-1} (n=3) and for the subsoil 34±7cm d^{-1} (n=3). In dependence of subsurface limestone, soil depth ranges from approximately 100cm up to several meters. The Ferralsol detected interlaces with Regosols and Acrisols. interlaces with Leptosols and Acrisols.

The C_{org} and N_t concentrations decrease from medium values for the topsoil to very low values for the subsoil.

For the whole soil profile the concentrations of P_{CAL} and K_{CAL} are low, and the pH (H_2O) is medium.

The CEC_{soil} decreases from high values for the topsoil and medium values for the subsoil.

The base saturation is medium for the topsoil and low for the subsoil. The main contribution to the base saturation derives from Ca followed by Mg and K, Na is negligible (Table 4-15A).

The oxalate extractable iron (Fe_o) of the topsoil is 0.15±0.03%m and the dithionite extractable iron (Fe_d) is 12.55±0.29%m with an average Fe_o-Fe_d ration of 0.012 (n=3). The Fe_o concentration of the subsoil is 0.21±0.01%m and the Fe_d concentration amounts to 13.41±0.78%m with an average Fe_o-Fe_d ratio of 0.016 (n=3). These are lowest Fe_o-Fe_d ratios of all three investigated areas.

Fluvisols (mostly Humi-Stagnic Fluvisols) are restricted to the vicinity of streams and streambeds and are mainly covered with riparian vegetation. Some Fluvisols are used for cultivation of rice and maize. The most prominent Fluvisol site was found at the deepest part of the study area along Mae Lana stream before entering Mae Lana cave. There the texture of the various layers consists of loam, sandy loam, silty clay loam, sandy loam, and clay loam.
Only horizons with a higher clay content show a subangular blocky structure, other horizons consist of single grains.
The C_{org} concentration for the whole soil profile is low.
The N_t concentration decreases from low for the topsoil to very low for the lower subsoil.
The CEC_{soil} remains around 25cmol$_c$ kg^{-1} throughout 1m soil depth.
The pH (H_2O) and base saturation increase from medium for the topsoil to high for the lower subsoil. The main contribution to the base saturation derives from Ca followed by K and Mg for the topsoil and followed to equal parts by K and Mg for the lower subsoil (Table 4-15B).

Gleysols (mostly Calcari-Humic Gleysol) are usually quite rare within karst areas. In Bor Krai Gleysols and gleyic properties were found in karst depressions, which are sealed by clayish alluvial deposits. In a small karst depression below the Bor Krai village one Gleysol was investigated (Figure 4-25). Due to land allocation problems the area with this Gleysol is not used agriculturally. Presently, shrubs and trees cover this land. Due to the high soil fertility vegetable production might be feasible. At this location the groundwater is supplied by a small karst spring and village waste water. The topsoil consists of silty clay loam with a weak subangular blocky structure. The Bg horizon below consists of loam with a weak angular blocky structure and shows an oximorphic colour pattern. The Br horizon underneath has also a texture of loam, but is structureless. This horizon is characterised by a reductomorphic colour pattern. In October 2004 the ground water level was just 10cm below the surface.
The C_{org} concentration within 1m soil depth is medium.
The N_t concentration decreases from medium for the topsoil to low for the subsoil.

The P_{CAL} concentration is high throughout 1m soil depth. This can be traced back to the waste water from the village.
The potassium concentration is medium for the topsoil and upper subsoil, and high for the lower subsoil.
The pH of the topsoil and upper subsoil is neutral, and medium for the lower subsoil.
The whole soil profile showed a medium CEC_{soil} and a very high base saturation. The amount of exchangeable Ca is very high, followed by K, Na and Mg (Table 4-15B). The high amount of exchangeable Ca can be traced back to the lime rich water of the karst spring. The low value for Mg is surprising, indicating a certain chemical variability of the limestone. The amounts of Na and K are exceptional for this area and can only be explained by the waste water supply.

Most **Leptosols** occur on limestone at sites of increased soil degradation. The texture is mostly clay loam with a subangular blocky structure. Nearly all Leptosols are not hyperskeletic and corresponding to definition less than 25cm thick. Most of them are classified as Calcari-Humic Leptosol and Humi-Mollic Leptosol. These soils are characterised by a lack of coarse fragments, which could accumulate at the surface to protect the soil below. Consequently, soils from limestone degrade unhampered down to the limestone.
Due to shallowness and the surface rockiness in the vicinity of Leptosols, agricultural land use is precluded, thus most Leptosols are covered with forest. After soil degradation to the stage of a Leptosol, agricultural land is often converted into forest. In the forest, erosion rates still remain high due to the yearly traditional man-made fires destroying the ground vegetation.

Luvisols dominate in lower elevations, below 800m asl. They are normally used for cultivation of upland rice and maize. At some Luvisol sites sesame, mango and banana are produced. At very steep or with difficult accessible locations Luvisols are covered with forest. In the Bor Krai area prominent eluvial horizons are not developed. Most of the Luvisols from claystone are classified as Ferri-Profondic Luvisol and those from limestone are mainly classified as Rhodi-Profondic Luvisol (see Table 4-4). Usually, the topsoil directly passes over into the Argic horizon. The topsoil mostly consists of clay loam with a subangular blocky structure. The boundary to the Argic horizon below is usually clear. The Argic horizon consists mainly of clay loam and clay with subangular blocky structure. The clay content dominates and at least increases between topsoil and 1m soil depth (Table 4-16B). Many Luvisols are profondic, which means that the clay content of the Argic horizon is more or less constant down to 1.5m soil depth.

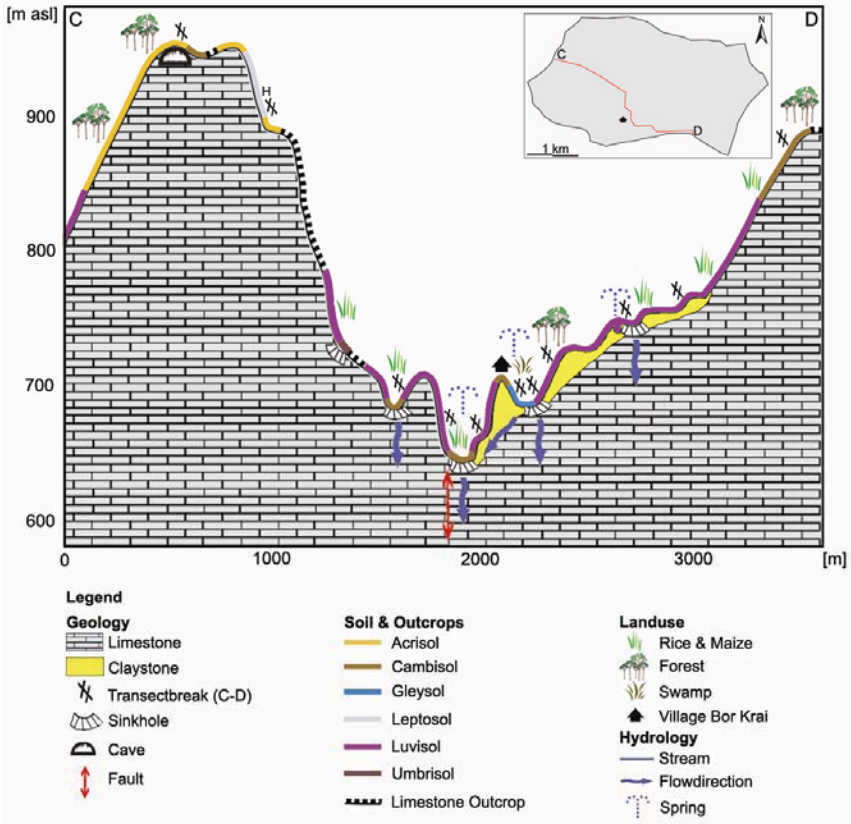

Figure 4-25: Transect II through the Bor Krai karst area

Luvisols from latite had the highest clay contents and the topsoils consist of silty clay with a granular to subangular blocky structure. The Argic horizon below consists of clay with an angular blocky and prismatic structure. The highest content of coarse fragments was found in Luvisols from claystone, siltstone, and sandstone. The lowest share of coarse fragments was found in Luvisols derived from limestone. The bulk density of the topsoil is only slightly lower 1.38±0.11g cm^{-3} for the topsoil, than for the subsoil 1.41±0.08g cm^{-3}.

The hydraulic conductivity is 32±32cm d^{-1} (n=2) for the topsoil and 14±17cm d^{-1} (n=7) for the subsoil. The soil depth of the Luvisols from limestone ranges from 25cm close to limestone outcrops to several meters in karst pockets. There Luvisols interlace with Leptosols and Cambisols. Luvisols from claystone, siltstone and sandstone often show a soil depth between 150 and 200cm.

Luvisols from Latite are at least 200cm thick. Luvisols from other parental materials than limestone mostly interlace with Cambisols.
In average the C_{org}, N_t concentrations decrease from low (topsoil) to very low (subsoil).
The K_{CAL} decreases from high for the topsoil to medium for the subsoil.
The P_{CAL} concentration is low, the CEC_{soil} is high, the pH (H_2O) and base saturation are medium throughout 1m soil depth. The main contribution to the base saturation derives from Ca, followed by Mg, K, and Na (Table 4-15B).
Low values for the micronutrients Zn, B and Mo were detected. Zn ranges from 9.5mg kg^{-1} in the topsoil to 2.7mg kg^{-1} in the subsoil. B ranges from 0.4mg kg^{-1} in the topsoil to 0.2mg kg^{-1} in the subsoil. Mo showed low values (<0.01mg kg^{-1}) throughout (Hüller 2006).
The oxalate extractable iron (Fe_o) of the topsoil is 0.43±0.29%m and the dithionite extractable iron (Fe_d) is 4.12±2.13%m with an average Fe_o-Fe_d ration of 0.112 (n=8). The Fe_o concentration of the subsoil is 0.19±0.11%m and the Fe_d concentration amounts to 5.01±1.85%m with an average Fe_o-Fe_d ratio of 0.038 (n=6).

Umbrisols (mostly Humi-Anthric Umbrisol) were found in karst depressions were eroded topsoil material accumulated from the upper slope. All of them are cultivated with rice and maize. At one site, charcoal indicated a soil accumulation of at least two meters. According to the villagers, the forest at this site was cleared around 30 years ago.
This indicates deposition rates of at least 6cm per year by assuming an age of 30 years for the charcoal and that this site was not used in prehistoric times. There the uppermost 15cm consist of silty clay with a granular structure, while the clay fraction prevails, followed by the silt fraction (Table 4-16B). The horizons below consist of clay with a subangular blocky structure. Most Umbrisols are at least 200cm thick.
The Umbrisol in such karst depressions show a C_{org} concentration decreasing from medium for the topsoil to very low values for the subsoil. The N_t concentration decreases from low for the topsoil to low for the subsoil.
The P_{CAL} concentration decreases from high for the topsoil to medium for the subsoil.
The K_{CAL} concentration decreases from medium for the topsoil to low for the subsoil.
The pH (H_2O) is medium throughout the soil profile.
The cation exchange capacity decreases from very high for the topsoil and upper subsoil to high for the lower subsoil.
The base saturation decreases from medium for the topsoil and upper subsoil to low for the lower subsoil. The main contribution to the base saturation derives from Ca followed by K and Mg. Exchangeable Na was not detected (Table 4-15B).

Table 4-15: Soil chemical properties of major soil groups in the Bor Krai area – Part A (Continuation on next page)

Depth		Acrisols N=4	Cambisols N=6	Chernozems N=1	Ferralsols N=1
0.0-0.2 m	C_{org} [g kg^{-1}]	33.3 ± 6.5	25.3 ± 11.7	54.4	28.3
	N_t [g kg^{-1}]	2.1 ± 0.4	1.9 ± 0.8	5.1	2.1
	P_{CAL} [mg kg^{-1}]	4.1 ± 0.6	18.8 ± 23.4	11.3	4.2
	K_{CAL} [mg kg^{-1}]	67 ± 26	168 ± 109	46	44
	pH*	6.4 ± 0.5 N=56	6.4 ± 0.5 N=74	7.3 ± 0.5 N=3	6.5 ± 0.5 N=4
	CEC_{soil} [$cmol_c kg^{-1}$]	30.8 ± 11.5	39.1 ± 13.0	42.7	31.3
	BS [%]	48.5 ± 17.8	42.4 ± 15.5	100	43.7
	Na^+ [$cmol_c kg^{-1}$]	0.1 ± 0.1	0.0 ± 0.0	0	0.1
	K^+ [$cmol_c kg^{-1}$]	0.5 ± 0.5	0.9 ± 0.4	0.2	0.2
	Ca^{2+} [$cmol_c kg^{-1}$]	12.1 ± 5.9	14.6 ± 10.1	41.4	12.7
	Mg^{2+} [$cmol_c kg^{-1}$]	2.0 ± 1.8	2.7 ± 1.6	1.1	1.0
0.4-0.6 m	C_{org} [g kg^{-1}]	18.7 ± 9.5	8.4 ± 4.9	NA	8.9
	N_t [g kg^{-1}]	1.0 ± 0.3	0.9 ± 0.3	NA	0.9
	P_{CAL} [mg kg^{-1}]	1.8 ± 1.6	10.8 ± 15.9	NA	3.2
	K_{CAL} [mg kg^{-1}]	12 ± 14	228 ± 284	NA	4
	pH*	6.3 ± 0.4 N=55	6.3 ± 0.5 N=66	7.2 ± 0.1 N=3	6.2 ± 0.5 N=4
	CEC_{soil} [$cmol_c kg^{-1}$]	19.3 ± 10.2	36.8 ± 6.8	NA	17.8
	BS [%]	25.3 ± 8.4	40.0 ± 14.3	NA	12.4
	Na^+ [$cmol_c kg^{-1}$]	0.0 ± 0.0	0.0 ± 0.0	NA	0
	K^+ [$cmol_c kg^{-1}$]	0.1 ± 0.0	0.6 ± 0.3	NA	0.1
	Ca^{2+} [$cmol_c kg^{-1}$]	3.5 ± 1.6	12.2 ± 7.8	NA	1.8
	Mg^{2+} [$cmol_c kg^{-1}$]	0.8 ± 0.7	2.3 ± 0.7	NA	0.4

Table 4-15: Soil chemical properties of major soil groups in the Bor Krai area – Part A (Continuation)

Depth		Acrisols N=4	Cambisols N=6	Chernozems N=1	Ferralsols N=1
0.8-1.0 m	C_{org} [g kg^{-1}]	15.8 ± 14.6	6.5 ± 5.1	NA	5.3
	N_t [g kg^{-1}]	0.7 ± 0.2	1.2 ± 0.4	NA	0.7
	P_{CAL} [mg kg^{-1}]	1.0 ± 1.7	1.6 ± 12.8	NA	1.6
	K_{CAL} [mg kg^{-1}]	NA	114 ± 65	NA	NA
	pH*	6.3 ± 0.5 N=52	6.3 ± 0.5 N=58	7.2 ± 0.1 N=2	5.9 ± 0.5 N=4
	CEC_{soil} [$cmol_c kg^{-1}$]	15.2 ± 8.0	34.2 ± 8.4	NA	16.1
	BS [%]	22.5 ± 13.1	37.7 ± 15.9	NA	10.2
	Na^+ [$cmol_c kg^{-1}$]	0.0 ± 0.0	0.0 ± 0.0	NA	0.0
	K^+ [$cmol_c kg^{-1}$]	0.1 ± 0.0	0.6 ± 0.2	NA	0.1
	Ca^{2+} [$cmol_c kg^{-1}$]	2.1 ± 1.1	10.7 ± 8.3	NA	1.3
	Mg^{2+} [$cmol_c kg^{-1}$]	0.7 ± 0.6	2.1 ± 0.9	NA	0.3

*N deviates from other analysis

Table 4-15: Soil chemical properties of major soil groups in the Bor Krai area – Part B
(Continuation on next page)

Depth		Fluvisols N=1	Gleysols N=1	Luvisols N=9	Umbrisols N=9
0.0 - 0.2 m	C_{org} [g kg^{-1}]	15.7	26.6	19.2 ± 6.6	28.1
	N_t [g kg^{-1}]	1.1	2.1	1.5 ±0.5	1.9
	P_{CAL} [mg kg^{-1}]	NA	22.3	4.8 ± 7.4	26.6
	K_{CAL} [mg kg^{-1}]	NA	91	232 ± 141	128
	pH*	6.7 ± 0.7 N=5	7.0 ± 1.2 N=2	6.4 ± 0.5 N=179	6.6 ± 0.4 N=2
	CEC_{soil} [$cmol_c kg^{-1}$]	24.7	24.0	27.0 ± 8.4	52.2
	BS [%]	48.6	92.3	42.9 ± 10.4	36.3
	Na^+ [$cmol_c kg^{-1}$]	0.0	0.2	0.1 ± 0.1	0.0
	K^+ [$cmol_c kg^{-1}$]	0.3	0.3	0.9 ± 0.4	0.8
	Ca^{2+} [$cmol_c kg^{-1}$]	11.5	11.5	8.7 ± 5.1	17.9
	Mg^{2+} [$cmol_c kg^{-1}$]	0.1	0.1	2.3 ± 1.6	0.3
0.4 - 0.6 m	C_{org} [g kg^{-1}]	13.9	21.3	6.9 ± 2.6	11.4
	N_t [g kg^{-1}]	1.0	1.5	0.9 ± 0.2	0.9
	P_{CAL} [mg kg^{-1}]	NA	23.4	0.1 ± 0.2	12.1
	K_{CAL} [mg kg^{-1}]	NA	89	100 ± 35	13
	pH*	6.9 ± 0.3 N=5	7.0 ± 1.5 N=2	6.3 ± 0.4 N=176	6.0 ± 0.0 N=2
	CEC_{soil} [$cmol_c kg^{-1}$]	25.7	19.0	28.5 ± 8.5	40.5
	BS [%]	49.9	97.4	35.4 ± 15.8	24.0
	Na^+ [$cmol_c kg^{-1}$]	0.0	0.3	0.1 ± 0.1	0
	K^+ [$cmol_c kg^{-1}$]	0.2	0.3	0.5 ± 0.2	0.2
	Ca^{2+} [$cmol_c kg^{-1}$]	12.4	17.9	7.6 ± 5.5	9.2
	Mg^{2+} [$cmol_c kg^{-1}$]	0.2	0.1	2.5 ± 2.9	0.2

Table 4-15: Soil chemical properties of major soil groups in the Bor Krai area – Part B (Continuation)

Depth		Fluvisols N=1	Gleysols N=1	Luvisols N=9	Umbrisols N=9
0.8 - 1.0 m	C_{org} [g kg^{-1}]	13.5	21.8	4.2 ± 1.7	5.5
	N_t [g kg^{-1}]	0.9	1.4	0.8 ± 0.1	0.6
	P_{CAL} [mg kg^{-1}]	NA	42.5	0.0 ± 0.1	5.2
	K_{CAL} [mg kg^{-1}]	NA	196	97 ± 50	10
	pH*	7.1 ± 0.5 N=5	6.8 ± 1.9 N=2	6.2 ± 0.5 N=158	6.2 ± 0.4 N=2
	CEC_{soil} [$cmol_c kg^{-1}$]	24.8	19.7	28.8 ± 8.0	36.5
	BS [%]	53.2	100	35.3 ± 18.8	19.1
	Na^+ [$cmol_c kg^{-1}$]	0.0	0.6	0.1 ± 0.1	0
	K^+ [$cmol_c kg^{-1}$]	0.2	0.6	0.5 ± 0.3	0.2
	Ca^{2+} [$cmol_c kg^{-1}$]	12.8	18.5	7.7 ± 5.9	6.5
	Mg^{2+} [$cmol_c kg^{-1}$]	0.2	0.1	2.5 ± 3.2	0.2

N deviates from other samples

Table 4-16: Soil physical properties of major soil groups in the Bor Krai area – Part A

Depth		Acrisols	Cambisols N=6	Chernozems N=1	Ferralsols N=1
0.0 - 0.2 m	Sand [% m]	9.3 ± 5.5 N=4	9.0 ± 11.5 N=6	12.0 N=1	3.3 N=1
	Silt [% m]	33.7 ± 12.0 N=4	40.4 ± 4.0 N=6	43.2 N=1	32.1 N=1
	Clay [% m]	57.0 ± 7.8 N=4	50.6 ± 10.1 N=6	44.8 N=1	64.6 N=1
	Bulk density [g cm-^{3}]	0.8 ± 0.1 N=3	NA	NA	0.7 N=1
	Ks [cm d^{-1}]	90.7 N=1	NA	NA	24.4 N=1
	Texture	clay loam, clay	clay loam, clay	silty clay	silty clay, clay
	Structure	granular	subangular blocky	granular	granular, subangular blocky
0.4 - 0.6 m	Sand [% m]	7.1 ± 3.0 N=4	11.1 ± 8.7 N=6	14.3 N=1	2.7 N=1
	Silt [% m]	18.8 ± 13.4 N=4	38.3 ± 4.4 N=6	41.7 N=1	17.6 N=1
	Clay [% m]	74.1± 12.1 N=4	50.6 ± 12.0 N=6	44.0 N=1	79.6 N=1
	Bulk density [g cm-^{3}]	0.7 – 0.8 N=2	NA	NA	0.8 N=1
	Ks [cm d^{-1}]	45.3 N=1	NA	NA	72.1 N=1
	Texture	clay loam, clay	silty clay	silty clay	clay
	Structure	subangular blocky	subangular blocky	subangular blocky	subangular blocky
0.8 - 1.0 m	Sand [% m]	6.4 ± 3.1 N=4	12.1 ± 10.2 N=5	-	3.8 N=1
	Silt [% m]	13.8 ± 10.9 N=4	38.1 ± 3.2 N=5	-	19.0 N=1
	Clay [% m]	80.4 ± 10.7 N=4	49.9 ± 11.6 N=5	-	77.3 N=1
	Bulk density [g cm-^{3}]	0.8 N=2	NA	-	1.0 N=1
	Ks [cm d^{-1}]	28.8 N=1	NA	-	41.2 N=1
	Texture	clay loam, clay	silty clay	-	clay
	Structure	subangular blocky	subangular blocky	-	subangular blocky

Table 4-16: Soil physical properties of major soil groups in the Bor Krai area – Part B

Depth		Fluvisols N=1	Gleysols N=1	Luvisols	Umbrisols N=1
0.0 - 0.2 m	**Sand [% m]**	41.6	18.3	20.0 ± 6.0 N=8	9.1
	Silt [% m]	36.5	54.0	39.8 ± 8.6 N=8	39.1
	Clay [% m]	21.9	27.8	40.1 ± 9.7 N=8	51.8
	Bulk density [g cm-^{3}]	NA	NA	1.4 ± 0.1 N=3	NA
	Ks [cm d^{-1}]	NA	NA	45.3 N=1	NA
	Texture	high variability: sandy loam – clay loam	silty clay loam	clay loam	silty clay, clay
	Structure	single grains, subangular blocky	subangular blocky	subangular blocky	granular
0.4 - 0.6 m	**Sand [% m]**	32.8	36.8	14.8 ± 6.5 N=8	8.5
	Silt [% m]	43.5	40.3	31.3 ± 8.2 N=8	34.0
	Clay [% m]	23.7	22.9	53.9 ± 12.2 N=8	57.5
	Bulk density [g cm-^{3}]	NA	NA	1.5 ± 0.0 N=3	NA
	Ks [cm d^{-1}]	NA	NA	10.3 N=1	NA
	Texture	high variability: sandy loam – clay loam	Loam	clay loam, clay	clay
	Structure	single grains, subangular blocky	subangular blocky	subangular blocky	subangular blocky
0.8 - 1.0 m	**Sand [% m]**	40.3	43.3	12.0 ± 5.2 N=8	14.1
	Silt [% m]	40.0	33.6	32.9 ± 11.7 N=8	37.5
	Clay [% m]	19.7	23.1	55.1 ± 12.1 N=8	48.4
	Bulk density [g cm-^{3}]	NA	NA	1.4 ± 0.1 N=3	NA
	Ks [cm d^{-1}]	NA	NA	8.2 N=1	NA
	Texture	high variability: sandy loam – clay loam	loam	clay loam, clay	clay
	Structure	single grains, subangular blocky	coherent	subangular blocky	subangular blocky

4.3 Local soil classifications

Local soil classification differed among the studied villages. Regardless of these differences, in all villages "local soil experts" with a profound knowledge of soil properties and crop suitability could be identified. Bor Krai and Huay Bong had more "local soil experts" than Mae Sa Mai.

4.3.1 Mae Sa Mai

In Mae Sa Mai soil types were mainly distinguished by subsoil colour and the thickness of the dark topsoil (where available). Six local soil types were identified by the farmers. According to this classification the mapping area consists to 47% of Red Soil, 32% of Shallow Black Red Soil, 15% of Deep Black Red Soil, 4% of Black Soil and to less than 1% of Grey Soil and Black Red Yellow Soil respectively (Figure 4-26).

The Black Soil is characterised by a black topsoil with a thickness of clearly more than an elbow (approximately 30cm) being too thick for the farmer to reach the subsoil. Deep Black Red Soil is characterised by a topsoil thickness of more than an elbow, but here the farmer can reach the red subsoil. The Shallow Black Red Soil has a topsoil thickness of less than an elbow and red subsoil. The Red Soil has either no dark topsoil or the topsoil is eroded. Black Red Yellow Soil is characterised by dark topsoil less than an elbow thick followed by red and yellow subsoil with increasing depth. Grey Soil features a grey colour within the working depth. The locations of the Grey Soils follow the locations of former paddy rice cultivation. The soils with the thickest topsoil are located at the highest elevations of the watershed. This corresponds with the interpolated A-horizon thickness for the watershed (Figure 4-9).

The local soil map corresponds with the present crop cultivation. At the valley bottoms and the lowest parts of the watershed rice and vegetables are cultivated mostly on Grey Soil. Between the valley bottoms and 1000m asl farmers prefer to cultivate lychee mostly on Red Soil. Above 1000m asl mainly vegetables are cultivated on Shallow Black Red Soil to Black Soil. At the highest elevations off-season lychees can be produced on Black Soil. Hmong farmers have also some basic perceptions of soil properties. The positive correlation between water infiltration and erosion hazard is extraordinary (Table 4-17), because water infiltration correlates normally negatively with runoff and soil erosion (Morgan 2005).

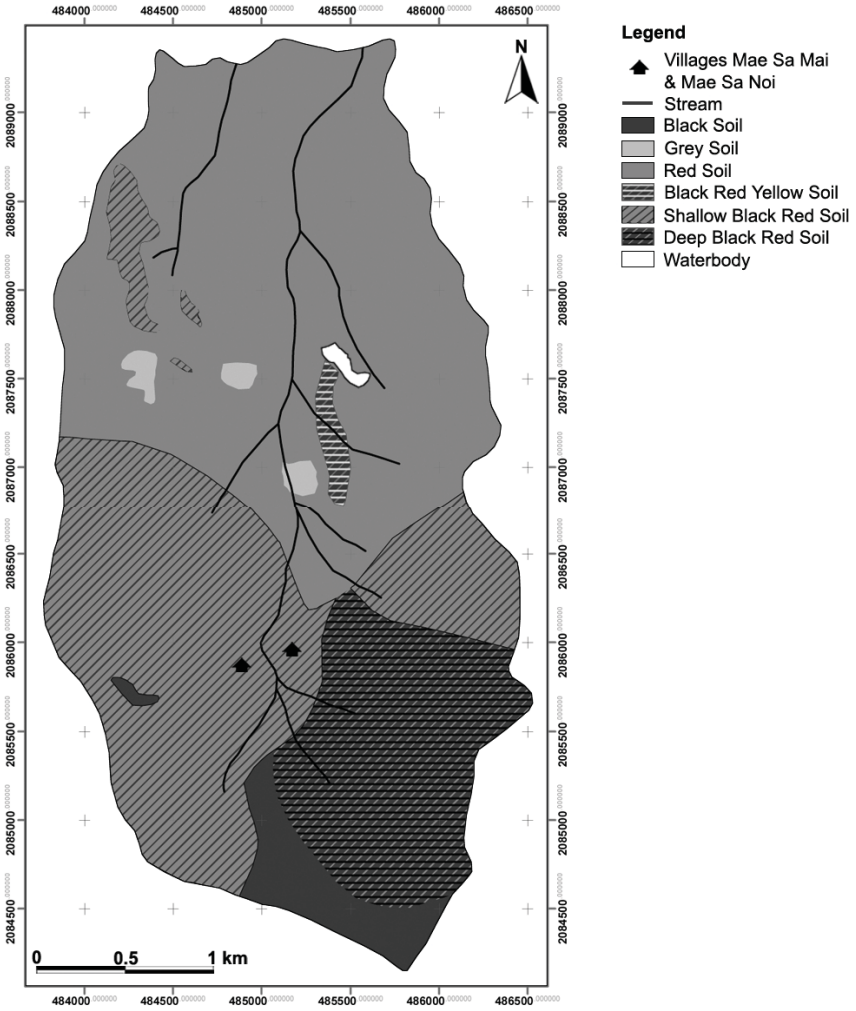

Figure 4-26: Local soil map of the Mae Sa Mai area

Table 4-17: Local soil properties of the Mae Sa Mai area

	Water infiltration	Erosion hazard	Weed pressure
Black Soil	high	very high	low
Deep Black Red Soil	high	high	low
Shallow Black Red Soil	high	high	low
Red Soil	low	low	low
Black Red Yellow Soil	very low	low	high
Grey Soil	very low	very low	high

4.3.2 Huay Bong

In Huay Bong three different local soil classification systems were identified. One group of villagers distinguished their soils according to the topsoil colour and stone content. The second group used subsoil colour and stone abundance. The third group distinguished their soils according to the colour and stone content of the lowest soil horizon which occurs within the depth of an elbow (approximately 30cm). The last group of people was considered to be – in terms of local knowledge, the most advanced of the village, so this classification was finally used for the local soil mapping. In the research area six local soil types were described. Accordingly, the area comprises 65% Red Stony Soil, 14% Black Soil, 11% Red Soil, 9% Black Stony Soil, and less than 1% of Red Black Stony Soil and Red Sandy Stony Soil, respectively (Figure 4-27).

According to this final map and the statements of the villagers Black Soils are mostly restricted to the valley and lower slopes. For this reason they correspond more or less with the Humic Cambisols in the valleys. Red soils are widespread on the sloping land above. They correspond mainly with Luvisols, but also with Regosols, Leptosols, and Dystric Cambisols on sloping land. In some cases farmers mentioned the occurrence of Black Soils for some hill tops. The preservation of this Black Soil might be due to the fact that these hills are still covered with forest and not yet affected by erosion. In this case there might be a correspondence with Luvisols. Generally, Black Soils show higher water infiltration rates, but slightly lower water retentions and a better workability than Red Soils. The main reason for the higher infiltration rates might be found in the better suited soil structure of the Black Soils.

The higher water retention capacities and worse workability can be explained for truncated Luvisols, where the clay rich Argic horizon is exposed. This is often the case, where the Red Soil unit is under cultivation.

The Black Soils are suitable for all kind of crops, whereas Red Soils are only suitable for maize, peanuts, soybeans, and tomatoes.

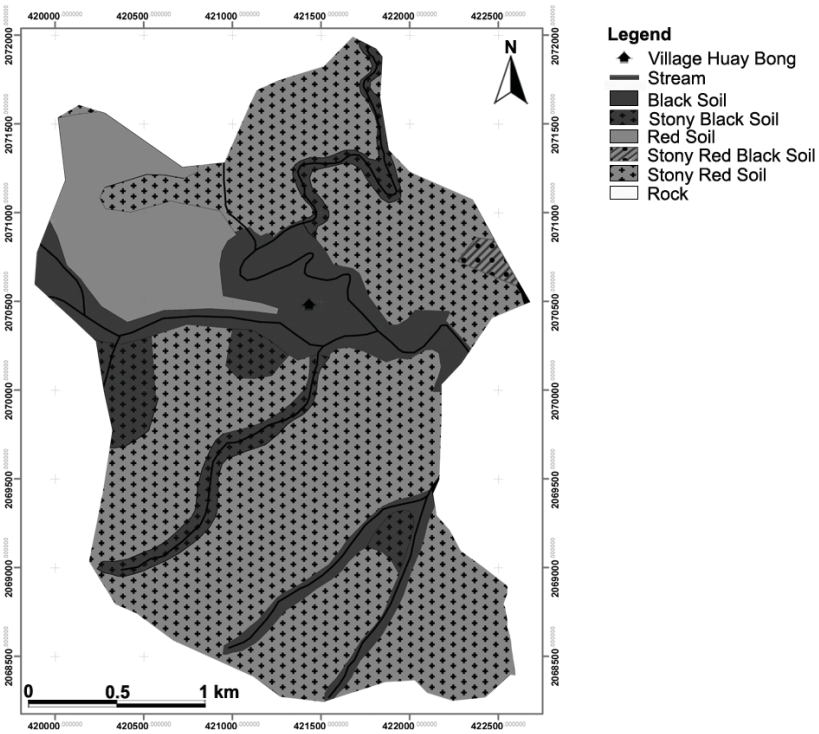

Figure 4-27: Local soil map of the Huay Bong area

According to this final map and the statements of the villagers Black Soils are mostly restricted to the valley and lower slopes. For this reason they correspond more or less with the Humic Cambisols in the valleys. Red soils are widespread on the sloping land above. They correspond mainly with Luvisols, but also with Regosols, Leptosols, and Dystric Cambisols on sloping land. In some cases farmers mentioned the occurrence of Black Soils for some hill tops. The preservation of this Black Soil might be due to the fact that these hills are still covered with forest and not yet affected by erosion.

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4.3.3 Bor Krai

Farmers in this area differentiate soils according to observable morphological parameters, which is mainly topsoil colour. Initially, the farmers distinguished only between two soil types: Black Soil and Red Soil. A minority also mentioned texture and water drainage. The farmers were well aware of more complex soil parameters, like fertility status, suitability for certain crops, and workability.

During the field trips to study the basic classification according to colour two additional soil colours were added: yellow and orange. The farmers identified five to seven soil types, using texture as an auxiliary criterion to differentiate within the colour classes. In a subsequent group discussion the farmers were asked to present a common soil classification. This was realised by asking farmers to sort soil samples according to soil properties. During this ranking process it turned out that farmers relate soil properties primarily to soil colour. Hence, the soil colour was focused in order to elicit a common classification. Farmers distinguished four main soil types, namely Black, Red, Orange, and Yellow Soils, which together make up more than 90% of the preliminary Local Soil Map.

Mixed local soil units occurred as well. Further interviews revealed the necessity to divide the Red Soil group into Hard Red Soils and Soft Red Soils. The Local Soil Map was updated accordingly with the help of experienced farmers whereby the preliminary local soil map and the topographic map were the main communication tools. In the final Local Soil Map (Figure 4-28) Black Soil covers 38% of the map area, followed by Hard Red Soil (34%), Soft Red Soil (18%), Orange Soil (2%), Yellow Soil (2%), and Mixed Soils (7%).

Once this map was created, farmers were asked for more details on the properties and crop suitability of each local soil unit (Table 4-18). The elicited crop suitability clearly shows the unsuitability of some local soil types for certain crops.

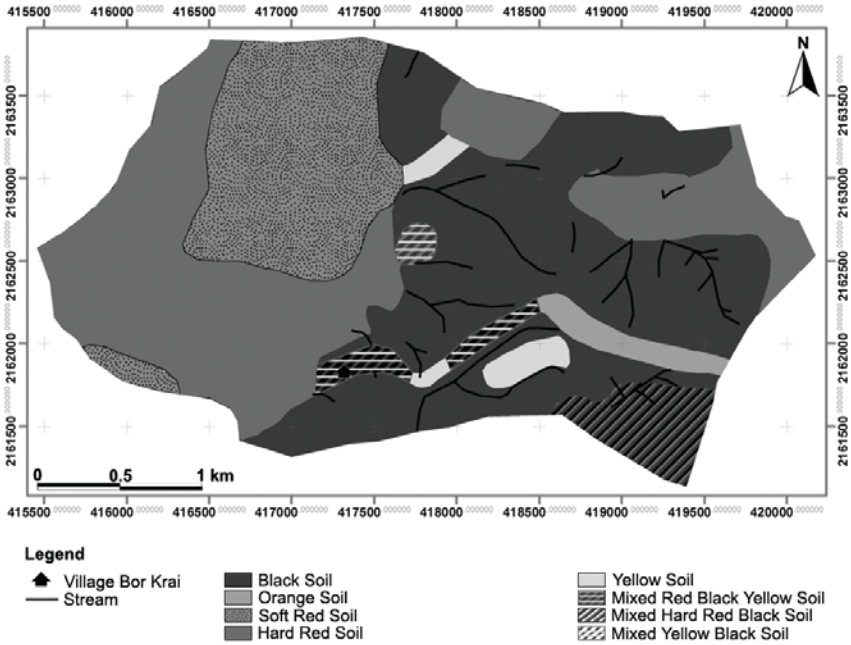

Figure 4-28: Local soil map of the Bor Krai karst area

Table 4-18: Local soil properties and crop suitability for the Bor Krai area

	Black Soil	*Hard Red Soil*	*Soft Red Soil*	*Orange Soil*	*Yellow Soil*
Estimated crop suitability:					
Banana	high	medium	high	high	high
Green bean	high	high	medium	unsuitable	unsuitable
Mango	high	medium	medium	high	high
Maize	high	medium	high	unsuitable	unsuitable
Sesame	high	high	unsuitable	unsuitable	unsuitable
Red Kidney Bean	unsuitable	medium	medium	unsuitable	unsuitable
Rice	high	high	unsuitable	unsuitable	unsuitable
Soybean	medium	medium	unsuitable	unsuitable	unsuitable
Other estimated properties:					
Weed pressure	high	low	low	low	low
Water infiltration rate	high	low	high	low	low
Erodibility	high	medium	low	high	high
Soil stickiness	high	low	medium	low	low
Measured properties:					
pH*	6,5	6,5	6,5	6,0	6,0
CEC soil [cmol(+) kg^{-1}]	33,8	32,1	40,3	18,5	21,0
Base saturation [%]	52,4	47,7	24,0	20,7	36,7
P (plant available) [mg kg^{-1}]	9,2	4,7	9,2	4,4	2,1
K (plant available) [mg kg^{-1}]	194,3	132,1	15,1	123,4	191,9
Organic carbon [g kg^{-1}]	28,7	31,2	11,4	14,6	15,2
Nitrogen [g kg^{-1}]	2,0	2,2	0,9	1,4	1,2
Ks measured with HOOD infiltrometer [cm h^{-1}]	11	10	>200	6	<1

* median values of topsoil

4.4 Randomised grid cell approach

According to the randomised grid cell approach the Bor Krai area contains 62.1% Luvisols, 16.0% Acrisols, 15.0% Cambisols, 5.9% limestone outcrops, and 1% Leptosols (see Figure 4-29).

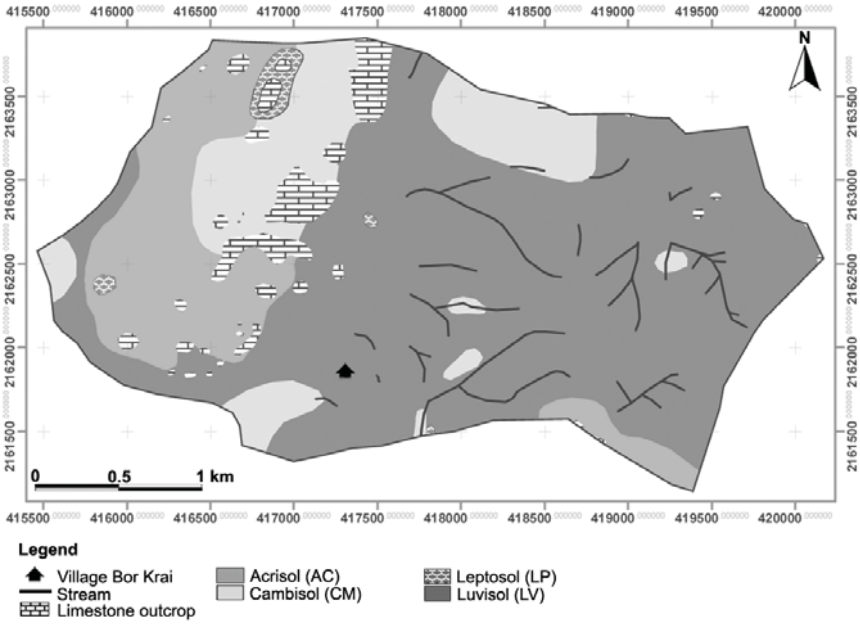

Figure 4-29: Randomised grid map based on the soil map of the Bor Krai karst area

The randomised grid based soil mapping approach satisfactorily reflects the major soil types, like Luvisols, Acrisols, and Cambisols. Minor soil types, i.e. Chernozems, Ferralsols, Gleysols, and Umbrisols were not detected. The validation with 50 independent sampling points revealed a positive match in 54% of all cases (Table 4-20). This approach showed the fairly good accordance with the reference soil map (best guess).

4.5 Maximum likelihood approach

The soil maps based on the maximum likelihood method (Figures 4-30, 4-32, 4-34) reflect very well the correspondent reference soil maps as the accordance between the soil map based on the maximum likelihood method and the reference soil map is 58% for Mae Sa Mai, 61% for Huay Bong and 64% for Bor Krai. The match for the major soil types was in most cases above 50% (see Table 4-19).

Table 4-19: Match of the maximum likelihood method and the randomised grid based approach (RGB) with the reference soil map (best guess) in [%]

Location/ Approach	**Mae Sa Mai**	**Huay Bong**	**Bor Krai**	
	Maximum likelihood method			**RGB**
Acrisols	68.4	None	78.0	68.3
Cambisols	47.0	51.3	39.8	37.9
Leptosols	5.6	2.6	3.7	21.1
Luvisols	None	72.8	66.1	87.7
Regosols	38.1	7.9	None	None
Water bodies	78.5	None	0.0	0.0
Limestone	None	None	35.4	98.5
Total area	**58.3**	**61.1**	**64.0**	**79.5**

The validation with 50 (additionally taken) independent sampling points for the Bor Krai area revealed a positive match in 60% of all cases (Table 4-20). Hence, the soil map based on the maximum likelihood approach represented the reality of the soil composition even more fitting than the reference soil map.

Table 4-20: Validation of different mapping approaches with 50 independent points (matches in %)

Method	Acrisols	Cambisols	Leptosols	Luvisols	Limestone	Total
Randomised	78	17	0	78	0	**54**
Maximum likelihood	78	67	0	61	50	**60**
Reference	78	0	0	96	0	**58**

For the **Mae Sa Mai** area the principle component analysis of all grids used for the maximum likelihood approach revealed that main variables are mainly the LANDSAT 7 bands 1, 2, 3, 5, 6 and 7 (Table 4-21).

Table 4-21: Main ML-variables according to principle component analysis

Soil type	Main* variables according to principle component analysis		
	Mae Sa Mai	**Huay Bong**	**Bor Krai**
Acrisols	L1, L2, L3, L5, L6, L7	None	L1, L2, L3, L5, L6, L7
Cambisols	L1, L2, L3, L5, L6, L7	S1, S2, S3, S4, L1, L2, L3, L5, L6, L7	S4, L1, L2, L3, L5, L6, L7
Leptosols	L2, L4, L5, L6, L7	S1, S2, S3, S4, L1, L2, L3, L4, L5, L6, L7	S1, L1, L2, L3, L5, L6, L7
Luvisols	None	S2, S3, S4, L1, L2, L3, L5, L6, L7	L1, L2, L3, L5, L6, L7
Regosols	slope, S4, L1, L7, L8	L1, L2, L3, L5, L7	None
Water bodies	S1, S2, S3, S4, L5, L7	None	None
Limestone	None	None	S4, L1, L2, L3, L5, L6, L7
ML-Mapping Units	L1, L2, L3, L5, L6, L7	S2, S4, L1, L2, L3, L5, L6, L7	L1, L2, L3, L5, L6, L7

*>75% correlation with the main principal component
L = LANDSAT 7 band
S = SPOT 5 band

This band combination enables the detection of different vegetation, soil moisture, agricultural features, and rock types. As most of the land in Northern Thailand is covered with vegetation, mainly the vegetation and its response to available soil water is of importance. The LANDSAT 7 and SPOT 5 images were taken during the dry season, for this reason a high range of vegetation responses to different soil moisture levels can be expected, which has a positive impact on the results. At this time, the deciduous forests at lower elevation are characterised by a lower leaf density. A high share of the remaining leaves show yellow and brown colours. The share of green leaves increases with elevation until the evergreen forest is reached. The high value of the satellite images used is mainly based on the fact that soils and vegetation respond in a similar way to the climate. The detection of the Cambisols in the valley bottom in Huay Bong and the Regosols in Mae Sa Mai was feasible because these sites are more or less characterised by bare soil during the dry season. The soil probability maps (Figure 4-31) indicate a transition from Acrisols to Cambisols with increased elevation. The high probability zone for the Cambisols in the southern part of the Mae Sa Mai area corresponds with the area of the local soil types “Black Soil” and “Deep Black Red Soil”.

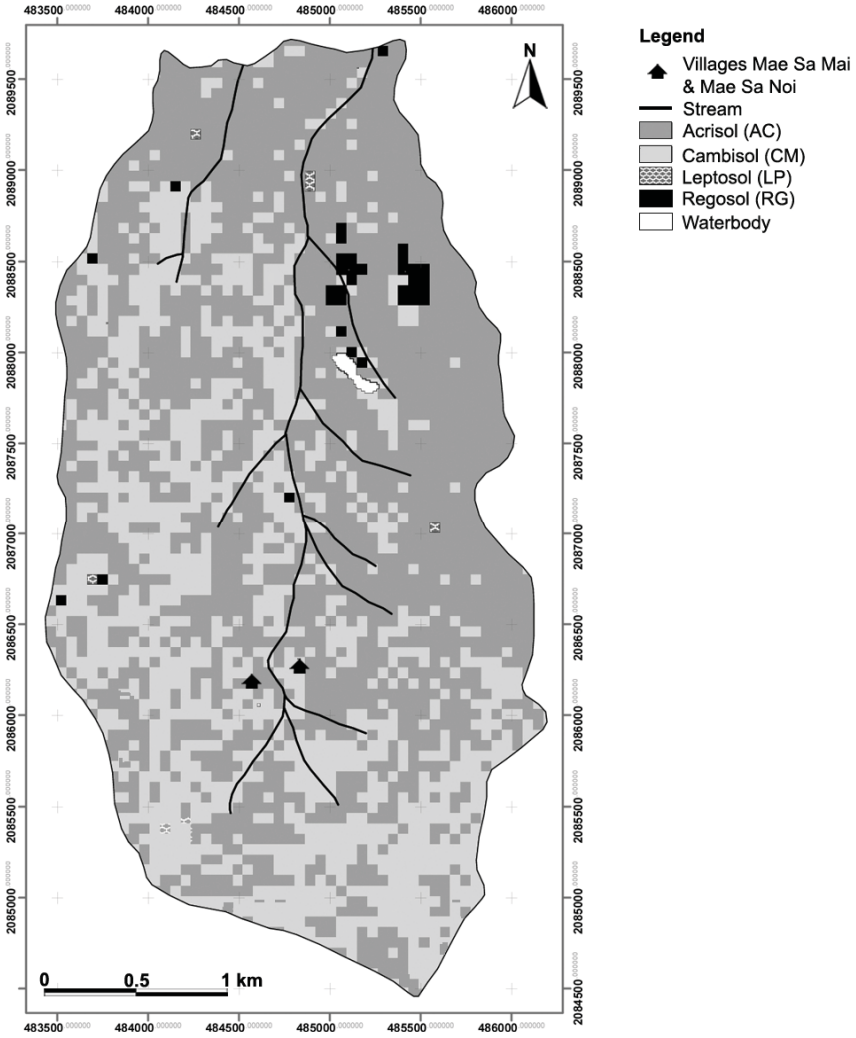

Figure 4-30: Maximum likelihood soil map of the Mae Sa Mai area

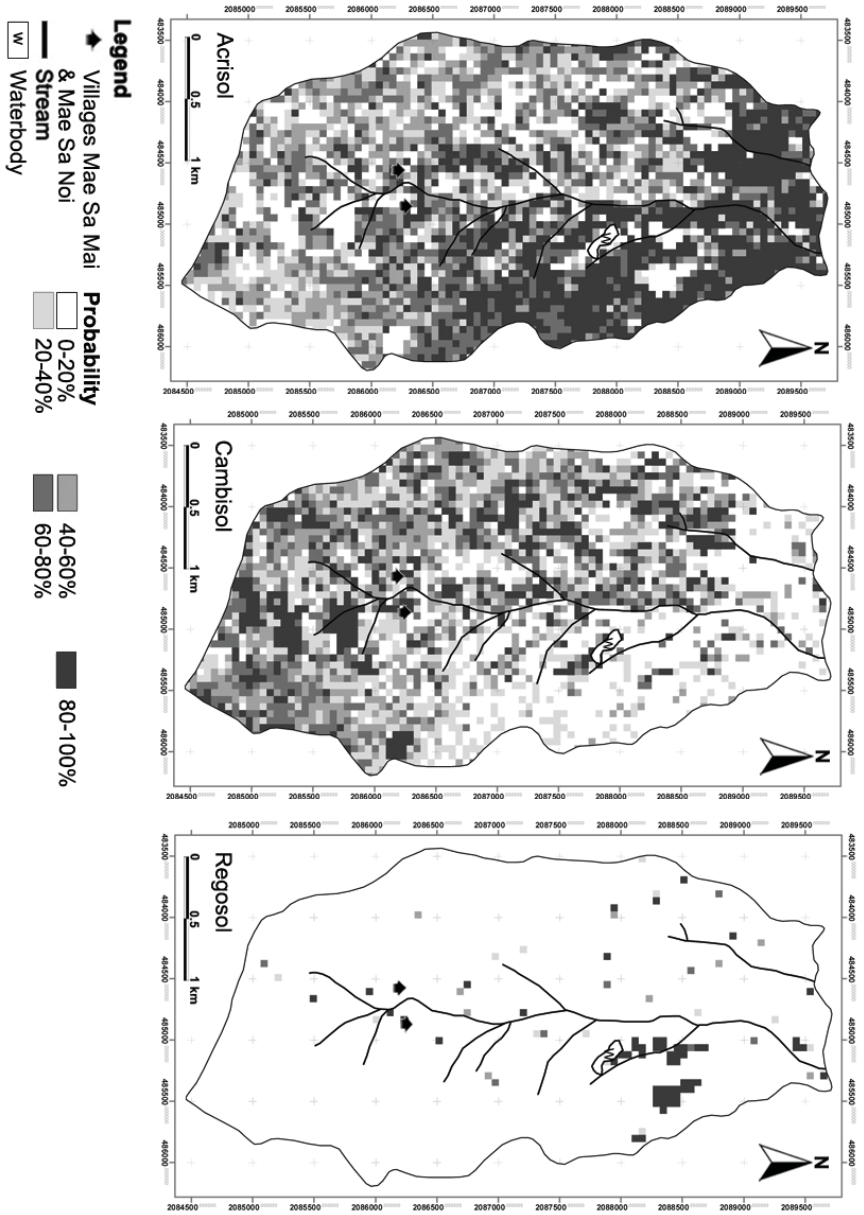

Figure 4-31: Probability maps of the three major soil types for the Mae Sa Mai area

For the **Huay Bong** area additionally the SPOT 5 bands 2 and 4 were identified as main variables for the maximum likelihood based soil mapping (Table 4-21). This combination provides a detailed discrimination between vegetated and non-vegetated areas, which is useful to detect the harvested paddy fields along the valley, corresponding more or less with the occurrences of the Humic Cambisols. As for Mae Sa Mai, the LANDSAT 7 band combination mainly allows the detection of soil moisture differences. Such differences can be expected between Luvisols (±Red Soils) and Cambisols (±Black Soils). The existence of such a difference was confirmed by Huay Bong villagers. The soil probability maps indicate a sharp transition for the rather coherent Cambisols in the valleys (Humic Cambisols) to other soil types (mainly Luvisols). For the sloping land the soil probability maps indicate an interlacing of Luvisols with other soil types. For this reason the Luvisols are much less coherent than the Cambisols in the valleys (Figures 4-32; 4-33)

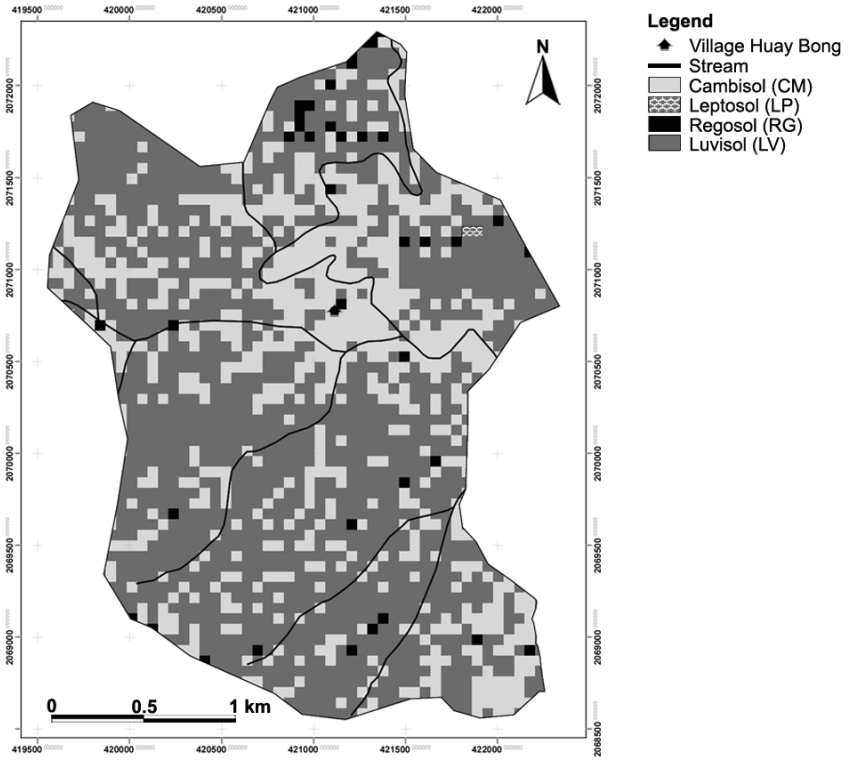

Figure 4-32: Maximum likelihood soil map of the Huay Bong area

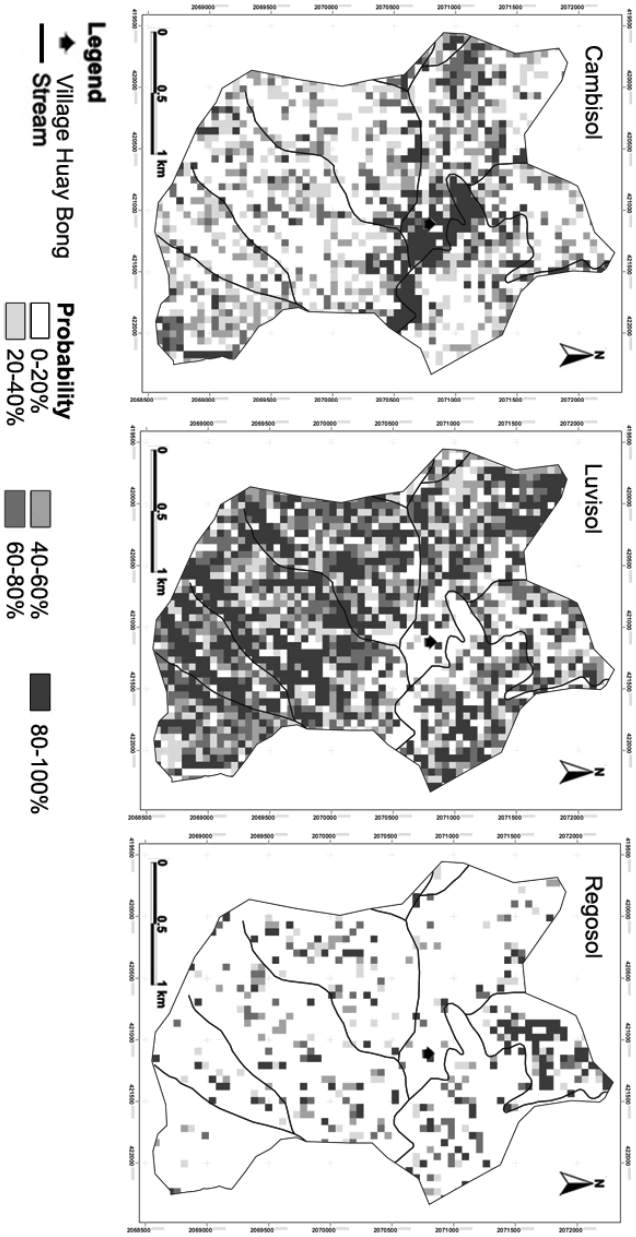

Figure 4-33: Probability maps of the three major soil types for the Huay Bong area

The soil distribution in the **Bor Krai** area can be explained with the same main variables as those used for Mae Sa Mai. The main similarity between Bor Krai and Mae Sa Mai is the elevation related transition of one soil group to the other. In the case of Bor Krai Luvisols pass over into Acrisols. This transition is related with a strengthening of the soil structure and connected with a change of the infiltration rate and water retention. This structural change was confirmed by Bor Krai villagers and is also expressed in the differentiation of the Red Soil into a Hard Red Soil and a Soft Red Soil. The measurements revealed at least 20 times higher hydraulic conductivity for the Soft Red Soil in comparison to the Hard Red Soil. According to the soil probability maps the transition from Luvisol to Acrisol is rather sharp (Figure 4-35). Highest probabilities for Cambisol occurrences were found for the vicinity of karst depressions and steep slopes.

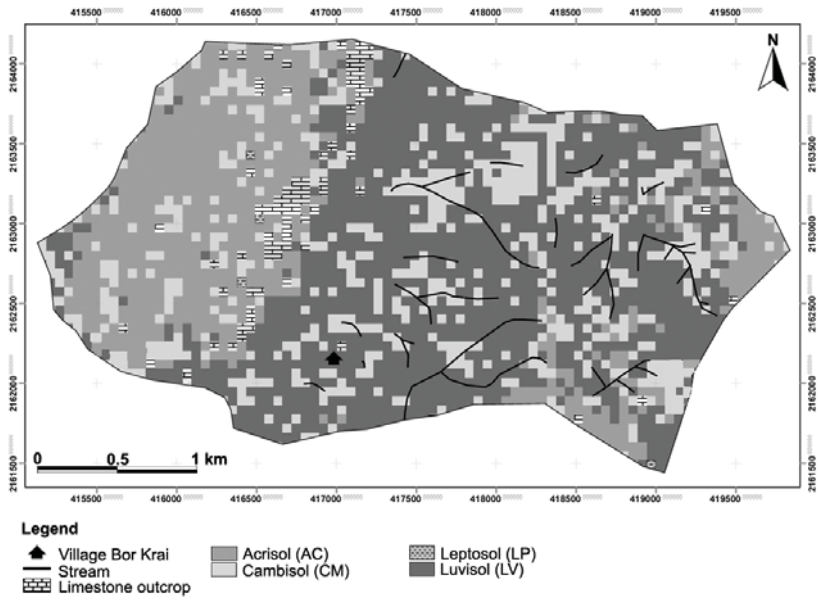

Figure 4-34: Maximum likelihood soil map of the Bor Krai karst area

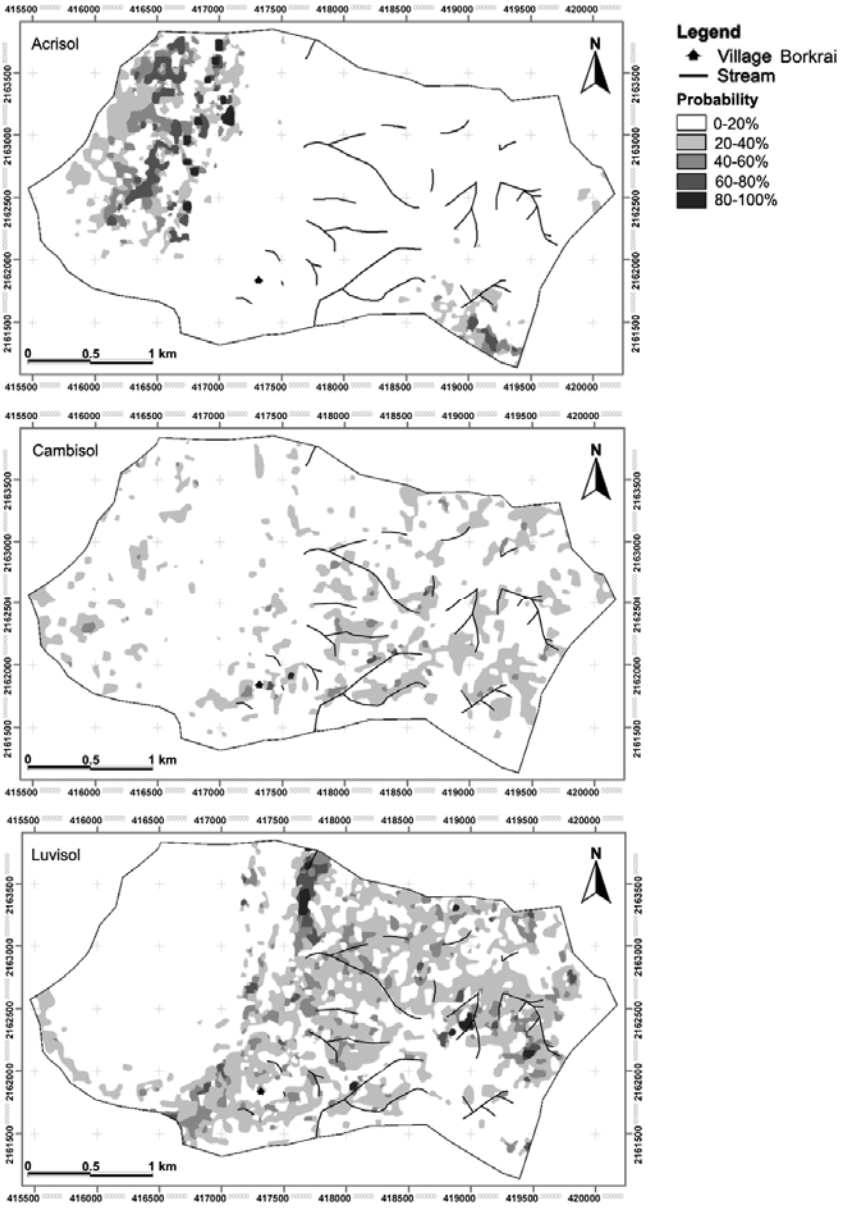

Figure 4-35: Probability maps of the three major soil types for the Bor Krai area

Finally, the Mae Sa Mai area was chosen to **test upscaling possibilities**. Upscaling from the Mae Sa Mai area (10.5km^2) to the whole Mae Sa watershed (138km^2) was achieved with the maximum likelihood approach using the investigation points of the Mae Sa Mai area and (only) 5 additional points in the Mae Sa watershed (Figure 4-36). These additional points consist of map units, which are not sufficiently represented in the Mae Sa Mai area, like Gleysols or Technosols. At this scale (Mae Sa watershed) it is indicated that the Cambisols are mainly restricted to the upper part of the watershed, whereas Acrisols dominate the central and lower part of the watershed. In the lower part of the watershed, where the groundwater comes close to the surface Acrisols interlace with Gleysols. Most of the Gleysols investigated in the lowlands consist of horizons with clay loam, silt loam, sandy clay loam, sandy clay, with a weak subangular blocky structure in the upper part and single grains in the lower part. All Gleysols are characterised by a gleyic colour pattern. The urban areas in the lowlands are dominated by "Technosols". Technosols are not defined according to the WRB 1998 soil classification. According to the WRB 2006 classification these soils either feature 20% or more artefacts in the upper 100cm or are sealed by concrete, asphalt and other artificial materials (FAO 2006). Fluvisols occur along streams, where deposition exceeds erosion. This is mainly the case for the lowlands (Chiang Mai basin). Most of the Fluvisols investigated in the lowland consist of horizons with silt, silty loam, sandy loam and loamy sand without any soil structure. The concentration of coarse fragments ranges from approximately 2%m to over 80%m. Leptosols occur at a few places at summits in the highest part of the watershed.

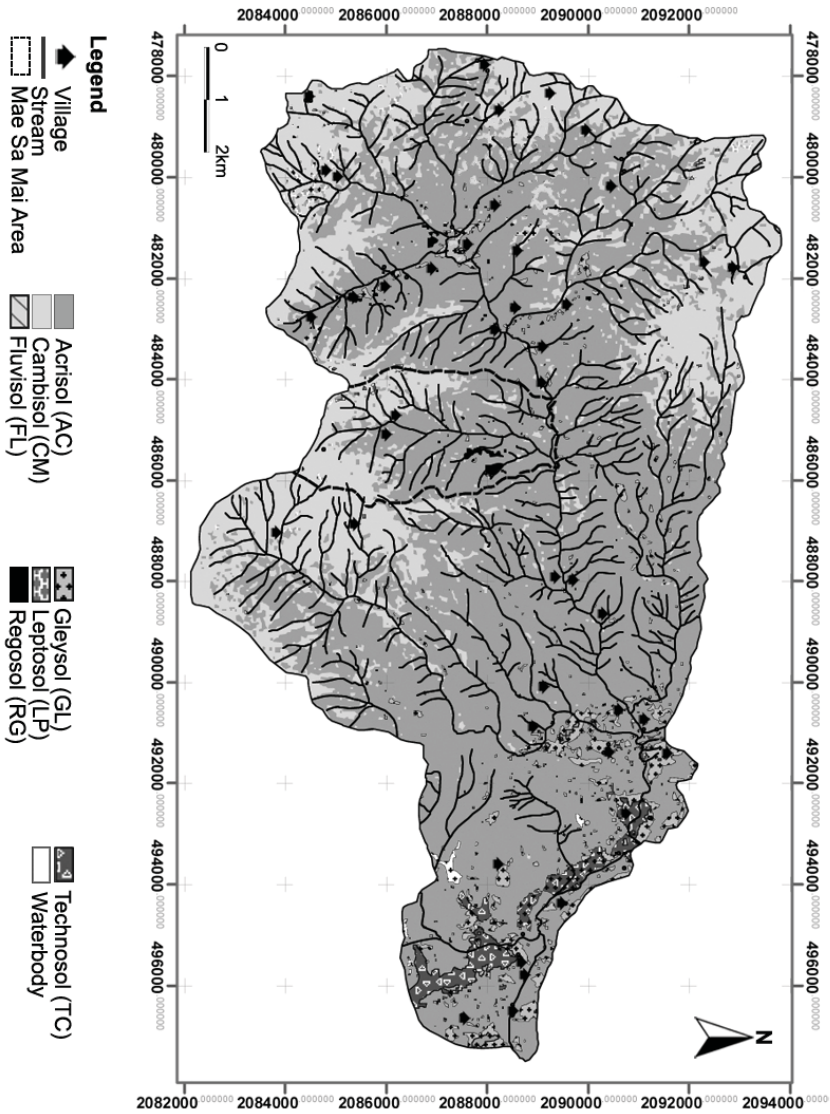

Figure 4-36: Maximum likelihood soil map of the Mae Sa area (including the Mae Sa Mai area)

5 Discussion

5.1 Petrography

In all three study areas the petrographic inventory detected was higher than so far reported (Raksasulwong and Tantiwanit 1984; Khositanont and Mahawat 1985 a,b; Tiyapirat and Tiyapan 1992).

The migmatite in the Mae Sa Mai area was also described by others (German Geological Mission 1975, Tiyapirat and Tiyapan 1992). The marble occurrence was so far only recorded for the Mae Sa watershed, but not for the Mae Sa Mai subarea itself. Also the freshwater limestone occurrences were not previously recorded. The main reason for this might be found in its minor extension, which can easily escape one's notice. Despite their small spatial coverage, the impact of the marble and freshwater limestone on water and soil chemistry is immense and not reflecting their negligible size. The karst water from the marble on the water chemistry in streams below has a severe impact as depicted in Figure 5-1. Some of this alkaline water is used for irrigation and has an influence on the soil pH, but also on degradation of used pesticides. The relationship between pH and pesticide degradation depends on the mode of degradation of the respective pesticide (Kah *et al.* 2007). The influence of alkaline-rich water was observed especially for the Bor Krai area. There alkaline water lead to the formation of a Chernozem in a mere 10 years.

For the Huay Bong area only Carboniferous sediments and alluvial deposits have been previously reported (German Geological Mission 1975, Khositanont and Mahawat 1985a,b). The plant fossils found in this area clearly underline the existence of Tertiary sediments (Figures 9-4 and 9-5). Slickensides on rock surfaces indicate the existence of a strike slip basin. The closest previously documented Tertiary basin is located in the Na Hong area (Morely *et al.* 2001) approximately 8.5km ESE from Huay Bong.

For the Bor Krai karst area so far only Permian limestone has been reported (German Geological Mission 1975, Raksasulwong and Mahawat 1984). The petrographic mapping conducted within this study revealed in addition the occurrences of claystone, latite, iron ore, bauxite, and freshwater limestone.

The occurrence of sinkholes and karst springs in the claystone units clearly indicate that the claystone is covering the limestone (Figures 4-24 and 4-25). The preservation of the claystone within this area might be traced back to a halfgraben. This halfgraben has a SSE to NNW length-extension and is flanked by a set of normal faults along its western boundary, which corresponds with the eastern part of the western mountain range (Figures 4-24 and 4-25). This fault zone is accompanied by sinkholes and caves among which Mae Lana Cave is one of the most striking.

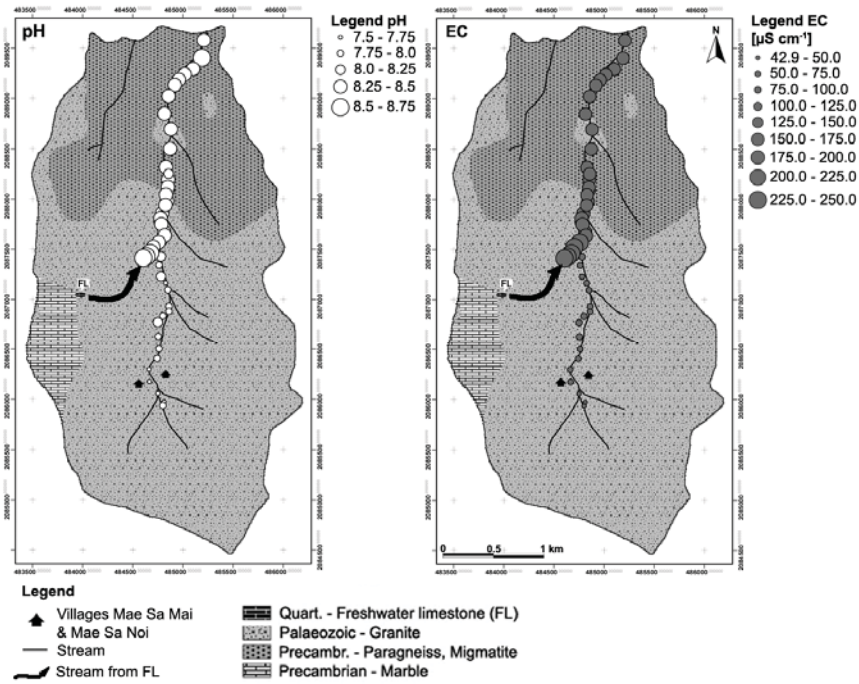

Figure 5-1: Impact of karst water from the marble on the water chemistry downstream

The eastern boundary of this halfgraben probably consists of a flexure. The onset of this flexure corresponds with the eastern boundary of the study area. The origin of the iron ore and bauxite are most probably related to latite intrusions. The best evidence is found in Mae Lana Cave, where latite, which intruded into the limestone, is interlaced with iron ores. The supposedly magmatic origin of this iron ores is confirmed by observations of blue azurite dripstones in Pha Mon Cave approximately 8km SE of the Bor Krai area (Sidisunthorn *et al.* 2006). It can be assumed that the magmatic intrusion was accompanied by a partial segregation in a silicate enriched melt and a sulfide one (sensu Matthes 1996). The silicate-dominated melt lead to latite, whereas the sulfide enriched melt lead to the formation of iron ores, which were dominated by pyrite (FeS_2), but also contain chalcopyrite ($CuFeS_2$). Finally, tropical weathering caused an alteration of the original composition of the iron ores towards a domination of bauxite, hematite, goethite, kaolinite, and ankerite. The high karstification of the limestone facilitates a strong alteration of the latite and iron ore down to several hundred meters below surfaces as personally observed in Mae Lana Cave.

Slickensides on iron ore close to the volcanite stock possibly relate this intrusion to tectonic activities. A hot spring with a water temperature of around 45˚C just 7.6km WNW of the Bor Krai village points out the tectonic activity of the region.
Occurrences of several distinct cave levels provide evidence for an uplift of the area (personal observations).

5.2 Soil variability

Presently, all three study areas are classified by the "General Soil Map of Thailand" (Vijarnsorn and Eswaran 2002) as "slope complex", providing no proper soil information. Some information on the soils of the Mae Sa Mai research area was previously available in the "soil map" of the "UNDP/FAO Mae Sa integrated watershed and forest land use project" (Irwin 1976), which gives some basic information about slope classes within the Mae Sa Mai area. More information is given for the Mae Sa Mai area by the soil map of Manajuti *et al.* (2004). This soil map consists of soil units, which are based on a cluster analysis of 37 investigation points, but the delineation of the soil boundaries remains questionable. At least the base data were quite useful and were incorporated in the soil survey of this study.
The Huay Bong and Bor Krai areas lack suitable soil maps.
The soils of the three study sites have been found to differ in: pH (H_2O), soil colour, A-horizon thickness and composition of major soil types.

5.2.1 Variability of pH values

In all three areas the pH (H_2O) mostly ranges between 5.5 and 7.0. The highest variability was found in the Mae Sa Mai area, where at zones of intensified land use and erosion rates soil patches with lower pH values occur. Highest pH values were found below a karst spring and in remnant forest. In the Huay Bong area, the lowest pH values were measured for soils from sandstone, breccia, and conglomerate on sloping land under deciduous forest. Spots of high pH (>7) were found in the valley bottoms.
Their occurrences might be traced back to alkaline rich groundwater, which emerges in the valley bottom and which percolated through marl. Evidence is given by fragments of freshwater limestone in some streambeds (personal observations). The lowest pH variability was observed for the Bor Krai area. As in Mae Sa Mai, spots with lower values are found with intensified land use and soil erosion. Spots of high soil pH (>7) can be traced back to alkaline water from the karst springs seeping through the soil matrix. In all three areas the soil pH generally decreases with the soil depth. This corresponds with the findings of Kirsch (1998). It can be postulated that root uptake of nutrients to the surface is responsible for this pH gradient (Blume *et al.* 2002).

This would also explain the lower pH values for sites of intensive land use where the forest was removed.

5.2.2 Variability of soil colour

For Mae Sa Mai and Huay Bong the soil colour value and chroma, in general, increases with soil depth. In Bor Krai the soil colour is essentially influenced by the parental material. Soils from limestone especially showed lower values for value and chroma compared to other soils. In addition most of the limestone originated soils have a hue of 2.5 YR or more reddish, while soils from sandstone, siltstone, and claystone mostly showed colours with a hue of 7.5 YR or more yellowish.

5.2.3 Variability of A-horizon thickness

The distribution of the A-horizon thickness is different in all three study areas. In Mae Sa Mai the A-horizon thickness generally increases with elevation, which was also described by Kubiniok (1999) for the transects at Mae Sariang – Hot, Phrao – Phayao, and Mae Moh – Chok Nai.

For Huay Bong no clear trend could be identified, while in Bor Krai the highest A-horizon thickness was found in karst depressions without outlets and at higher elevations under lower land use intensity. The differences between the three areas regarding the A-horizon thickness can be traced back to petrography, climate, and land use intensity. In Mae Sa Mai climate and land use intensity are crucial for the development of the A-horizon thickness and with increasing precipitation the risk of ground fires decreases. This leads to the preservation of litter, which protects the A-horizon. In addition, increased precipitation hampers forest destruction by man-made fires. In Huay Bong climate gradients and human impacts are not strong enough to influence the A-horizon thickness. In Bor Krai, weathering of limestone caused dolines and karst depressions. These depressions act as sediment traps leading to a high A-horizon thickness. Below karst springs the nutrient supply is responsible for increased plant growth and good soil structure. This also facilitates the development of a thick A-horizon.

5.2.4 Variability of soil types

From the investigation of the three different study areas it was found that Acrisols, Cambisols, and Luvisols are the main soil types in mountainous areas of North-western Thailand. In the Mae Chan area Kirsch (1996) recorded the same soil types.

He also postulated Nitisols for a small occurrence of basic volcanites, but the respective soil profiles were not sufficiently investigated in order to prove their existence. In the Sa Poeng – San Pa Yang area in Mae Taeng district Yemefack (1995) could also identify Luvisols, Acrisols, and Cambisols as the main soil types (according to WRB 1998 classification). For marble areas Phaeozems are postulated as major soil types below 700m asl independent of slope inclination. This assumption is only based on two soil profile descriptions each located at 620m asl.

Own investigations detected Phaeozems on marble bodies within the Mae Sa watershed, but mostly Acrisols, Cambisols, and Leptosols were found.

The transect studies of Hendricks (1981) also indicate that Acrisols, Luvisols, and Cambisols are the three major soil types of this area. Alisols might also play a role, but due to a lack of information about aluminium saturation and the total reserve of bases their existence could not be confirmed.

The investigation of soils in the Doi Inthanon area (Weltner 1996) revealed Cambisols, Acrisols, Nitisols, Ferralsols, and Arenosols as major soil types, but this data cannot clearly confirm the existence of the Nitisols, Arenosols, and Ferralsols. The uncertainty for the Ferralsol and Nitisol classification is based on a lack of information about the water-dispersible clay content and weatherable minerals in the 50-200mm fraction. The existence of Arenosols is especially questionable, as those soils require a texture of loamy sand or coarser at least to 1m soil depth. Additionally, the amount of coarse fragments should not exceed 35% (by volume) according to FAO (1998). A high content of coarse fragments was described for all 4 soil profiles, but for only one soil profile the texture was analysed. There, the texture ranges from sandy loam to clay loam. It can be assumed, that the so called “Arenosols” are most probably Cambisols or Regosols.

Between Mae Sariang and Hot Kubiniok (1999) identified Ferralsols as the fourth major soil type in the region. There, Ferralsols occur on stable and rather old landforms, while all three study areas are rather young and characterised by uplifts, therefore Ferralsols are of minor importance. In the Mae Sa Mai area uplift is indicated by a steep V-shaped valley and some small waterfalls. In the Huay Bong area, uplift is indicated by conglomerates above the Mae Yot River, landslides, Leptosols, and Regosols. An uplift of the Bor Krai area is mainly indicated by several cave levels.

The three major soil types of North-western Thailand (Cambisols, Acrisols, and Luvisols) can be distinguished mainly by degree of clay illuviation, cation exchange capacity of clay, and base saturation.

5.2.5 Variability of soil forming processes

The degree of **clay illuviation** is an indicator for the existence of an Argic horizon (FAO 1998, 2001, 2006). In general, clay illuviation consists of three processes, namely dispersion, transport, and deposition. The degree of dispersion depends mainly on the salt concentration in the soil water, the content of exchangeable cations, and the kind of clay minerals. The degree of dispersion increases with decreasing salt concentration in salt water and exchangeable Ca^{2+} content, and increases with the swelling potential of the different clay minerals. Below pH 5, the degree of dispersion decreases with the pH due to an increased amount of Al-ions causing coagulation. The optimum dispersion ranges between pH 6.5 and 5. The transport of the clay particles occurs in coarse and medium pores exclusively. Transport in finely grained soils is only feasible if shrinking cracks or biopores occur. As the existence of shrinking cracks requires dry periods clay illuviation is more pronounced for seasonal climates were fluctuations of soil moisture occur (Eswaran and Sys 1979, Blume *et al.* 2002). The deposition of the translocated clay particles occurs either at the transition from coarse and medium pores to finer pores, or where increased salt concentration or high amounts of exchangeable Ca^{2+} cause coagulation (Blume *et al.* 2000).

In all three study areas clay illuviation is the dominant soil-forming process. The degree of clay illuviation decreases with elevation only in Mae Sa Mai. The soils of all three areas are mostly decalcified and the pH values range between 5.5 and 7.0. The salt concentration and amount of exchangeable Ca^{2+} seems not to hamper clay illuviation.

In Bor Krai and Mae Sa Mai finely grained soils prevail. Clay illuviation mainly occurs via shrinking cracks and biopores. The latter occur, but can be ignored. The amount and intensity of shrinking cracks mainly depend on the seasonality of the climate, which is most severe in lower elevations. This seasonality decreases with increasing elevation, due to a positive correlation between elevation and annual precipitation and a negative correlation with temperature (Weltner 1996). The decrease of temperature and increase of rainfall along with the elevation leads to a decreasing ratio of evapotranspiration to rainfall resulting in a higher seepage (Herrmann *et al.* 2007) and hamper the development of shrinking cracks and, therefore, the possibility for clay illuviation in finely grained soils. This corresponds with Hansen (1991), who ascribed clay illuviation to soil moisture differences between the dry and rainy seasons. Therefore, a negative correlation between clay illuviation and elevation for soils originating from granite was detected. Consequently, above a certain elevation the degree of clay illuviation is not sufficient to fulfil the requirements for an Argic horizon.

This is the case in the Mae Sa Mai area, where the Argic horizon wedges out at around 1300m asl, leading to a transition from Acrisols to Cambisols (Humic Cambisols and Ferralic Cambisols). Approximately 20km north of the Mae Sa Mai area the data of Yemefack (1995) indicate the same transition for elevations above 1000m asl, but these data are insufficient to pinpoint the exact location of this transition. For the Doi Inthanon area the data of Weltner (1996) revealed the same transition for approximately 1600m asl and the data of Kirsch (1998) indicate the existence of this boundary in the Mae Chan watershed at approximately 950m asl. According to the climate map of Thailand (ASEAN 1982) the precipitation increases from Doi Inthanon (<1200mm a^{-1}), Mae Sa Mai (<1300mm a^{-1}) to Mae Chan (approximately 1600mm a^{-1}). In all these cases, the soils are mostly finely grained and derived from granite and gneiss.

It seems that the degree of clay illuviation there at least decreases with increasing precipitation.

The preliminary soil investigation of Thailand's highest limestone mountain Doi Chiang Dao in Chiang Mai province, rising to 2198m asl indicates that clay illuviation exists even at the mountain summit (Schuler, unpublished data). The transition from Acrisols to Cambisols seems to be not realised for all limestone areas (including Bor Krai) in Northern Thailand. The main reason might be found in a comparably higher permeability of the karstified limestone than for granite and gneiss, leading to more pronounced soil moisture differences and facilitating clay illuviation via shrinking cracks (even at highest elevations).

In the Huay Bong area, the combination of sandstone, breccia and conglomerate leads to the formation of more coarsely textured soils additionally facilitating clay illuviation by frequent soil moisture change and providing coarse and medium pores.

In conclusion, the degree of clay illuviation depends on the climate and the parent rock material.

The **cation exchange capacity for clay (CEC_{clay})** especially of the subsoil is an essential parameter for soil classification in North-western Thailand. Depending on the soil classification the CEC_{clay} either helps to distinguish between Luvisols and Acrisols in the case of the WRB 1998 classification or between Acrisols, Alisols and Luvisols according to the WRB 2006 classification (for North-western Thailand). At regional scale (North-western Thailand) the CEC_{clay} of the subsoil shows a negative correlation with elevation. In consequence, above a certain elevation Luvisols (and Alisols) pass over into Acrisols. This was observed for the limestone area of Bor Krai, where the CEC_{clay} 24cmol kg^{-1} line was found to be located at around 800m asl and marked the abrupt transition from Luvisols to Acrisols. For the Mae Taeng area the data of Yemefack (1995) indicate the same transition on granite somewhere above 500m asl.

These data were insufficient to narrow this boundary down to a precise elevation. The data of Kirsch (1998) (Mae Chan) indicate that on granite Luvisols gradually pass over to Acrisols at around 500m asl. Here also most of the data are insufficient to differentiate between the two soil types. According to own measurements and the climate map of Thailand (ASEAN 1982) precipitation increases from Bor Krai (<1200mm a^{-1}), Mae Taeng (<1500mm a^{-1}), to Mae Chan (>1600mm a^{-1}). For this reason, the CEC_{clay} at least decreases with increasing precipitation. It can be assumed that the transition from Luvisols to Acrisols is caused by kaolinite and gibbsite formation. According to Herrmann *et al.* (2007) gibbsite formation corresponds with the percolation due to low evapotranspiration to rainfall ratios. Higher precipitation rates in the Mae Sa Mai area might be the reason for the dominance of Acrisols between 600 and 800m asl, while in Bor Krai Luvisols prevail at this elevation range. In some cases differences of CEC_{clay} levels are due to parental materials. This is the case for the limestone and claystone in Bor Krai. There, the analysed soil profiles from claystone cover an elevation range from 690 to 822m asl, and soils from limestone cover a range from 680 to 930m asl. Strong differences between CEC_{clay} cannot only be explained by climate factors alone. The influence of the clay mineral content of the different parental materials might be negligible, as the claystone contains already 14% more kaolinite than the limestone dissolution. Hence, it can be assumed that the clearly lower CEC_{clay} values of the limestone can be explained by higher percolation rates leading to an increased gibbsite formation. Evidence is also given by the measurements of the hydraulic conductivity, which is for Acrisols originated from limestone twice that of Luvisols from claystone. It can be assumed that the transition from Luvisols to Acrisols on claystone in the Bor Krai area is at clearly higher elevations than that for limestone. Unfortunately, the claystone within the Bor Krai area is restricted to elevations below 850m asl; hence it was not possible to find this boundary on claystone.

Other CEC_{clay} levels in dependence of the parent rock material (Figure 5-2) have to be traced back to different precipitation rates. The climate measurement revealed clearly higher precipitation rates for the Mae Sa Mai area than for Bor Krai and also for the Huay Bong region. Therefore, it is not astonishing, that the soils originating from granite and gneiss in this area revealed the lowest CEC_{clay} values. The high CEC_{clay} values for soils from sandstone, breccia, and conglomerate can be explained by the low precipitation rates in the Huay Bong area. The exceptional high values for soils from latite can be explained by its extreme low percolation rates due to its high clay content. This corresponds with the findings of Gray and Brain (2002) and Gray and Humphreys (2004).

The extreme low values for soils from bauxite and iron ore can be explained by the expected high amount of gibbsite in these soils.

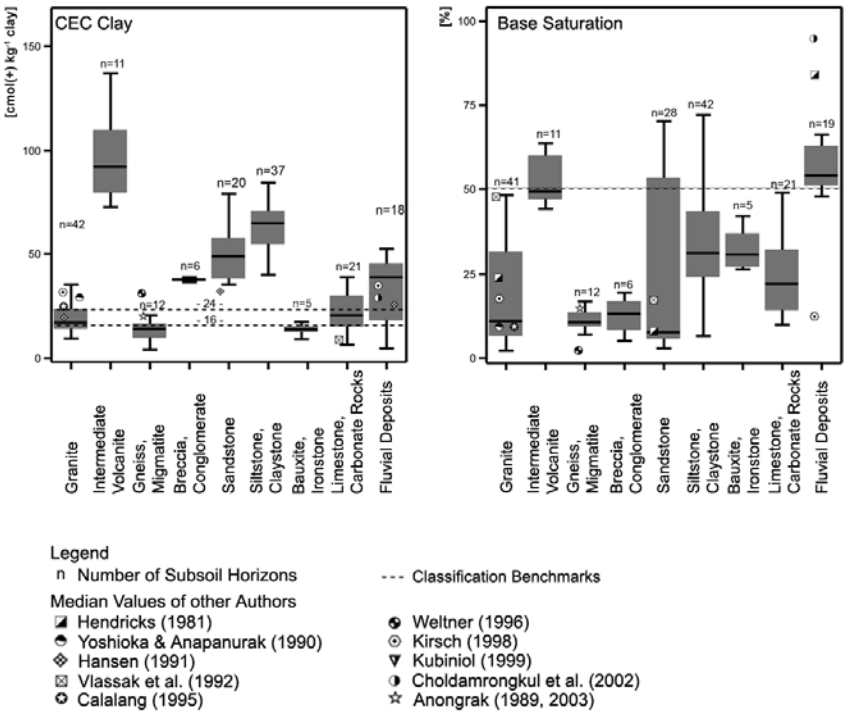

Figure 5-2: Variability of subsoil (B- and C-horizons exclusively) CEC_{clay} and base saturation according to petrography

The **base saturation** is another important parameter for soil classification. For the formerly used FAO soil classification (FAO 1990) base saturation together with CEC_{clay} were important parameters to distinguish Luvisols, Acrisols, Alisols, and Lixisols. Luvisols have been characterised by a CEC_{clay} >24cmol (+) kg^{-1} clay and a base saturation >50%, Acrisols required <24cmol (+) kg^{-1} clay and <50% base saturation, while Alisols required >24cmol (+) kg^{-1} clay and <50% base saturation, and Lixisols have been characterised by <24cmol (+) kg^{-1} clay with >50% base saturation.

According to this FAO soil classification (FAO 1990) most of the soils in North-western Thailand are Acrisols and Alisols, because their base saturation is mostly below 50%. With the introduction of the WRB 1998 classification the FAO system was modified.

The most severe changes were that Luvisols did not require anymore a base saturation >50% and that Alisols require the so called "Alic properties" for most layers between 25 and 100cm soil depth (FAO 1998). These "Alic properties" were never met by any soils, thus, all Alisols of the former FAO system had to be reclassified as Luvisols. Nevertheless, in the new WRB 2006 soil classification (FAO 2006) the "Alic properties" were deleted and Alisols regained their former importance. However, as the study was already in mid-process, when the new WRB 2006 was issued, its application was not feasible.

Like the CEC_{clay} concentration, the base saturation shows a negative correlation with increasing elevation and the therewith related precipitation (Table 4-3). This corresponds with Gray and Humphreys (2004), who found that the base saturation increases with drier climates. Subsoils from intermediate volcanite and alluvial deposits showed exceptional high base saturation values (Figure 5-2). The possibility to find an Acrisol on such parental material is quite low, especially at lower elevations. Median values below 20% were found in soils originating from gneiss, conglomerates, and sandstone. Such values were expected, because the parental material mainly provides the easily soluble K^+ and Na^+ ions. The broad value ranges can be explained by different losses of bases due to varying elevation (amount of precipitation) and land use. The variable composition of sandstone might be a further reason.

As the measurement of the base saturation is quite expensive and time consuming, finding usable correlations as proxies for other parameters can help to reduce the needed effort.

At all scales, but not for all cases, positive correlations with pH (H_2O) were found (see Table 4-5), since the degree and kind of correlation varies with the respective petrography. Especially soils originating from limestone and claystone show clearly different gradients (Figures 5-3 and 5-4). It is advisable to take the petrography –where possible- into consideration for the correlation.

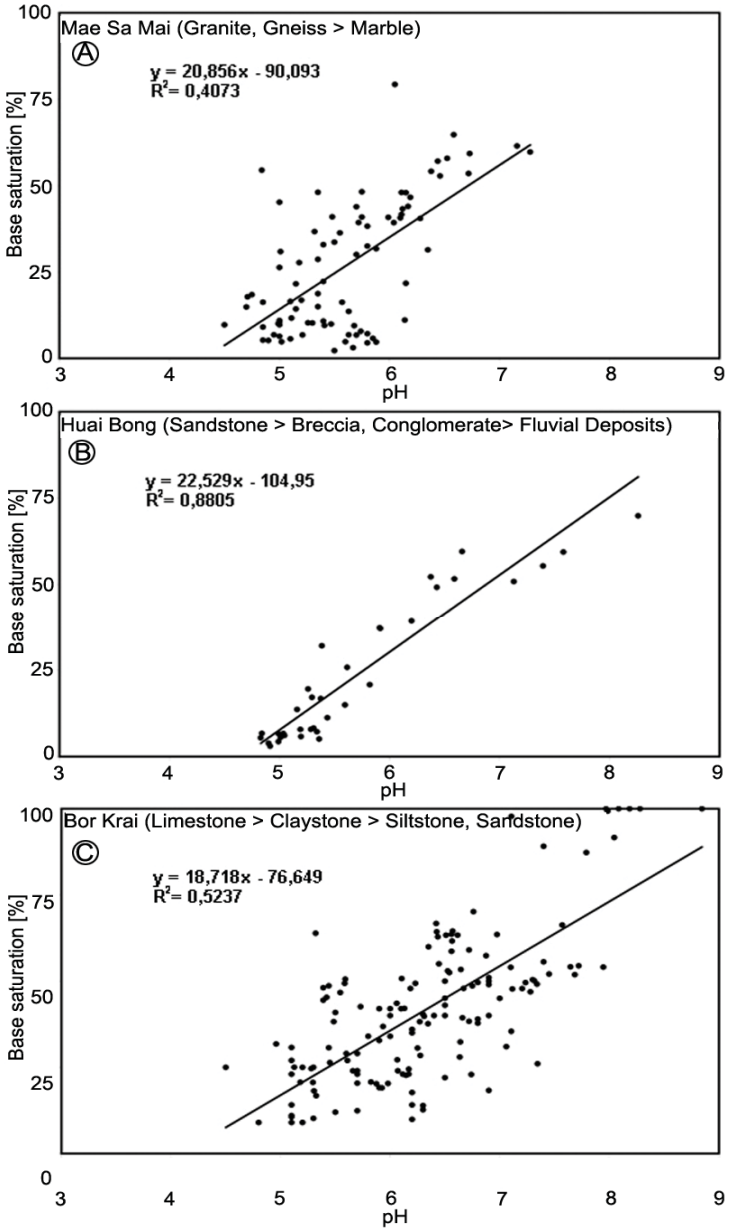

Figure 5-3: pH – base saturation relation according to different locations

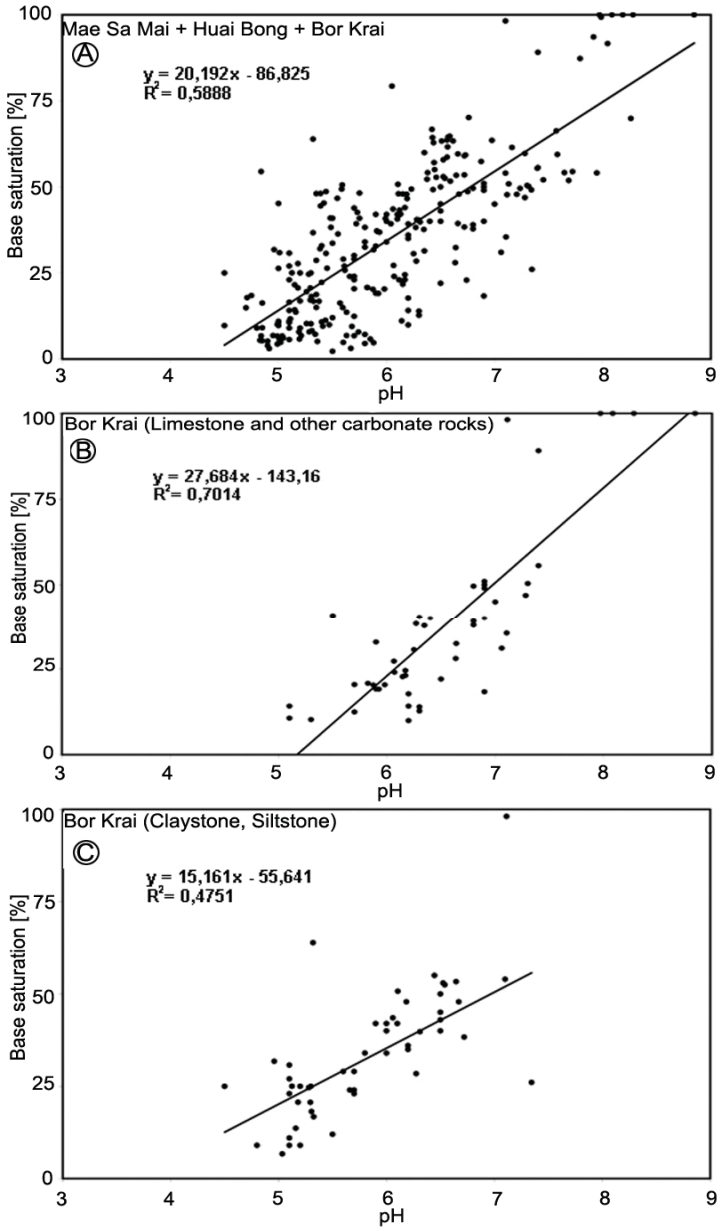

Figure 5-4: pH – base saturation relation according to different petrography

The comparison of CEC_{clay} and base saturation of the most common soil types with the findings of other authors revealed high accordance (Figure 5-5). The exceptionally low base saturation values from Yoshioka and Anapanurak (1990) and Kirsch (1998) can be traced back to Ferralic Cambisols at higher elevations.

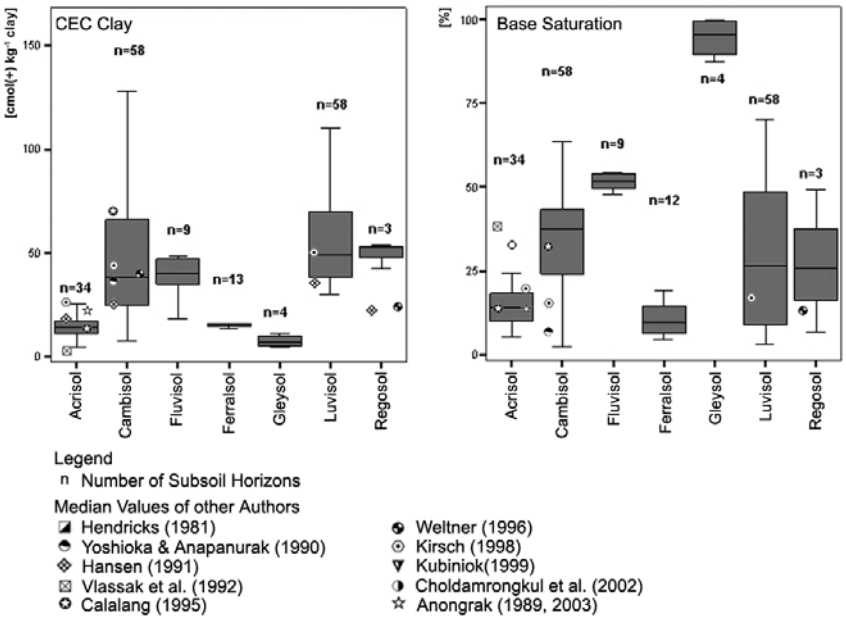

Figure 5-5: Variability of subsoil (B- and C-horizons exclusively) CEC_{clay} and base saturation according to WRB soil groups

5.2.6 The major soils of North-western Thailand

In order to identify the characteristics of soils and soil properties and to facilitate predictive soil mapping in North-western Thailand, the main soil groups of the different areas are compared below.

Acrisols were found in Mae Sa Mai and in Bor Krai. In Mae Sa Mai Acrisols from migmatite dominate below 1300m asl. Above 1300m asl they pass over to Ferralic Cambisols. For the Mae Chan watershed the data of Kirsch (1998) indicate the same trend where Acrisols from granite pass over to Humic Cambisols or Ferralic Cambisols at around 950m asl.

For the Doi Inthanon area the data of Weltner (1996) also shows a similar trend, where Acrisols and Ferralsols from migmatite and gneiss pass over to Cambisols at around 1600m asl. Due to their content of coarse fragments, these "Ferralsols" are most probably Humic Cambisols or Ferralic Cambisols. Despite this, Acrisols originated from limestone in Bor Krai start to occur above 800m asl.

In Mae Sa Mai the degree of clay illuviation decreases with elevation. This observation corresponds to the findings of Hansen (1991). According to Hansen (1991) the lower boundary of the Bt horizon (for soils on granite and gneiss) also decreases with increasing elevation.

Acrisols in Mae Sa Mai are mostly used for the production of lychee and vegetables. In Bor Krai most of the Acrisols are covered with forest, the rest is used for cultivation of upland rice and maize.

Acrisols in both areas have a similar texture of clay loam in the topsoil and clay loam to clay in the subsoil. In both areas a granular structure of the topsoil and a subangular blocky structure of the subsoil are common, but the development of the structure is by far higher in the Bor Krai area than in the Mae Sa Mai area. The better developed structure in Bor Krai goes along with a higher porosity, where the bulk density averages around 0.3g cm^{-3} lower for the topsoil and even 0.5g cm^{-3} lower for the subsoil than in Mae Sa Mai. Additionally, the hydraulic conductivity of Acrisols in the Bor Krai area is 10 to 100 times higher than in the Mae Sa Mai area (Spohrer 2007).

Due to the occurrence of limestone, Acrisols in the Bor Krai area are limited by a sharp and wavy to irregular boundary at their lowest horizon.

Acrisols in Mae Sa Mai are mostly deeply weathered with a diffuse and smooth boundary to the granite and gneiss below. Only in the vicinity of the marble the lower boundary is sharp and wavy.

Acrisols in the Bor Krai area generally provide better suited chemical soil properties for crop production than those in the Mae Sa Mai area. C_{org}, N_t, pH (H_2O), CEC_{soil}, base saturation are clearly higher than in Mae Sa Mai. Only the plant available phosphorous content of the topsoil and the plant available potassium content and exchangeable potassium content of the entire soil were higher in Mae Sa Mai than in Bor Krai. The higher values of plant available phosphorous and potassium of the topsoil can be explained by the significant application of fertilizer. The higher exchangeable potassium content might be traced back to the common mica content of the Acrisols in the Mae Sa Mai area. The cation exchange capacity and base saturation of all investigated Acrisols are in the range described by most authors (e.g. Anongrak 1989, 2003; Hansen 1991, Calalang 1995, Kirsch 1998) (see also Figure 5-5).

The topsoils of Acrisols in the Mae Sa Mai area have micronutrient deficiencies in Zn (<=2.5mg kg^{-1}), Cu (<=0.9mg kg^{-1}) and B (<=0.2mg kg^{-1}) (Inthasan 2006).
The values for Zn and B are much lower than those for the topsoil of the Luvisols in Bor Krai. The former values are rather equal to subsoil values of the Luvisols in Bor Krai.
The clay fraction of Acrisols from Mae Sa Mai, Bor Krai, and Doi Inthanon consists mainly of kaolinite and gibbsite followed by quartz. Illit, vermiculite, and interstratified clay minerals (1.0 - 1.8nm) occur only in traces (Herrmann *et al.* 2007, Anongrak 2003).

Anthrosols were only found at very restricted locations of former paddy rice production in the Mae Sa Mai area. Anthrosols were also expected for the paddy fields at Huay Bong, but were not found. The reason might be the loamy texture and the restriction of the flooding period to some months in the rainy season only. For the paddy fields at lower elevations (not investigated in this study) under intensive cultivation the occurrence of Anthrosols can be expected (Anongrak 2003).

Cambisols were found in all three study areas, where altogether three kinds of Cambisols exist. The first group occurs mostly on steep and convex slopes and was derived mostly from Luvisols and Acrisols by soil erosion. The second group occurs in depressions, lower slopes, and valleys, where colluvial processes dominate. The third group occurs, where the degree of clay illuviation is not sufficient to fulfil the requirements of an Argic horizon, as observed in the Mae Sa Mai area for elevations above 1300m asl. For this reason Cambisols show the highest range of variability with respect to the different soil properties. Depending on petrography and elevation the texture can range from sandy clay loam to clay. Cambisols originating from granite, gneiss, limestone and claystone mostly consist of clay loam with a subangular blocky structure, while those from sandstone feature a rather loamy texture with a subangular blocky structure.
Cambisols in the Mae Sa Mai area showed highest C_{org} and plant available K values and the lowest base saturation in the three research areas. These high C_{org} values can be explained by the fact that most Cambisols are covered with forest and that man-made ground fires in the Mae Sa Mai area are less common than in other areas. The high plant available K and low base saturation values can be traced back to the parent rock material consisting mainly of migmatite. Cambisols from granite with exceptional low base saturation values were also found by Kirsch (1998) and Yoshioka and Anapanurak (1990) (Figure 5-5). The low CEC_{soil} and CEC_{clay} values of many Cambisols are caused by a high share of kaolinite and gibbsite in their clay fraction.

This assumption was confirmed by the investigation of a Cambisol from granite in the Mae Chan watershed, where the clay fraction contained kaolinite and gibbsite (Kirsch 1998). Gibbsite forms, where the percolation is sufficiently high due to low evapotranspiration to rainfall ratios and where the percolation is sufficiently fast due to coarser textured parental and/or underlying materials (Herrmann *et al.* 2007). Both are given for higher elevations on migmatite, gneiss, and granite. This together with a lack of clay illuviation will lead to the formation of Ferralic Cambisols. Ferralic Cambisols are characterised by an extremely low CEC_{clay} and base saturation. Chemically they correspond with Ferralsols, but their high share of weatherable minerals sets them apart. For this reason many of the described Ferralsols (Weltner 1996) are most probably Ferralic Cambisols. Cambisols from Huay Bong showed the highest base saturation and the lowest values for C_{org}, N_t, plant available K, and exchangeable K^+. The high base saturation value and low plant available K and exchangeable K^+ might be traced back to the occurrence of sandstone. The low values for C_{org} and N_t might be caused by low precipitation rates and a short vegetation period, which hamper the accumulation of organic matter. Relative high temperatures and coarse material at the surface also facilitate the decomposition of organic matter and reduce the formation of clay-humus complexes. The production of organic matter is much lower compared to other areas. In addition, the impact of the man-made fires is more severe. Cambisols from Bor Krai showed the highest mean values for CEC_{soil}, plant available P, exchangeable K^+, and Ca^{2+}. These values can be traced back to the parent rock material mostly consisting of claystone and limestone.

Fluvisols were found along streams and streambeds, where alluvial deposits are accumulated. This is the case in the Bor Krai area, Huay Bong area, and the Mae Sa watershed, but not in the Mae Sa Mai area, where uplift prevails, causing the streams to incise into the valley bottoms and hampering sediment accumulation. The composition of the various Fluvisols depends on the size of the streams and the respective catchment. Fluvisols along the streambeds of a very small catchment within the claystone unit in the Bor Krai area are dominated by textures ranging from loam to clay. Fluvisols in the Huay Bong area are dominated by loamy sand, while these along the larger streams contain different horizons with textures ranging from sand to clay. The nutrient stock also shows a high variability, but goes along with the clay content of the respective horizons.

Normally **Ferralsols** derive from ferralitisation (FAO 2001, Blume *et al.* 2002), which is hydrolysis in an advanced stage.

If the soil temperature is high and percolation intense, all weatherable primary minerals will ultimately dissolve and be removed from the soil mass.
Less soluble compounds such as iron and aluminium oxides and hydroxides, and coarse quartz remain behind. Ferralitisation is favoured by low soil pH and low concentrations of dissolved weathering products in the soil solution, which promote desilication and build-up of high levels of (residual) Fe and Al. Further, a geomorphic stability over prolonged periods of time is essential, as ferralitisation is a very slow process. Finally, basic parental material increase ferralisation, due to its relatively high content of iron, aluminium in easily weatherable minerals, and little silica (FAO 2001). Ferralsols were only found at one location in the Bor Krai area. These Ferralsols are derived from displaced rock debris consisting of bauxite and iron ore on a moderately steep slope. The Ferralsols are interlaced with Leptosols and Acrisols.
The texture ranges from silty clay to clay with moderate to strong granular to subangular blocky structure. These Ferralsols were derived by alteration of this exceptional parental material and not generated by ferralitisation. Due to the current uplift in most parts of North-western Thailand, including all three study areas, ferralitisation seems to be impossible there. For tectonically rather stable areas mainly consisting of plateaus of supposedly Tertiary age, Kubiniok (1999) found Ferralsols, which are characterised by a complete alteration of their feldspar content and corrosion of quartz grains. The soil matrix is dominated by kaolinite (Kubiniok 1999). These Ferralsols are restricted to the supposedly oldest landforms. At flat relief sites leaching of Fe is accompanied with clay translocation. At sites with higher elevation, Kubiniok (1999) observed the formation of brownish soil colours for the topsoil through clay skins. Micromorphologically, these clay skins differ from the soil matrix by a lack of Fe-oxides or Fe-hydroxides, leading to a decrease of aggregate stability and to an increase of water-dispersible clay. In conclusion, the existing Ferralsols are either relicts or derived from exceptional parental material. The process of ferralitisation cannot occur under the present climate conditions in North-western Thailand. The relictic Ferralsols will mostly alter to Acrisols due to clay translocation or to Cambisols where the clay translocation is not sufficient, but where the reorganisation of soil matrix will lead to increased water-dispersible clay contents until the requirements are not met anymore.

Luvisols dominate in the Bor Krai and Huay Bong area. While Luvisols in the Huay Bong area are characterised by a prominent elluvial horizon, such a horizon is lacking in the Bor Krai area. Huay Bong is the only area, where that kind of a clear elluvial horizon is developed.

The main reason therefore can be found in the parental material consisting mainly of sandstone, breccia, and conglomerate. Most of the Luvisols have a texture of clay loam to clay with a subangular blocky structure. Luvisols in Bor Krai are characterised by far better suitable chemical properties for agriculture, than those in Huay Bong. C_{org}, N_t, plant available K, pH, CEC_{soil}, base saturation, exchangeable Na^+, K^+, Ca^{2+}, and Mg^{2+} show clearly higher values in Bor Krai. Only the plant available P content of the subsoil is slightly higher in Huay Bong. The clay fraction of Luvisols originating from granodiorite in Mae Chan watershed contains shares of kaolinite, gibbsite, and illite (Kirsch 1998). Most probably the share of illite is higher, and the shares of kaolinite and gibbsite are lower in Luvisols than in Acrisols. For Bor Krai it can be assumed that the evapotranspiration to rainfall ratio decreases with the elevation and is directly connected the gibbsite and kaolinite content. The CEC_{clay} content decreases, leading to the described transition from Luvisols to Acrisols at around 800m asl. Findings from Kirsch (1998) indicate a similar trend for the Mae Chan watershed. There, Luvisols originating from granite pass over to Acrisols at around 500m asl. The micronutrients B, Zn and Mo are deficient for the Luvisols of the Bor Krai area (Hüller 2006). The stock of macro- and micronutrients of the Argic horizon is much less than for the topsoil. This is the main obstacle for water harvesting techniques on these soils, and therefore, the higher plant water availability of the Argic horizon is of no value to the cultivation of many crops. Therefore, cultivation of Acrisols is mainly restricted to the rainy season.

5.2.7 Soil forming factors and their consequences for predictive mapping

Predictive soil mapping relies on secondary information, which corresponds with soil forming factors. The degree of importance of each soil forming factor has to be known. Soil formation (s) is a function of time (t) in dependence of parent rock (p), climate (c), relief (r), fauna and flora (o) and man (m): **s = f(p,c,r,o,m)t** (Jenny 1941, Blume *et al.* 2002).

The investigations of this study revealed that the seasonal tropical **climate** in the research areas stipulates clay illuviation as the main soil forming process at regional scale causing a dominance of Acrisols and Luvisols. As mentioned above, the degree of clay illuviation mainly depends on the seasonality of the climate and rock permeability. This leads to a transition from Acrisols to Cambisols at the highest elevations on low permeable rocks due to decreased clay illuviation as a consequence of reduced soil moisture fluctuations (hampering the formation of shrinking cracks). The climate has also an impact on the composition of clay minerals.

In the Bor Krai area at around 800m asl Luvisols pass over into Acrisols probably because of a positive correlation between precipitation and percolation rates, additionally the amount of kaolinite and gibbsite in the clay fraction increases in the same way as suggested by the data of other authors (Kirsch 1998, Kubiniok 1999).

The relation between organic matter and elevation described by Hansen (1991) and Kubiniok (1999) could not be confirmed. Based on eleven samples of Ultisols Hansen (1991) calculated a linear relationship between C_{org} of the upper 100cm and the elevation range. Kubiniok (1999) presumed that the relationship between elevation and C_{org} of the topsoil for 21 samples followed an exponential function (r^2=0.71) rather than a linear function (r^2=0.66).

These findings cannot be confirmed using the 280 samples of the present study (see Equation 4-1 to 4-4). All equations delivered no significant r^2 values.

The distribution of the available C_{org} values for this study (see Figure 4-4) shows clearly that C_{org} does not solely depend on the elevation as suggested by other authors (Hansen 1991, Kubiniok 1999). It primarily depends on the local climate, which does not necessarily correspond with elevation at a regional scale. Further factors like human impact, slope inclination, curvature, vegetation, termite activity and parent rock might also have to be taken into consideration. The data were not sufficient to derive a significant regression equation based on these factors.

The locally positive correlation between C_{org} and elevation can be attributed to a decreased decomposition of organic matter due to cooler air temperatures at higher elevations. The frequencies of ground fires at lower elevations may also lead to a greater loss of organic matter compared to sites at higher elevations (Hansen 1991). The best positive correlation between C_{org} and elevation was found for samples from a linear slope in Mae Sa Mai. There, both C_{org} as concentration, as well as total mass of the topsoil showed positive, but not significant (r^2<0.4) correlations with elevation. This correlation corresponds with the A-horizon thickness distribution (Figure 4-9) and the local soil map (Figure 4-26) of the area. Both maps suggest an increase of organic matter rich topsoil with increased elevation.

Nowadays, destructive human activities have often reached the highest elevations and will superimpose the climate based distribution of organic matter. Man-induced soil erosion is especially responsible for a downward translocation of organic matter. This often results in an accumulation of organic matter in valleys, concave slopes, and in depressions as observed for Cambisols and Umbrisols in Huay Bong and Bor Krai. The relative low amount of concave slopes and flat areas (potential deposition areas) in the Mae Sa Mai area might explain at least the existence of a certain positive correlation between C_{org} and elevation.

In addition, organic matter accumulates, where soils periodically have high water content, hampering the mineralisation of organic matter (Blume *et al.* 2002). This happens at lower elevations where the groundwater level is close to the surface and is often related with Gleysols, where water periodically percolates through the soil as in the case of the Chernozems. No clear correlation was found for forest or for arable land. Reddish soil colours are mostly connected with hematite, which requires high temperatures and low organic matter content for its formation. The latter inactivates iron through iron-humus complexes. At least nowadays, the soil colour might depend mainly on the temperature. For this reason, reddish soil colours prevail at lower elevations, while brownish soil colours are quite common in the highest elevations. The upper boundary of the red soils might depend on local climate gradients. In the Mae Sa Mai area the upper boundary of red coloured soils is around 1300m asl, while Weltner (1996) described for the Doi Inthanon area a dominance of brownish Cambisols above 1600m asl. The soil colour boundary corresponds with the transition boundary between Acrisols and Cambisols. As with the transition from Acrisols and Cambisols the elevation of the boundary decreases with increasing precipitation and decreasing temperature. Many soils have independently of their elevation brown topsoils. According to Kubiniok (1999) this brown colour is not only caused by the organic matter content, but also by the clay iron plasma of the clays and clay cutans. Micromorphologically, these cutans lack cracks and secondary fillings. Kubiniok (1999) interpreted this reorganisation of the soil matrix and clay mobilisation as a young process.

For predictive soil mapping the local climate has to be taken into account. As long as no accurate climate map is available, digital elevation models have to be taken as a replacement. This can be done only for a local scale. It is advisable to subdivide the area into zones of homogenous temperature and precipitation gradients and to carry out the predictive mapping for each zone individually.

The investigations of this study revealed that the **parent rock material** has influence on several soil properties, especially the degree of clay illuviation, soil hydraulic conductivity, texture, amount of coarse fragments, CEC_{clay}, CEC_{soil}, base saturation, and soil nutrient status. According to Yemefack (1995) the influence of the parental material on soil distribution and soil fertility exceeds the effect of topography.
Parent rock materials like granite, claystone, and limestone alter to finely grained soils mostly consisting of clay. Gneiss alters mostly either to clay or sandy clay loam. Fluvial deposits often alter to coarser grained textures like loam, clay loam, and sandy loam.

Sandstone, breccia, and conglomerates alter mainly to coarser grained soils, consisting mainly of sandy clay loam. Soils originating from sandstone have more coarse and medium pores than soils from other parental materials. The amount of these pores facilitates clay illuviation, which is strongly pronounced on these soils. The question whether the amount of these pores is sufficient to facilitate clay translocation independently from the seasonal climate remains unanswered. Unfortunately, sandstone soils at elevations higher than 1200m asl were not investigated. Additionally, the parental material influences indirectly the water infiltration rate of the soils. The permeability of the parental material often corresponds with that of the derived soils.

Hence, soils derived from claystone and latite clearly showed lower hydraulic conductivities and related percolation rates than soils from limestone. It seems that highly permeable rocks like karstified limestone facilitate the development of a drainage system within the soil. Hence, limestone soils show high soil moisture fluctuations, facilitating shrinking cracks and related clay illuviation even at the highest elevations. The percolation rates correlate negatively with CEC_{clay}. Hence, comparably higher CEC_{clay} values were found for soils from claystone and latite. In consequence, the observed transition from Luvisol to Acrisols from limestone in the Bor Krai area is supposed to occur at much higher elevations for soils from claystone and latite. Unfortunately, the claystone and latite of the investigation area were limited to lower elevations.

This study revealed that skeleton content depends mainly on the composition of the parental material. The lowest skeleton contents were found in limestone soils. The skeleton content has an influence on erosion rates. Soils originating from limestone contain almost no rock fragments. In consequence, erosion rates are more or less continuous until the parental limestone is finally exposed. Hence, Leptosols on limestone represent only the transient stage on the way towards a rock desert. Soils from other parental materials, especially sandstone interlaced with conglomerate and breccia have the highest shares of skeleton. Here, soil erosion causes an accumulation on the surface, leading to a decrease of soil erosion. On the steepest slopes shear stress impedes the development of such a protective sheet of coarse fragments, leading to Skeletic Regosols and Hyperskeletic Leptosols, which consist mainly of highly altered rock material.

The amount of plant available nutrients is also often related to the parent rock material. Topsoils of limestone soils showed the highest values for N_t and P (CAL), while soils originated from claystone showed rather low values.

Soils from claystone featured clearly higher values for K (CAL) than soils from limestone.

The skeleton content and the amount of rock outcrops are also often related to the parent rock material. Consequently, present land use patterns often correspond with the parent rock material. In the Mae Sa Mai area a section of the boundary between the marble-freshwater limestone complex and paragneiss is exactly congruent to the boundary between cropland and forest. Another example for this is provided by the Tertiary sandstone occurrence of the Huay Bong area, which corresponds with the main cultivation site for maize, while slate sites are covered with forest. In Bor Krai almost the whole claystone area is used for crop production, while a high share of the limestone area is still covered with forest. The Chernozem occurrence on the freshwater limestone patch in Bor Krai is used for maize production exclusively.

Unusual parent rock material is often responsible for uncommon soils. Examples are the Ferralsols in Bor Krai and the Chernozem occurrences in Mae Sa Mai and Bor Krai. The Ferralsols in Bor Krai were not expected, because they usually occur on slopes in association with Acrisols and Leptosols. Ferralsols are mostly described for stable landforms (Zech and Hintermaier-Erhard 2002). In contrast, the different cave levels in the Bor Krai area give evidence for a recent uplift, thus, this landform can be considered to be rather young. The existence of Ferralsols in the Bor Krai area is the result of veins with iron ore and bauxite. The existence of Chernozems, well known from the steppe of Russia (FAO 2001), is indirectly a result of the parent rock material. In contrast, the Chernozems from Bor Krai and Mae Sa Mai derive from freshwater limestone, which formed below a karst spring.

In conclusion, the petrography has a major influence on soils and their properties. In order to achieve sound predictive mapping this relationship has to be considered.

Firstly, to accomplish this, the area has to be subdivided into petrographic landforms. Afterwards predictive mapping can be carried out for each landform, respectively.

The **relief** often influences the distribution of soils and soil properties (Blume *et al.* 2002). This study revealed that the occurrence of the major soil groups depends on the elevation due to local correlations with the climate. For this reason, the above mentioned transitions form Luvisols to Acrisols to Cambisols occur with increasing elevation. Exceptions are old stable plateaus with their dominance of relictic Ferralsols (Kubiniok 1999). Other soil types also show more or less dependencies on relief position. Gleysols, Chernozems, and Fluvisols occur below springs and are restricted to moderate and lower elevations. Most of the Leptosols were found at the highest elevations, where the geomorphologically most stable rocks are common, which often lead to shallow soils or even emerge out of the soil cover. Slope and inclination have a secondary influence on soil distribution.

Within this study Acrisols and Luvisols were commonly found on moderate slopes and crest positions. This reflects the findings of other authors (Weltner 1996, Kirsch 1998, Kubiniok 1999). In dependence of the slope position different kinds of Cambisols occur. The first kind is primarily located on upper and convex slopes, the second occurs mostly on lower and concave slopes. The first derives mainly from degradation of Acrisols and Luvisol, the second kind is caused by colluvial deposits. Both types were mostly classified as Humi-Dystric Cambisols according to WRB 1998 classification (FAO 1998). In this case, the WRB 2006 (FAO 2006) classification is much more helpful, because the first ones will be mainly classified as Alisols, Luvisols, and Acrisols and the other as Haplic Cambisol (Colluvic, Humic). Leptosols and Regosols are quite common on very steep slopes.

This matches with Kubiniok (1999), who found Leptosols on very steep slopes along the Mae Chaem valley upstream of Hot. Umbrisols were found in well drained karst depressions without outlets, where colluvial sediments consisted mainly of eroded topsoil material. Within this study, Gleysols were found in valleys and in the inter mountain basins. In karst areas Gleysols are located in sealed karst depressions with a high groundwater level.

Umbrisols and Gleysols in karst areas of North-western Thailand were not previously reported. The topsoil thickness increases from upper slope to lower slope positions due to colluvial processes (Weltner 1996). This can be confirmed for Bor Krai and Huay Bong. Exceptions were found for some karst depressions ending in a sinkhole impeding soil accumulation. In the Mae Sa Mai area colluvial processes are quite unusual since uplift rates are responsible for the incision of streams, resulting in increased erosion rates at the base slopes. Finally, the degree of erosion depends not only on the infiltration rate alone, but also on the balance of incoming and outgoing sediment at a certain location. For the Doi Inthanon area, Weltner (1996) found Ferralsols on crests suggesting these were parts of a former plain. At the slopes in between, she discovered mainly Acrisols. Such Ferralsols could not be found in the Mae Sa Mai area, which is comparable to the Doi Inthanon area in many other aspects. Due to sandstone fragments this classification as “Ferralsol” is rather questionable.

According to Hendricks (1981) and Weltner (1996) in most cases slope degree has a smaller role than expected for the variability of soils. This can only be confirmed for the Bor Krai area, where the soil variability stands behind the amount of slope classes. In contrast, in Mae Sa Mai and Huay Bong the relief influenced the recent soil distribution where Cambisols and Leptosols are quite strongly related to slope steepness.

In consequence, for predictive mapping relief has also to be taken into consideration.

As long as no detailed climate maps are available, digital elevation models have to be taken as a replacement. For most parts of North-western Thailand, the relief is less important than petrography and climate. The only exceptions are the tectonically stable landforms with their relictic Ferralsols (Kubiniok 1999).

Vegetation has a strong impact on soil pH, erosion rates, organic matter, and nutrient stock (Maxwell 2004, Panomtaranichagul 2006). As mentioned above, the observed general decrease of soil pH with increasing soil depth is most probably caused by the plant nutrient uptake to the surface. For relatively undisturbed forests Anongrak (2003) described that soils under moist evergreen forest and hill evergreen forest have thicker surface layers than those under the drier dipterocarp forest cover. Under moist evergreen forest at higher elevations gibbsite dominates in the clay fraction, whereas a mixed situation between gibbsite and kaolinite domination is found in a hill evergreen forest environment, while kaolinite dominates the clay fraction of soils under dipterocarp forests. The vegetation is not the cause for the clay mineral composition, but more likely the amount of precipitation. This determines the forest type as well as the clay mineral composition by different percolation rates (Herrmann *et al.* 2007). Under a change from hill evergreen forest to paddy rice environment soils show stagnant water characteristics, while kaolinite dominates the clay fraction. Here again, the domination of kaolinite can be most probably explained by low percolation rates.
Forests with dense ground vegetation prevent soil erosion (Kubiniok 1999). Maxwell (2004) considers deforestation as the ultimate cause for flash flooding, soil erosion, and change of local climate.

Bradshaw *et al.* (2007) found a positive correlation between natural forest area loss and flood frequency. In disturbed forests, where the ground vegetation is removed, destroyed, or not developed due to allelopathy, soil erosion cannot be prevented (Brandt 1988, Valentin *et al.* 2004). The water of streams draining relatively undisturbed forests is quite clear even during the rainy season (personal observations). A study of the riparian zone in Laos revealed that banana and natural grass plots act as active sinks of sediment and water, while land covered with bamboo and upland rice was an active source of water and sediment to streams. Measured sediment concentrations of runoff from upland rice plots was 3.5 times the sediment concentration of runoff entering the plots, and nine to seven times the sediment concentration of runoff removed from the banana and natural grass plots (Vigiak *et al.* 2006). Such increased erosion rates of upland rice were also observed in the Bor Krai area. Teak plantations have also a negative impact on soil erosion.

Investigations of teak plantations from Laos and Thailand showed yearly erosion rates between 0.3 and 12.4kg m^{-2} (mean 2.7kg m^{-2} per year), which represent an average of 2mm of removed topsoil every year, namely nearly 10 times the currently "tolerable" accepted soil loss. Poorly developed understory vegetation can also be due to shading effects and/or allelopathy, which inhibits growth of seedlings as well. The litter layer can be rapidly destroyed by termite and soil microbe activity, consequently a large part of the soil surface remains insufficiently protected against the direct impact of large drops, if no understory vegetation is present. These large raindrops concentrate and fall from tree leaves with a kinetic energy that exceeds even that of free falling raindrops (Brandt 1988, Valentin *et al.* 2004).
The kind of vegetation itself depends mainly on climate, pedology, petrography and human impact. One can draw conclusions from the type of vegetation on its determining factors.

For predictive mapping, vegetation plays an important, but indirect role by influencing the wavelength ranges and radiation intensities of satellite images. The kind of vegetation and its response to different soil moisture conditions reflects the different soil types very well (personal observations).

Animals play an important role for the turnover of nutrients and soil material. The biofurcation activity of termites, ants, earthworms, as well as crickets and many soil-living insect larvae (mainly beetles and cicadas) brings subsoil material to the surface, enriches the soil with nutrients, resulting in an increase of organic matter, pH, and electrical conductivity (Kirsch 1998). Considering their obvious activity in the research areas, the main biofurcating organisms in North-western Thailand might be termites. Within the claystone area of Bor Krai at least one termite mound per ha was observed. Termites remove organic material from the surface and bring fresh soil material from the subsoil to the surface (Kirsch 1998). After a termite mound is abandoned the collected material and nutrients are released to the surface. Channels and holes build by termites were found in most of the soil profiles. These activities improve the soil structure and increase the infiltration capacity. The same positive impact was observed for the earthworm, *Pheretima leucocirca,* which prefers forest habitats or Eucalyptus plantations. Its activities lead to an increase of water infiltration, a decrease of water runoff, and soil erosion (Jouquet *et al.* 2006).
In general, animals have only a minor role for soil distribution and can therefore be ignored for predictive mapping.

Human impact plays an increasing role for the distribution of soils and their properties. Increasing land and water scarcity is now forcing farmers to shorten their fallow periods, leading to an intensification of land use (Puginier 2002).

The investigations of lake sediments at Phayao clearly showed that intensified land use caused increased soil erosion during the last 20,000 years (Penny and Kealhofer 2005). This highly unsustainable land use intensification is likely to result in the destruction of soils in one generation. Furthermore, own investigations in reforestation sites in Mae Sa Mai indicate that recovery might take many decades. The short term thinking and irresponsible behaviour of previous and present generation is going to result in a negative impact on the livelihoods of the coming generations. The investigation at the three research areas revealed that most of the soils on sloping land lost its former potential due to soil erosion, as soil truncation exceeds by far topsoil formation. Measurements of water infiltration and nutrient stock indicate that as soon as the surface reaches the clay-enriched Bt horizon the infiltration capacity and soil fertility decreases dramatically. In consequence, runoff increases along with decreasing amounts of drinking water, irrigation water, and crop yields. Further, the collection of the increased runoff water is mostly not efficient due to its high sediment load. Flooding in the lowland areas occurs more frequently causing severe damage to urban infrastructure (Bradshaw *et al.* 2007). The main reasons for soil erosion lie in the removal of the vegetation cover either by logging, slashing, herbicides, fire or a combination of all (Brunijnzeel 1990, 2004, Maxwell personal communication, personal observation,).

In Thailand during every dry season the burning of the ground vegetation is common, creating massive air pollution. In consequence, the visibility in Chiang Mai for March and April 2007 amounted to less than 2km. In the Bokeo province, Laos, the burning in April 2007 was so massive that at noon the sunlight turned red and finally disappeared for several minutes (personal observations).

The reasons for this traditional, yet highly destructive practice are manifold: clearing or extending agricultural land, facilitation of easy hunting and collecting of mushrooms, and just pyromania, or even to be paid to extinguish the self-inflicted fires (Maxwell and Elliot 2001, personal observations). After destruction of the ground cover vegetation much bare soil will be easily eroded at the beginning of the following rainy season. After severe land degradation formerly arable land will be abandoned, leading either to a relatively useless growth of bamboo, grasses or weeds (e.g. Doi Chiang Dao area) or to the slow regrowth of a degraded forest (e.g. Bor Krai). Such regenerated forests are characterised by a low number of species and diversity (Maxwell 2007).

In order to replace the unusable land, more fertile land with forest will be converted into arable land (personal observations).
In the Bor Krai area the destruction of the forest vegetation and the reduction of fallow periods speeds up soil erosion to a dramatic extent, rendering some parts of the land completely without topsoil, while at lower slope position the dark topsoil is covered with the subsoil material from upper slope positions. The morphology of limestone in the Bor Krai area indicates for some areas a soil loss of at least 0.5m since the establishment of the village in the 1970s. Many Cambisols on slopes derived from Luvisols and Acrisols by profile shortening were induced by human activities. Umbrisols arise at lower slope position and in depressions where the colluvial material consists mainly of organic matter rich soil material. In the Bor Krai area one Humi-Anthric Umbrisol was found, consisting of at least 2m of eroded topsoil originated from uphill. If the colluvial material consists of a mixture of topsoil and subsoil material the soil will develop towards a Cambisol. As expected, the colluvium will consist of an increasing amount of parental material causing the development of Regosols.
In conclusion, human activities have to be taken increasingly into account for predictive mapping.
The detection of human activities can be done rather easily using aerial photographs and satellite images. Nevertheless, human impact is still not fully responsible for the distribution of the three main soil types of the study areas (Luvisols, Acrisols, and Cambisols).

Soils underlie permanent changes and modifications. The degree of soil formation goes along with **soil age**. Unfortunately, it is not possible to determine the age of each process. Kubiniok (1999) equates the assumed age of relief units with the soil age. For instance, the Sanan-plateau is supposed to date back to Tertiary times. In consequence the Ferralsols found there are supposedly to be of the same age (Kubiniok 1999). In this case it is assumed, that the stability within a region goes along with the degree of soil modification. This approach disregards the impact of climate changes on soil properties, which influence in contrast is negligible for very instable sites. Such instable sites with high uplift rates are often characterised by Regosols, Leptosols and Cambisols, lacking Ferralsols. Stability and age are not the only reasons for the occurrence of a special soil. A good example for this is a Ferralsol patch in Bor Krai, which only can be explained by bauxite and iron ore occurrences. The determination of human impact on soil formation is much easier than the determination of soil genesis itself, especially if the time of settlement as well as kind and duration of human activities are known.

For example the land above an Umbrisol occurrence in the Bor Krai area was cleared around 30 years ago, indicating deposition rates in the depression below of at least 6.6cm per year. In the Mae Sa valley a plastic package with date stamp from 1980 was found 67cm deep (in 2006) indicating deposition rates of 2.5cm per year for this location.

A curiosity of human impact with known age was found in the Bor Krai area, where lime rich-water leaked out of a water pipe and percolated through organic matter rich colluvial soil material leading to soil properties, which fulfill the requirements of a Chernozem. The water pipe was installed just 10 years ago, which represents the maximum age of this exceptional soil.

The only problem for the estimation of human impact on soils consists in unknown human activities in former times. The more than 2000 years old coffins in the caves in the Bor Krai area are evidence of the long-term settlement history along with the resulting impacts on managed soils in the region (Sidisunthorn *et al.* 2006). For areas without caves, graves, or any other archaeological evidence ancient human activities can only be assumed.

The soil age is mostly not important for the soil distribution and remains in many cases unknown. Exceptions are the relict Ferralsols, where the age of the landform corresponds with the soil age. In general, the soil age can be ignored for predictive mapping.

5.2.8 Interdependency of soil forming factors

Many of the soil forming factors mentioned show a strong **interdependency**. The most important interdependency is the correlation between climate and topography, which is related to the distribution of the main soil types, with Luvisols at the lowest elevations or precipitation rates, followed by Acrisols and Cambisols (for low permeable rocks only) with increasing elevation and precipitation and decreasing temperature. In addition the parent rock has a modifying influence on the soil distribution (Figure 5-6).

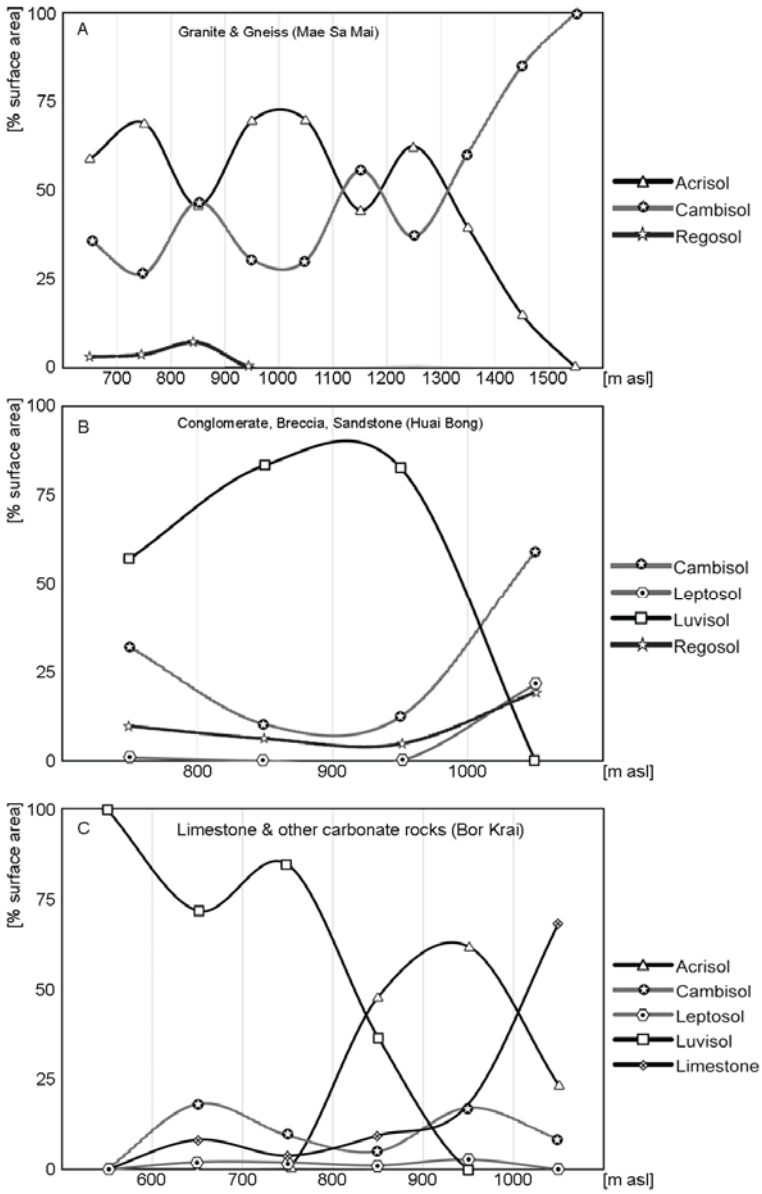

Figure 5-6: WRB soil group distribution on different petrography according to elevation

According to Figure 5-6, all three petrographic areas have in common soils, which are characterised by clay illuviation, which dominates at the lowest, but not at the highest elevations. Mae Sa Mai and Huay Bong have in common that Cambisols prevail at the highest elevations, but featuring different kinds of Cambisols. In Mae Sa Mai, Cambisols at the highest elevations exist because the climate conditions hamper clay illuviation of finely grained soils. They were mainly classified as Ferralic Cambisols and Humic Cambisols. In Huay Bong, Cambisols at the highest elevations prevail because the uplift rates are causing a steeper relief, facilitating soil degradation. Soil formation is by far not as advanced as in Mae Sa Mai, therefore no Ferralic Cambisol was found. The Cambisols at these elevations were mainly classified as Humi Cambisols or Dystric Cambisols. In Bor Krai, the highest elevations are dominated by limestone outcrops forming mainly limestone towers. In between Acrisols prevail. Another important interdependency is the influence of the parental material on the geomorphology, which is related to relief and discharge. Granite seems to weather more easily than other rocks, mostly leading to 5 to 10m thick soils (Hansen 1991). Gneiss behaves similar to granite, but results in shallower soils. Consequently, landforms in the study areas dominated by granite and gneiss mostly show a smooth relief. Cliffs are rare and occur only in the vicinity of mountain tops, canyons, and waterfalls. Claystone, siltstone, and sandstone alter similarly to gneiss. Landforms dominated by these rocks are also characterised by smooth mountains, however, cliffs are quite rare. Breccia and conglomerates are more resistant, often going along with cliffs and steep slopes, where Leptosols and Regosols are dominant. In contrast, limestone leads to a unique karst relief with karst towers, depression, and sinkholes mostly lacking surface discharge. The soils here are characterised by the highest infiltration rates and highest aggregate stability.

The exceptional high infiltration rates might be a reason for the dominance of Acrisols at the highest elevations next to limestone outcrops. The existence of Umbrisols in karst depressions is also caused by the interaction of relief and parental rock material. Furthermore, parental material has a direct influence on human activities as these are mostly restricted to easily accessible land. Human activities themselves have a direct influence on vegetation. For example, the increase of human activities goes mostly along with a decrease of forests and an increase in soil erosion as well as an increase in air temperature (Maxwell 2004). However, if soil degradation exceeds a critical degree, the forest cover increases again as exploited fields will be abandoned (e.g. in Bor Krai). Weltner (1996) and Wetzel *et al.* (2002) described that intensive cultivation on lower slopes leads to profile truncation, lower organic matter contents, and reduced soil fertility compared to steeper slopes uphill, which are still covered with forest.

Additionally, the speed of soil and vegetation regeneration increases along with elevation, especially for sites above 1000m asl, which are more humid and less fire disturbed (Weltner 1996, Kubiniok 1999).

5.3 Evaluation of local soil knowledge

The elicitation of the local soil knowledge revealed that for all three study areas soil colour was the main differentiation criterion. The use of colour as the prime criterion is very common in local soil classifications (Ettema 1994; Talawar and Rhoades 1998). The comprehensive study on ethnopedology by Barrera-Bassols and Zinck (2003) concluded that all local soil classifications reviewed used colour as a parameter, because it is the most obvious and distinguishable for any kind of soil.

Further criteria were the A-horizon thickness as in Mae Sa Mai and Huay Bong; the texture and content of coarse fragments, as in Huay Bong; and the soil structure as in Bor Krai (Schuler *et al.* 2007). In most cases the value of local knowledge has been proven by own investigations (Table 4-18). The local soil map of Mae Sa Mai corresponds with the A-horizon thickness map. Contradictions were found in the perceptions of the water infiltration capacity and the erosion hazard. For Black Soils the villagers of Mae Sa Mai incorrectly assumed high water infiltration rates and a high erosion hazard, while for Red Soils the opposite was assumed. The explanation for this might be found in the high land use intensity at Black Soil locations and the low land use intensity at Red Soil locations, superimposing the infiltration rates. The low erosion hazard of the Grey Soil is mainly based on its position in the valley bottom, where very low infiltration rate is not a factor. For Huay Bong a good match between Black Soils and the Humic Cambisols along the valley floor was found. The field check of the stone-free Red Soil confirmed that this soil is free of coarse fragments and that it has indeed a distinct red colour. For the Huay Bong area, soils with a lack of coarse fragments are extraordinary. This gave a hint to the special petrography of this location, finally leading to the detection of the Tertiary coal, sandstone, and plant fossils. For this reason, the elicitation was indirectly very useful for elaborating the geological map. Furthermore, the elicitation of local knowledge in Huay Bong revealed that the present land use does not correspond with the perception of land suitability, because the boundary of the conservation forest was set by governmental decree. This discrepancy between political and local perception of useful land use planning clearly shows that it is advisable to involve local people in the process of decision making (Schuler *et al.* 2006). For Bor Krai, local knowledge could be used to confirm mapping and measurements.

High correspondence was found between the local soil map (Figure 4-28), the soil colour value map of 40 to 60cm depth (Figure 4-21), and the geological map (Figure 4-3). The main reason was the high impact of the parent rock material on soil colour. The perception of water infiltration rates could be confirmed in 4 of 5 cases. Local soil classification is not always consistent, which was also reported in other studies (e.g. Oudwater and Martin 2003). This explains the disparity between own results and findings by Tinóco-Ordónez (2003), who, also in Bor Krai, identified five major soil classes according to colour (black, red, yellow, yellow mottled, and grey) and six classes according texture. Villagers of Bor Krai and Huay Bong clearly revealed a high knowledge about the degree of crop suitability for certain local soil types. Researchers and extension service officers are well advised to elicitate local knowledge in advance before carrying out experiments or promoting crops. Often other elicitated properties (e.g. water infiltration, bulk density, soil structure, soil fertility) give hints for land use planning and can help to reduce usage of agrochemicals, amounts of irrigation water, and soil erosion. Local religion and beliefs have also to be taken into consideration for land use planning. Predictable for Bor Krai is that efforts to abolish upland rice cultivation or to introduce alley cropping systems will not be easily accepted by the villagers as upland rice cultivation has an important role in the Lahu culture, where also local customs forbid subdividing fields with trees.

5.4 Mapping approach evaluation

In order to find out the most appropriate method to map soils and soil properties at different scales in Northern Thailand, several mapping approaches have been carried out and subsequently compared (Table 5-1).

Intensive soil mapping for reference maps still delivers the best results, but also requires, by far, the highest density of sampling points. Due to the steepness and the partly impenetrable vegetation investigations along straight transect lines (Schlichting *et al.* 1995) are often not feasible. Soils were mostly investigated along local trails where necessary samples in between the local trail network were taken. Depending on the attention and the skills of the cartographer, minor soil types and local peculiarities might be detected with this approach. The discovery of the Ferralsol, Gleysol, Chernozem, latite, bauxite, and iron ore in Bor Krai was only possible using this intensive mapping approach.

Table 5-1: Properties of mapping approaches tested

Mapping approach	Scale optimum	Advantage	Disadvantage	Application
Intensive	watershed	accurate	time consuming, expensive, requires trained staff	all
Randomised	watershed	systematic	inaccurate, sampling points are often difficult to find/access	scientific
Interpolation	watershed	fast	requires many sampling points; extrapolation impossible	scientific, extension
ML	landform	fast, extrapolation possible	relies on various secondary information with excellent resolution	scientific, regional land use planning, extension
Local knowledge	village area	local impact	only of local importance	extension, participatory land use planning

The Tertiary sandstone and coal in Huay Bong (detection facilitated by local knowledge) as well as the marble and the freshwater limestone in Mae Sa Mai are hardly detectable using other mapping approaches. Even if the occurrences of these specialities are quite small-sized their significance for the present land use and environment should not be underestimated. At least the location of the Tertiary sandstone in Huay Bong is one of the most important production sites for maize in this area. The Chernozem occurrence in Bor Krai is also an important site for maize production. The karst water from the little marble body in the Mae Sa Mai area has significant influence on the water chemistry of Mae Sa Noi stream (Figure 5-1). An intensive mapping approach is best suited for mapping smaller watersheds. Especially for steep and inaccessible areas, an intensive mapping approach has the disadvantage of being exceedingly time-consuming and costly. The common concept mapping approach (Holland 1995) requires certain *ex-ante* knowledge of the soil distribution of the area. This was not available for this study, because all of North-western Thailand was mapped as “slope complex” (Vijarnsorn and Eswaran 2002). Other studies did not include many sandstone and limestone areas, while most granite areas were mapped or investigated (Weltner 1996, Kirsch 1998). These analyses were often not sufficient to carry out a classification according the WRB 1998 system. Finally, the information given produced valuable information about the potential soil variability, but was not sufficient to lead to any conclusive predictions.

The **randomised grid based (RGB) mapping approach** is an advancement of the randomised approach. During application of the original randomised mapping approach in a study in Southern Benin some regions were not sampled at all (Weller 2002).

In order to avoid this problem, a grid was laid over the map of the research area and filled with at least three random sampling points per grid cell. This approach shows several inherent difficulties. The main problem is the choice of the grid cell size. This presumes *ex-ante* knowledge of the soil variability. Further obstacles were detected during the field work. In the vicinity of limestone cliffs and under dense vegetation the GPS device received hardly any signals from the satellites. Together with an inaccurate map the locating of prefixed sampling points was almost impossible. Especially at inconvenient sites like in spiny fallow vegetation or on almost vertical limestone slopes, continuous movement, which is necessary for the GPS device to determine the direction, was so reduced that the GPS handheld often points into the wrong direction – resulting in an exhausting and futile struggle.
The concept of a randomised grid based mapping approach assures an objective mapping of the main soil types and properties. This method can be applied also in larger watersheds with moderately steep slopes. The prefixed sampling points avoid a biased investigation focusing on roads and easily accessible areas. This approach can be used for contract mapping, also if the hired cartographers' experience is in doubt. For mapping of pH (H_2O) the RGB approach produced good results, but the intensive mapping approach revealed even better results, but required 267 additional sampling points (Table 5-2). The RGB approach is inappropriate to locate specialities or to map remote or inaccessible areas.

The **interpolation** method is useful for the illustration of soil properties. There are several interpolation methods available like triangulation, kriging, and cokriging and regression kriging (Scholich 2005).
Due to the high variability of soil properties in Northern Thailand the application of these interpolation methods should be restricted to smaller watersheds or smaller areas. Using kriging the distance of the sampling points can be determined with variograms (Nielsen and Wendroth 2003). Often a high amount of sampling points is necessary to generate satisfactory maps. The interpolation of soil properties visualises the spatial distribution and helps to identify transport processes in the landscape and in the soil profile. Cokriging and regression kriging also allow the utilisation of secondary information (Simbahan *et al.* 2006). The importance of secondary information is reflected by the fact that its inaccuracy can worsen the result.

For the Bor Krai area interpolations of the pH values with kriging and cokriging were carried out. For the interpolation with cokriging additionally the elevation, slope, and curvature were included, but without achieving any remarkable improvements (Table 5-2). This can be explained by a lack of correlation for the pH value of the upper 20cm with elevation and slope and only a small negative correlation with the curvature (-0.122) for the range between 40 and 60cm and a small negative correlation with the curvature (-0.139) and elevation (-0.126) for the range between 80 and 100cm. All found correlations were significant at the 0.05 level (Spearman; 2-tailed).

Table 5-2: Validation of randomised grid based & intensive soil mapping approaches with 19 independent pH measurements for the Bor Krai area

Soil depth [cm]	**Error**			
	Cokriging		**Kriging**	
	RGB* (N=58)	**IM** (N=325)**	**RGB* (N=58)**	**IM** (N=325)**
0-20	0.18 +/- 0.49	0.13 +/- 0.60	0.18 +/- 0.43	0.14 +/- 0.59
40-60	0.15 +/- 0.68	0.12 +/- 0.49	0.17 +/- 0.53	0.12 +/- 0.47
80-100	-0.11 +/- 0.65	-0.08 +/-0.56	-0.10 +/- 0.56	-0.09 +/- 0.52

*RGB=randomised grid base mapping approach; **IM=intensive mapping approach

The **maximum likelihood (ML) method** is well known for the interpretation of satellite images. In North-eastern Thailand this method was successfully applied for soil salinity mapping and showed an accuracy of more than 83% (Katawatin and Kotrapat 2004). Digital concept soil mapping in Northern Germany produced an accuracy of 50% (Schmidt *et al.* 2007). The high correspondence to reference soil maps of Mae Sa Mai (58.3%), Huay Bong (61.1%), and Bor Krai (64.0%) has to be considered as a success. In order to assure an accurate calibration many investigation points were used. Their amount is similar to that for compiling a reference soil map, which is based on an intensive soil survey (Figures 9-1, 9-2 and 9-3). Subsequently, the effort for upscaling to larger areas is very small. The only conditions are the petrographic, geomorphologic, and climatic comparability of the original area (calibration area) with the target area. For instance, the upscaling of the soil map from the Mae Sa Mai area (10.5km^2) to the whole Mae Sa watershed (approx. 138km^2) required only 5 additional sampling points. The reliability of the soil map for the whole Mae Sa watershed was qualitatively proven by additional soil surveys in this area.

In conclusion, maximum likelihood requires a rather intensive soil mapping of a small area, but can deliver a reliable soil map for an area of at least 10 times in size of the original area (in the case of the Mae Sa watershed, the soil map obtained was 13 times larger than the intensively investigated Mae Sa Mai area). This method is the most efficient soil mapping approach among those tested for this study.

The application of the maximum likelihood approach for an upscaling to whole North-western Thailand seems to be not feasible using only the maximum likelihood approach. The combination of the SOTER approach (Van Engelen and Wen 1995) with the maximum likelihood method could be one solution to create a sound, but time and cost efficient soil map for whole North-western Thailand.

Using this combinatory approach the region has to be subdivided first into terrain units according to petrography and geomorphology. Mae Sa Mai would belong to a terrain unit dominated by granite and gneiss and morphology consisting of mountains, which are characterised by steep slopes and are dissected with V-shaped valleys. Huay Bong would belong to a terrain unit dominated by sandstone and a morphology of mountains, which are dissected by valleys. The Bor Krai area would belong to a terrain unit prevailed by limestone and a morphology of steep, often cone-shaped mountains consisting of mostly massive limestone with karst depressions in between.

The principles of soil distribution detected in this study can subsequently be used for the compilation of a ML concept soil map. Based on the expected soil variability calibration areas will be chosen under the condition that they cover the expected major soil types. Then mapping will be executed using local soil knowledge in order to reduce sampling points to a necessary minimum. Finally, based on the findings, ML soil mapping will be refined and validated.

The maximum likelihood method also relies strongly on secondary information, hence, the results correspond to the quality, availability, and resolution of this information. With continually increasing quality and resolution of satellite images and other secondary information the maximum likelihood method is gaining importance. To avoid artefacts the variation of secondary information should be linked to the variability of soils and their properties. Comparable to the intensive mapping approach the accuracy increases with the number of calibration zones.

Blending the maximum likelihood map with the probability map offers the possibility to illustrate areas, where at least two different soil types interlace. This case is found in Bor Krai, where Acrisols, limestone outcrops, and Leptosols show a high degree of interaction.

The information about cultivation antagonistic map units, like limestone outcrops and Leptosols occurring between the Acrisols, would be helpful for land use planning there.

As soon as their probability exceeds a certain threshold agricultural land use might be not efficient even if the main soil has quite favourable properties.

Local soil maps are mostly focused on the topsoil which is fundamental for land use planning by decision-making farmers (Barrera-Bassols *et al.* 2006). In contrast the WRB system is mainly based on chemical and physical properties invisible to the naked eye under strong consideration of the subsoil (Schuler *et al.* 2006). This often leads to a rather poor correlation between WRB-based soil maps and local soil maps as also reported by Payton *et al.* (2003) and Ali (2003). Productive synergies can be expected by combining the two different systems as suggested by WinklerPrins, (1999), Ali (2003) and Erkossa *et al.* (2004). Soil maps containing both systems are more relevant and easily understood by local farmers (Krasilnikov and Tabor 2003). It is to be expected that local soil-classification systems differ between regions and ethnic groups (Schuler *et al.* 2006). Despite this, local knowledge provides valuable information on essential sites and soils and can contribute to enhance the efficiency of other soil mapping approaches.

6 Conclusion and Outlook

6.1 General conclusions

The distribution of soils in North-western Thailand and soil properties follows certain patterns, which could be specified in the present study. A seasonal climate is responsible for clay illuviation as the main soil forming process, leading to a dominance of Acrisols and Luvisols. At a regional scale, the climate influences the degree of clay illuviation and the clay mineral formation. At watershed scale parent rock material, topography, and human activities are causes for the present soil associations and their properties.

North-western Thailand is still tectonically active and most areas are still underlying certain uplift, thus most soils are relatively young. Exceptions were described for stable plateaus having rather old soils (Kubiniok 1999).

6.2 Consequences for Upscaling

As mentioned above, the investigations allowed to derive general rules for soil distribution in mountainous North-western Thailand, which can be used for creating concept maps of larger areas (upscaling). These rules comprise:

1. Clay illuviation is the dominant soil forming process, mainly leading to Acrisols and Luvisols.
2. The degree of clay illuviation correlates positively with the ratio of evapotranspiration to rainfall for finely grained soils on rocks with low permeability. This leads to a dominance of Cambisols above a certain elevation for soils from granite and gneiss.
3. Soils originating from sandstone, breccia, and conglomerate lead to relatively coarser grained soils, with many coarse and medium sized pores and the best pronounced clay illuviation.
4. Soils originating from limestone lead to fine grained, well-drained soils, facilitating clay illuviation even at the highest elevations.
5. The CEC_{clay} concentration correlates negatively with the ratio of evapotranspiration to rainfall. Luvisols pass over to Acrisols at a certain elevation in dependence of the local climate and petrography. The distinctness of transition depends on the parent rock material. On limestone the transition from Luvisols to Acrisols is rather sharp, while on granite this transition seems to be more gradual.

6. The pH (H_2O) correlates with base saturation, however the transfer function depends highly on the parent rock material. In general, the pH (H_2O) decreases with soil depth.
7. Luvisols dominate in tectonically active areas with rather young landscapes on moderate slopes with a precipitation less than 1400mm a^{-1}.
8. Acrisols dominate in tectonically active areas with rather young landscapes on moderate slopes with a precipitation more than 1400 mm a^{-1}.
9. Three different types of Cambisols were detected. The first type occurs on steep slopes and is derived mainly from Acrisols and Luvisols by soil erosion. The second type is common on lower and concave slopes, depressions, and valleys controlled by colluvial deposits. The third type dominates the highest elevations with a precipitation of more than 2000mm a^{-1} on low permeable rocks (mainly granite and gneiss).
10. Ferralsols exist on stable plateaus, where the former soil formation is still preserved (Kubiniok 1999), or where the parental material has an exceptional composition like the bauxite and iron ores of Bor Krai. Relictic Ferralsols on stable plateaus gradually alter to Acrisols and Cambisols.
11. Anthrosols occur on paddy fields with clayey sediments, while on less clayey sediments Cambisols prevail.
12. Chernozems were found below calcareous springs and leaking water pipes with alkaline-rich water.
13. Fluvisols occur in the vicinity of streams mostly at locations with low uplift rates or upstream of a restriction, such as the narrowing of a valley, the entrance of a sinkhole, or a cave.
14. Gleysols mostly occur below springs either along streams or in sealed karst depressions.
15. Leptosols are found in the vicinity of limestone and marble outcrops.
16. Umbrisols were detected in karst depressions lacking an outlet.
17. Regosols occur on steep slopes, on clastic sediments, or in man-made landscapes.

6.3 Comparison of mapping approaches

The suitability of different mapping approaches depends mainly on the scale of the intended application.

At field and watershed scales an intensive mapping approach based on transect investigations, randomised points, and additional points for zones of high soil and petrographic variability produced the highest resolution and most accurate results. This approach is the most time consuming and most expensive. An alternatively applied randomised grid based mapping approach had quite good results, but is hardly suitable for mapping steep areas with dense vegetation cover, where it is almost impossible to find the exact location of the prefixed investigation points. Both mapping approaches deliver results, which can be easily used for further studies. The interpolation of data points is useful for the illustration of soil properties, but is only feasible, where sufficient data are available.

The cheapest and most rapid approach for soil mapping at a sub-watershed scale is offered by the elicitation of local soil knowledge. This study revealed that farmers have a profound knowledge about their soils, soil properties, and respective crop suitability. Local soil maps feature a high potential for land use planning. Local soil classification is restricted to village areas and cannot be easily transferred to the international soil classification systems.

At scales larger than a watershed the application of the above mentioned mapping approaches is hardly suitable, where the intensive mapping approach is too costly and time consuming. Due to the steepness and inaccessibility of vast areas in the highlands of Northern Thailand, the application of the randomised grid based mapping approach is hardly feasible. The interpolation of soil properties is presently not possible due to a low data point density. The application of local knowledge is also hardly practicable because the scale exceeds the village level. Furthermore, the above mentioned mapping approaches cannot be used for extrapolation. The investigated maximum likelihood approach offers a good opportunity for upscaling procedures. It is still questionable whether it can be applied to areas with high petrographic variability. It is advisable to combine it with the SOTER approach, in which North-western Thailand would be first subdivided in terrain units based on petrography and geomorphology under consideration of local climate gradients. The principles of soil distribution detected in this study can then be applied for the compilation of a maximum likelihood concept soil map. Based on the expected soil variability calibration areas have to be chosen under the condition that they cover the expected major soil types. Mapping can then be done using local soil knowledge in order to reduce sampling points to a necessary minimum.

Finally, based on the findings maximum likelihood soil mapping will be refined and validated.

7 Summary

7.1 Summary

Towards Regionalisation of Soils in Northern Thailand and Consequences for Mapping Approaches and Upscaling Procedures

The purpose of this study was to identify the key factors of soil formation and distribution in North-western Thailand in order to enable predictive mapping. Further objectives were to investigate different soil mapping approaches, regarding their suitability for specific areas and scales and to assess the potential of local (soil) knowledge for soil mapping and land use planning.

In order to cover the essential petrographic inventory of North-western Thailand three different petrographic areas were selected. The investigated topics were petrographic diversity, spatial organisation of soils and variability of their physical and chemical properties, as well as local soil knowledge of farmers in the respective areas. In addition thematic maps were generated comprising geology, WRB soil groups, and different soil properties.

Soil mapping was carried out by using four different methods, viz the intensive mapping approach, maximum likelihood method, randomised grid cell approach, as well as elicitation of local knowledge. The intensive mapping approach comprised transect investigations, investigation points of the randomised grid cell approach, and additional investigation points, which were selected for areas with increased soil and petrographic variability. All maps based on the intensive mapping approach contained the highest sampling point density and maximum amount of information. These maps were used as a reference for the other mapping approaches applied here.

The results revealed that the petrography of the Mae Sa Mai area comprises mainly Precambrian paragneiss with Triassic granite intrusions, while also Precambrian marble and Quaternary freshwater limestones were detected.

The Huay Bong area is dominated by Carboniferous sandstone, breccia, conglomerate, marl, and claystone. Additionally, Quaternary alluvial deposits and conglomerates were found. Plant fossils give evidence for the Tertiary age of sandstone and coal.

The Bor Krai area features mainly Permian limestone and claystone while latite, iron ore, bauxite, and freshwater limestone were also found.

For all three areas, the petrographic variability was higher as reported in previous studies and maps. The soil mapping revealed that the soils of the Mae Sa Mai area are dominated by Acrisols and Cambisols. Anthrosols, Chernozems, Gleysols, Leptosols and Regosols were also found.

Acrisols dominate moderate steep slopes below 1300m asl; while Cambisols prevail on steep and convex slopes and above 1300m asl. Anthrosols occur at some locations of former paddy rice cultivation. Chernozems were found below a karst spring on freshwater limestone. Gleysols were found below springs, mostly along the streams. Leptosols mostly occur in the vicinity of marble outcrops and on very steep slopes along the Mae Sa Noi stream canyon. Regosols were detected in the Botanical Garden and can be described as a result of man-made soil degradation.

In the Huay Bong area, Luvisols and Cambisols dominate. Further, Leptosols, Regosols, and Fluvisols were found. Luvisols are dominant on moderate slopes in the whole area. Cambisols prevail on steep and convex slopes as well as in the valley bottom. Leptosols and Regosols were found on very steep slopes and on crests.

In the Bor Krai area, Luvisols, Acrisols, and Cambisols prevail. Ferralsols, Fluvisols, Gleysols, Leptosols, and Umbrisols were also found. Luvisols are dominant on moderate slopes below 800m asl. Acrisols prevail on moderate steep slopes above 800m asl. Cambisols mostly occur on steep and convex slopes as well as on lower slopes and in karst depressions. Ferralsols were found below a bauxite and iron ore outcrop and most probably derived from translocated bauxite. Fluvisols occur along some streams and streambeds. Gleysols were found below springs in sealed karst depressions. Leptosols mostly occur in the vicinity of limestone outcrops. Umbrisols were recorded within karst depressions without outlets and with high colluvial deposition rates.

Luvisols, Acrisols, and Cambisols are the main soil types of North-western Thailand. Ferralsols are to be another important soil type, but their existence is more or less relictous and for this reason they are mainly restricted to old, stable plateaus. In contrast, all three areas investigated are still underlying a certain uplift and can be considered as rather young.

General rules were derived from the combination of own findings with the data of other authors. Basically, clay illuviation was identified as the main dominant soil forming process in the region. The amount of gibbsite and kaolinite increases with elevation, and corresponds to the decrease of CEC_{clay}. For this reason, with increasing elevation (and precipitation), Luvisols change to Acrisols. The degree of clay illuviation decreases with increasing precipitation, for finely grained soils on low permeable rocks (like granite and gneiss). Hence, above a certain elevation (and precipitation) an additional transition occurs at much higher elevations, where Acrisols change to Cambisols, because the degree of clay illuviation decreases below the threshold value. The elevation and distinctness of this transition zone also depends on the parent rock material.

The test of different soil mapping approaches, regarding their suitability for specific areas and scales and the assessment of the potential of indigenous (soil) knowledge, were further objectives.

The soil map, based on the randomised grid based approach for Bor Krai, revealed a correspondence of even 79.5% to the reference map.

The soil maps for all three areas based on the maximum likelihood approach also revealed high correspondences with the reference soil map. The accordance was 58.3% for Mae Sa Mai, 61.1% for Huay Bong, and 64.0% for Bor Krai.

The validation with 50 independent sampling points for the Bor Krai area showed matches of 54% for randomised grid based approach, 60% for maximum likelihood approach, and 58% to the reference soil map.

The investigation of local (soil) knowledge revealed the profound knowledge of farmers about soils, soil properties, and crop suitability. Local soil classification is mainly focused on topsoil and topsoil thickness. The main differentiation criterion of the farmers for all three areas was soil colour. Additional criteria were texture, content of coarse fragments, and structure. Local soil knowledge is not consistent (interregional or even in the same village), and hence hardly suitable for upscaling procedures.

The randomised grid based mapping approach produced maps with the highest correspondence with the reference soil map. This approach is not suited for mountainous regions of North-western Thailand, especially the locating of the pre-fixed investigation points in the field proved to be the main obstacle.

Maps created using the maximum likelihood method also showed high correspondences with the respective reference soil maps. This approach seems to have a high potential for upscaling procedures.

In conclusion, principles of soil type and property distribution were identified.

This facilitates the application of the concept mapping approach either for soil mapping or for testing alternative mapping approaches. The maximum likelihood approach has the highest potential for upscaling. Its suitability for an upscaling to all of North-western Thailand remains unproven. With respect to the influence of petrography on soil distribution it seems feasible to apply the maximum likelihood approach in combination with the SOTER concept. In this case, the maximum likelihood approach can be applied for soil mapping of the SOTER related terrain units. Intensive soil mapping of a small calibration area is required. To assure that the size of the calibration area is sufficient to cover the whole soil inventory of the respective terrain unit, a rapid conceptual mapping approach can be applied beforehand using the soil distribution rules established here. To increase efficiency, indigenous (soil) knowledge can facilitate soil mapping of the calibration area and of further training zones.

7.2 Zusammenfassung

Zur Regionalisierung der Böden von Nordthailand und ihre Auswirkung auf mögliche Kartieransätze und Upscaling Verfahren

Ziel dieser Arbeit war, die Grundprinzipien der Bodengenese und Bodenverteilung in Nordthailand zu erfassen, um damit eine Konzeptkartierung zu ermöglichen. Des Weiteren werden verschiedene Kartieransätze hinsichtlich Ihrer Eignung für verschiedene Skalen und Fragestellungen überprüft. Darüber hinaus wurde das Potential des lokalen Wissens hinsichtlich Bodenkartierung and Landnutzungsplanung untersucht.

Um die Petrographie von Nordwestthailand im Wesentlichen abzudecken, wurden drei petrographisch unterschiedliche Untersuchungsstandorte ausgewählt und in Bezug auf Petrographie, Bodeninventar, physikalischen und chemischen Eigenschaften untersucht. Zusätzlich wurde das lokale Bodenwissen der jeweilig ansässigen Bevölkerung erhoben. Außerdem wurden für jedes Gebiet zahlreiche thematische Karten erstellt. Diese stellen die räumliche Variabilität von Geologie, Bodentypen, einigen Bodeneigenschaften und auf lokalem Wissen basierenden Bodentypen dar. Die Bodenkartierung der auf WRB basierenden Bodenklassifikation wurde mit vier verschiedenen Ansätzen durchgeführt, deren Effizienz und Genauigkeit getestet werden sollten. Die intensive Bodenkartierung basiert auf Transektkartierung, gitterbasierter randomisierter Kartierung, sowie auf zusätzlichen Untersuchungspunkten für den Bereich erhöhter Variabilität von Böden und Ausgangsgestein. Alle auf der intensiven Bodenkartierung basierenden Karten zeichnen sich durch höchste Beprobungsdichte und maximalen Informationsgehalt aus. Daher wurden diese Karten als Referenz für die anderen Kartieransätze herangezogen.

Die Untersuchungen ergaben, dass das petrographische Inventar des Mae Sa Mai Gebiets von präkmabrischem Paragneis und triassischen Granitintrusionen dominiert wird. Zusätzlich wurde präkambrischer Marmor und rezenter Süsswasserkalk gefunden. Im Huay Bong Gebiet dominieren karbonischer Sandstein, Konglomerate, Brekzien, Tonstein und Mergel. Außerdem wurden pleistozäne Konglomerate, rezente Flussablagerungen, tertiäre Sandsteine und Kohle gefunden, deren Alter durch fossile Blattabdrücke spezifiziert werden konnte.

Im Bor Krai Gebiet kommt hauptsächlich permischer Kalksteinen und Tonstein vor. Des Weiteren wurde Latit, Eisenerz, Bauxit sowie rezenter Süsswasserkalk gefunden.

Die Variabilität der Petrographie aller drei Untersuchungsgebiete war deutlich höher als vorangegangene Studien und Kartierungen vermuten ließen.

Die Bodenkartierung ergab, dass die Böden von Mae Sa Mai im Wesentlichen Acrisole und Cambisole sind. Zusätzlich wurden Anthrosole, Chernozeme, Gleysole und Regosole gefunden. Die Acrisole dominieren auf gemäßigt steilen Hängen unterhalb von 1300m ü NN. Cambisole treten meistens auf steilen und konvexen Hängen, sowie oberhalb von 1300m ü NN auf. Anthrosole wurden im Bereich von ehemaligen Nassreisfeldern gefunden. Chernozeme treten unterhalb von Karstquellen auf Süsserwasserkalk auf, während Gleysole besonders häufig unterhalb von Quellen entlang der Fliessgewässer zu finden waren. Leptosole treten hauptsächlich im Bereich der Marmor-Aufschlüsse und auf extremen Steilhängen innerhalb der Felsschlucht des Mae Sa Noi Bachs auf. Sämtliche gefundenen Regosole lassen sich auf von Menschenhand verursachten Bodenabtrag zurückführen. Dies ist insbesondere im Bereich des botanischen Gartens der Fall.

Im Huay Bong Gebiet dominieren Luvisole und Cambisole. Des Weiteren treten Fluvisole, Leptosole und Regosole auf.

Luvisole überwiegen auf gemäßigt steilen Hängen innerhalb des gesamten Untersuchungsgebietes. Cambisole treten hauptsächlich auf steilen und konvexen Hängen, sowie im Bereich der Talauen auf. Kleinere Fluvisolvorkommen wurden entlang der Fliessgewässer gefunden. Leptosole und Regosole finden sich meist auf extremen Steilhängen und schmalen Bergrücken.

Im Bor Krai Gebiet kommen hauptsächlich Luvisole, Acrisole und Cambisole vor. Ferner wurden Ferralsole, Gleysole, Leptosole und Umbrisole gefunden. Dabei dominieren die Luvisole auf gemäßigt steilen Hängen unterhalb von 800m ü NN. Oberhalb von 800m ü NN gehen die Luvisole vollständig in Acrisole über. Cambisole treten vorwiegend auf steilen und konvexen Hängen auf. Des Weiteren finden sich Cambisole recht häufig in Unterhangposition sowie in Karstsenken. Ferralsole wurden unterhalb eines Bauxit- und Eisenerzaufschlusses gefunden. Es ist anzunehmen, dass diese aus Hangschutt bestehenden Böden aus Bauxit und Eisenerz hervorgegangen sind. Kleinere Gleysol-Vorkommen fanden sich unterhalb von Quellen innerhalb von versiegelten Karstsenken mit hohem Grundwasserstand. Leptosole treten hauptsächlich im Bereich der Kalksteinaufschlüsse auf. Kleinere Umbrisol-Vorkommen wurden in abflusslosen Karstsenken mit starker kolluvialer Bodenakkumulation gefunden.

Die Untersuchungen ergaben, dass Luvisole, Acrisole und Cambisole die Hauptbodentypen von Nordwestthailand sind. Ferralsole scheinen ein weiterer wichtiger Bodentyp zu sein. Allerdings sind diese meist nur reliktisch und somit im Wesentlichen auf stabile Landflächen beschränkt. Im Gegensatz dazu unterliegen die 3 Untersuchungsgebiete einer gewissen Hebung und können von daher als eher jung angesehen werden.

In Kombination mit den Daten anderer Untersuchungen lassen sich grundlegende Prinzipen der Bodenvariabilität ableiten.

Grundsätzlich kann die Tonverlagerung als der dominierende bodenbildende Prozess im Bergland von Nordwestthailand angesehen werden. Der Gibbsitanteil und Kaolinitanteil der Tonfraktion nimmt mit zunehmendem Niederschlag zu. Folglich nimmt mit zunehmender Meereshöhe die Kationenaustauschkapazität des Tons derart ab, dass es zu einem Übergang von Luvisolen zu Acrisolen kommt. Bei feinkörnigen Böden aus schlecht wasserdurchlässigem Ausganggestein nimmt zudem der Grad der Tonverlagerung mit zunehmendem Niederschlag und damit verbunden mit zunehmender Höhe ab, so dass es ab einer bestimmten Niederschlagesmenge zu einem weiteren Übergang von Acrisolsen zu Cambisolen kommt. Dabei hängen diese beiden Übergänge nicht allein von der Niederschlagsmenge ab. Das Ausgangsmaterial hat zumindest einen sekundären Einfluss auf die Meereshöhe der Übergänge und deren Schärfe.

Eine weitere Zielsetzung dieser Arbeit lag in der Erprobung verschiedener Kartieransätze hinsichtlich ihrer Eignung für verschiedene Skalen und Fragestellungen.

Die auf gitterbasierter Randomisation beruhende Bodenkartierung von Bor Krai lieferte eine Übereinstimmung mit der Referenzbodenkarte von 79,5%.

Die auf der Maximum likelihood Methode basierenden Bodenkartierungen zeigten ebenfalls hohe Übereinstimmungen mit der Referenzbodenkarte. Für Mae Sa Mai betrug die Übereinstimmung 58,3%, für Huay Bong 61,1% und für Bor Krai 64,0%. Die Validierung mit 50 unabhängigen Probenpunkten aus dem Bor Krai Gebiet lieferte für die Referenzbodenkarte eine Trefferquote von 58%, für die auf gitterbasierter Randomisation basierende Bodenkarte 54% und für die auf der Maximum likelihood beruhenden Bodenkarte 60%.

Die Untersuchung des lokalen Wissens ergab, dass die Landwirte aller drei Gebiete über ein tiefgründiges Bodenwissen verfügen.

Dieses Bodenwissen umfasste in den meisten Fällen die Wesentlichen Bodeneigenschaften, sowie deren landwirtschaftliche Anbaueignung. Daher konnte für jedes Gebiet eine lokale Bodenklassifizierung und Kartierung durchgeführt werden. In allen drei Gebieten orientiert sich die lokale Bodenklassifikation am Oberboden und der Oberbodenmächtigkeit. Das wesentliche Unterscheidungskriterium der Bauern in allen Gebieten war die Bodenfarbe. Zusätzlich benutzten sie Bodenart, Steingehalt und das Bodengefüge. Dieses lokale Bodenwissen ist jedoch nicht konsistent (überregional oder sogar innerhalb desselben Dorfes), und von daher für Upscaling kaum geeignet.

Die auf gitterbasierter Randomisation basierende Bodenkarte wies die höchste Übereinstimmung mit der Referenzbodenkarte auf.

Allerdings erwies sich dieser Ansatz als ungeeignet für das Bergland von Nordthailand. Insbesondere das exakte Auffinden der im Voraus festgelegten Punkte erwies sich als das Hauptproblem. Die auf der der Maximum likelihood Methode basierenden Bodenkarten wiesen hohe Überstimmungen mit den jeweiligen Referenzkarten auf. Des Weiteren zeigte dieser Ansatz das höchste Upscalingspotential.

Zusammenfassend ist festzuhalten, dass die Grundprinzipien der Bodenverteilung und derer Eigenschaften erfolgreich erfasst wurden. Damit wird die Anwendung des Konzeptkartenansatzes als auch die Erprobung alternativer Kartieransätze möglich. Dabei zeigt der Maximum likelihood Ansatz das höchste Potential für Upscaling. Trotzdem konnte dessen Anwendbarkeit auf ganz Nordthailand nicht bewiesen werden. Hinsichtlich des Einflusses der Petrographie auf die Bodenverteilung erscheint eine Kombination von Maximum likelihood Ansatz mit dem SOTER Ansatz durchführbar. In diesem Fall würde die Maximum likelihood Methode zur bodenkundlichen Kartierung der Terrain units des SOTER Konzepts verwandt werden.

Dafür ist die intensive Kartierung eines Kalibrationsgebietes notwendig. Zur Gewährleistung, dass dieses Kalibrationsgebiet auch das gesamte Bodeninventar der entsprechenden Terrain unit abdeckt, kann eine grobe Konzeptkartierung basierend auf den hier gewonnen Erkenntnissen der Bodenverteilung durchgeführt werden. Ferner kann lokales Bodenwissen zur Effizienzsteigerung des Kalibrationsgebietes und weiterer Trainingsgebiete eingesetzt werden.

7.3 บทคัดย่อ

การทำแผนที่ดินในภาคเหนือของประเทศไทยเพื่อกระบวนการขยายขนาดและผลที่เกิดขึ้นจากแนวทางการทำแผนที่

วัตถุประสงค์ของการศึกษานี้เพื่อระบุปัจจัยหลักของการเกิดดินและการกระจายของดินในพื้นที่ทางตะวันตกเฉียงเหนือของประเทศไทยเพื่อการทำ predictive mapping นอกจากนี้ยังมีวัตถุประสงค์เพื่อศึกษาแนวทางการทำแผนที่ดินต่าง ๆ โดยคำนึงถึงความเหมาะสมของพื้นที่และขนาดที่เฉพาะเจาะจง และเพื่อประเมินศักยภาพของความรู้ท้องถิ่น(ดิน) ในการทำแผนที่ดินและการวางแผนการใช้ประโยชน์ที่ดิน

ในการที่จะครอบคลุมถึงระบบการจำแนกสัณฐานดินในพื้นที่ทางตะวันตกเฉียงเหนือของประเทศไทยนั้น ได้มีการเลือกพื้นที่ที่มีลักษณะดินแตกต่างกันใน 3 พื้นที่ด้วยกัน โดยศึกษาในหัวข้อ ความหลากหลายของชนิดดินและหิน การจัดการดินในแง่ของพื้นที่รวมถึงความแตกต่างของคุณสมบัติทางกายภาพและทางเคมี เช่นเดียวกับ ความรู้ท้องถิ่นเรื่องดินของเกษตรกรในพื้นที่ดังกล่าว นอกจากนี้ได้มีการจัดทำแผนที่ thematic โดยรวบรวมข้อมูลทางด้านธรณีวิทยา กลุ่มดินของฐานอ้างทรัพยากรดินของโลก) WRB) และคุณสมบัติต่าง ๆ ของดิน

ในการทำแผนที่ดินนั้น ได้ดำเนินการโดยใช้แนวทาง 4 แบบ ด้วยกัน คือ intensive mapping approach, maximum likelihood method, randomized grid cell approach รวมถึงการดึงเอาความรู้ท้องถิ่นมาร่วมด้วย โดย intensive mapping approach นั้น ประกอบไปด้วยการศึกษาในเรื่องของภาคตัดขวาง จุดศึกษาของ randomized grid cell approach และ จุดศึกษาอื่น ๆ เพิ่มเติม ซึ่งถูกเลือกจากพื้นที่ที่มีการเพิ่มขึ้นของความแตกต่างของดินและรูปสัณฐานหิน แผนที่ทั้งหมดอาศัยพื้นฐานของ intensive mapping approach ซึ่งประกอบไปด้วยบริเวณที่มีความหนาแน่นของจุดตัวอย่างสูงสุดและมีปริมาณข้อมูลสูงสุด ดังนั้นแผนที่เหล่านี้จึงถูกนำมาใช้อ้างอิงสำหรับแนวทางการทำแผนที่แบบอื่น ๆ ที่ประยุกต์ใช้ในการศึกษานี้

การศึกษาด้านธรณีวิทยาแสดงให้เห็นว่าพื้นที่แม่สาใหม่นั้นโดยหลักแล้วประกอบไปด้วยพาราไนส์อายุพรีแคมเบียน) Precambrian paragneiss) ที่ถูกแทรกซอนด้วยหินแกรนิตอายุไทรแอสซิก) Triassic granite) นอกจากนี้ ยังพบหินอ่อนอายุพรีแคมเบียน) Precambrian marble) และ หินปูนน้ำจืดยุคควอเทอร์นารี) Quaternary freshwater limestone) อีกด้วย

พื้นที่ห้วยบงส่วนใหญ่ประกอบไปด้วยหินทรายคาร์บอนนิเฟอรัส) Carboniferous sandstone), หินกรวดเหลี่ยม (Breccia), หินกรวดมน) Conglomerate), หินมาร์ล (Marl) และ หินเคลย์ (Claystone) นอกจากนี้ยังพบการสะสมของตะกอนลำน้ำอายุควอเทอร์นารี)Quaternary alluvial) และ หินกรวดมน) Conglomerate) ฟอสซิลพืชที่พบนั้นแสดงให้เห็นว่ามี หินทรายยุค Tertiary และ ถ่านหิน รวมอยู่ด้วย

พื้นที่บ่อไคร้ประกอบไปด้วยหินปูนยุคเพอร์เมียน) Permian limestone) และ หินเคลย์ (Claystone) เป็นหลัก นอกจากนี้ยังพบ Latite, แร่เหล็ก, Bauxite และ หินปูนน้ำจืด

ในพื้นทีทั้งสามนั้นพบว่ามีความหลากหลายทางด้านชนิดของดินและหินสูงกว่าที่พบในรายงานจากการศึกษาและแผนที่ก่อน ๆ

แผนที่ดินแสดงให้เห็นว่าพื้นที่แม่สาใหม่ได้รับอิทธิพลจาก Acrisols และ Cambisols โดยนอกจากนี้ ยังมีการพบ Anthrosols, Chernozems, Gleysols, Leptosols และ Regosols อีกด้วย Acrisols นั้น มีอิทธิพลอย่างมากในพื้นที่มีความลาดชันปานกลางต่ำกว่า 1300 เมตรจากระดับน้ำทะเล ส่วน Cambisols นั้นกระจายอยู่บนพื้นที่มีความลาดชันและโค้งนูนที่ระดับความสูงกว่า 1300 เมตรขึ้นไป Anthrosols นั้น พบในบางพื้นที่ที่เคยเป็นพื้นที่ปลูกข้าวมาก่อน

Chernozems พบในพื้นที่ที่ต่ำกว่าตาน้ำบนหินปูนน้ำจืด Gleysols พบในบริเวณที่ต่ำกว่าตาน้ำ โดยพบตามลำห้วยเกือบทั้งหมด Leptosols ส่วนมากพบตามบริเวณใกล้เคียงส่วนที่เป็น marble outcrops และ บนพื้นที่มีความลาดชันมากตามหุบเขาในลำห้วยแม่สาน้อย Regosols พบในพื้นที่สวนพฤกษศาสตร์และสามารถนำมาใช้อธิบายถึงผลของการพังทลายของดินที่เกิดจากมนุษย์

ในพื้นที่ห้วยบง พบ Luvisols และ Cambisols มากในพื้นที่นี้ นอกจากนี้ยังพบ Leptosols, Regosols และ Fluvisols ในส่วนของ Luvisols นั้นพบมากในบริเวณที่มีความลาดชันปานกลางของพื้นที่ทั้งหมด Cambisols พบมากในพื้นที่มีความลาดชันและโค้งนูน และในบริเวณด้านล่างของหุบเขา Leptosols และ Regosols พบในพื้นที่ที่มีความลาดชันสูงและบนยอดเขา

พื้นที่บ่อไคร้ ได้รับอิทธิพลจาก Luvisols, Acrisols และ Cambisols นอกจากนี้ ยังพบ Ferralsols, Fluvisols, Gleysols, Leptosols และ Umbrisols ในส่วนของ Luvisols นั้น พบมากในพื้นที่ที่มีความลาดเอียงปานกลาง ต่ำกว่า 800 เมตร จากระดับน้ำทะเล ส่วน Acrisols พบได้ทั่วไปในพื้นที่ลาดเอียงปานกลาง สูงกว่า 800 เมตร จากระดับน้ำทะเล Cambisols ส่วนมาก พบในพื้นที่ลาดชันและโค้งนูนเช่นเดียวกับตำแหน่งที่อยู่ด้านล่างของพื้นลาดชันและในพื้นที่ที่มีการยุบตัวของหินปูน ด้าน Ferralsols พบในจุดที่ต่ำกว่า Bauxite และจุดที่สังเกตุเห็นแร่เหล็กได้) Iron ore outcrop) และส่วนมากน่าจะพัฒนามาจาก Bauxite ที่มีการเคลื่อนตัว Fluvisols พบตามลำห้วยและท้องร่อง Gleysols พบในจุดที่ต่ำกว่าตาน้ำในบริเวณที่มีการยุบตัวของหินปูนแบบปิด) sealed karst depressions) Leptosols นั้นโดยปกติพบในบริเวณใกล้เคียงกับพื้นที่ที่เป็น Limestone outcrops ส่วน Umbrisols มีการตรวจพบในบริเวณที่มีการยุบตัวของหินปูน โดยไม่พบร่องน้ำและมีอัตราการเกิดดินตะกอนสูง

การศึกษาได้แสดงให้เห็นว่าดินหลักในพื้นที่ คือ Luvisols, Acrisols และ Cambisols ผลการศึกษานี้สอดคล้องอย่างมากกับผลการศึกษาจากผู้เขียนท่านอื่น ๆ) e.g. Yemefack 1995, Weltner 1996 และ Kirsch 1998) นอกจากนี้ Ferralsols ยังเป็นดินอีกชนิดหนึ่งที่มีความสำคัญ (Kubiniok 1999) อย่างไรก็ตาม ส่วนที่พบนั้นไม่มากก็น้อยเป็นเพียงส่วนที่เหลืออยู่และด้วยเหตุผลนี้จึงพบอยู่ในพื้นที่จำกัดบริเวณที่ราบสูงที่คงที่แล้ว ในทางกลับกัน พื้นที่ศึกษาทั้งสามแห่งยังได้แสดงให้เห็นถึงการยกตัวที่ชัดเจนซึ่งสามารถนำมาพิจารณาได้ว่ายังมีอายุค่อนข้างน้อย

จากการรวบรวมผลการศึกษาของตนเองร่วมกับข้อมูลของผู้เขียนท่านอื่น) e.g. Yemefack 1995, Weltner 1996 และ Kirsch 1998) ทำให้ได้กฎสามัญขึ้นมา โดยพื้นฐานแล้วสามารถระบุได้ว่า Clay illuviation เป็นกระบวนการที่ส่งอิทธิพลหลักต่อการเกิดดินในภูมิภาค นอกจากนี้ การแลกเปลี่ยนระหว่าง Gibbsite และ Kaolinite นั้นเพิ่มขึ้นตามระดับความสูง โดยมีส่วนเกี่ยวข้องกับการลดลงของ CEC_{clay} ด้วยเหตุผลนี้ โดยการเพิ่มขึ้นของระดับความสูง (และ ปริมาณน้ำฝน) Luvisols จึงเปลี่ยนรูปเป็น Acrisols สำหรับดินเนื้อละเอียดที่พบบนหินที่มีอัตราการซึมผ่านต่ำ) เช่น หินแกรไนต์ และ หินไนส์) ระดับของ Clay illuviation จะลดลงเมื่อปริมาณน้ำฝนเพิ่มขึ้น ดังนั้น ณ จุดที่ระดับความสูง (และ ปริมาณน้ำฝน) มากกว่า จะเกิดการเปลี่ยนรูปเพิ่มเติม โดย Acrisols เปลี่ยนเป็น Cambisols เนื่องจากระดับของ Clay illuviation ลดลงต่ำกว่าค่าวิกฤติ ซึ่งระดับความสูงและความคงที่ของ transition zone นี้ ยังขึ้นอยู่กับหินที่เป็นวัตถุต้นกำเนิดอีกด้วย การศึกษาแผนที่ดินแนวทางต่าง ๆ กัน โดยคำนึงถึงความเหมาะสมของพื้นที่ที่จำเพาะเจาะจงและขนาดและการประเมินศักยภาพของความรู้ท้องถิ่น) ดิน) จึงเป็นวัตถุประสงค์ลำดับต่อไป

แผนที่ดินที่อาศัยแนวทางแบบ randomized grid based ของบ่อไคร้ แสดงให้เห็นถึงความสอดคล้องกับแผนที่อ้างอิงถึง 79.5%

แผนที่ดินซึ่งอาศัยพื้นฐานของแนวทางแบบ maximum livelihood แสดงให้เห็นว่าพื้นที่ทั้งสามแห่งนั้นมีความสอดคล้องกันอย่างสูงกับแผนที่อ้างอิง โดยคิดเป็น 58.3% ในหมู่บ้านแม่สาใหม่, 61.1% ในบ้านห้วยบง และ%64.0 สำหรับบ้านบ่อไคร้

การตรวจสอบความถูกต้องของข้อมูลโดยใช้ การสุ่มตัวอย่างแบบอิสระ 50 จุด จากบ้านบ่อไคร้ แสดงความสัมพันธ์ 54% กับ แนวทางแบบ randomized grid based 60% สำหรับแนวทางแบบ maximum likelihood และ%58 สำหรับแผนที่ดินที่ใช้อ้างอิง

การศึกษาความรู้ท้องถิ่น (ดิน) แสดงให้เห็นถึงความรู้ลึกซึ้งของเกษตรกรเกี่ยวกับเรื่องดิน คุณสมบัติของดิน และ ความเหมาะสมของพืชปลูก การจำแนกดินแบบท้องถิ่นนั้นเน้นไปที่ผิวดินและความหนาของผิวดินเป็นหลัก โดยเกษตรกรในทั้งสามพื้นที่ต่างใช้สีของดินเป็นเกณฑ์หลักในการจำแนก และ มีปัจจัยเสริม ในเรื่องของ เนื้อดิน องค์ประกอบหยาบของส่วนที่แตกหักและโครงสร้าง เพื่อช่วยในการจำแนก

แนวทางแบบ randomized grid based mapping แสดงให้เห็นว่าเป็นการทำแผนที่ที่มีความสอดคล้องสูงสุดกับแผนที่ดินที่ใช้อ้างอิง แต่อย่างไรก็ตามแนวทางนี้ไม่เหมาะสมต่อพื้นที่สูงทางตะวันตกเฉียงเหนือของประเทศไทย โดยเฉพาะอย่างยิ่งในกรณีที่พิสูจน์แล้วว่าพื้นที่ที่จุดศึกษาที่กำหนดไว้ก่อนหน้านั้นเป็นอุปสรรค

แผนที่ซึ่งเขียนขึ้นโดย maximum likelihood method นั้นแสดงให้เห็นถึงความสอดคล้องอย่างสูงเมื่อเปรียบเทียบกับแผนที่ดินที่ใช้อ้างอิงเช่นกัน ซึ่งแนวทางนี้ดูเหมือนว่าจะเป็นแนวทางที่มี ศักยภาพสูงที่จะนำมาใช้ในกระบวนการขยายขนาด

การดึงเอาความรู้ท้องถิ่นเรื่องดินแสดงให้เห็นถึงความรู้เรื่องดินที่ลึกซึ้งของเกษตรกร อย่างไรก็ตามความรู้ท้องถิ่นยังขาดความสม่ำเสมอ) ระหว่างพื้นที่หรือแม้แต่ในหมู่บ้านเดียวกัน) และ ดังนั้นจึงมีความเหมาะสมน้อยที่จะนำมาใช้ในกระบวนการขยายขนาด

โดยสรุปแล้ว งานวิจัยชิ้นนี้ได้ระบุหลักการกระจายชนิดและคุณสมบัติของดิน ซึ่งความรู้ในส่วนนี้มีส่วนช่วยในการนำหลักการของแนวทางการทำแผนที่ไปประยุกต์ใช้ทั้งในด้านการทำแผนที่ดินหรือเพื่อทดสอบทางเลือกอื่น ๆ สำหรับการทำแผนที่ โดยแนวทางแบบ maximum likelihood นั้น พบว่ามีศักยภาพสูงสุดในการขยายขนาด อย่างไรก็ตามแนวทางนี้ยังไม่ได้รับการยืนยันในแง่ของความเหมาะสมในการใช้ขยายขนาดพื้นที่ทั้งหมดทางตะวันตกเฉียงเหนือของประเทศไทย ซึ่งเมื่อคำนึงถึงอิทธิพลของรูป สัณฐาน หิน และการกระจายของดินแล้ว ดูเหมือนว่าเป็นไปได้ที่จะนำแนวทางแบบ maximum likelihood มาประยุกต์ใช้ร่วมกับหลักการ SOTER ซึ่งในกรณีนี้ maximum likelihood สามารถนำไปใช้ร่วมกับแผนที่ดินจาก SOTER ในส่วนที่มีภูมิประเทศ) terrain unit) สัมพันธ์กัน ทั้งนี้จึงต้องการ intensive soil mapping ของพื้นที่ขนาดเล็กเพื่อใช้เป็นมาตรฐาน โดยในการที่จะรับรองว่าขนาดของพื้นที่ที่ใช้เป็นมาตรฐานนั้นเพียงพอที่จะครอบคลุมดินทุกชนิดตามรายการทั้งหมดภายใต้ terrain unit นั้นได้ สามารถนำแนวทาง rapid conceptual mapping มาประยุกต์ใช้ร่วมกับกฎการกระจายตัวของดินที่เขียนขึ้นในงานวิจัยชิ้นนี้ และเพื่อเพิ่มประสิทธิภาพ สามารถนำ ความรู้ท้องถิ่น (ดิน) มาใช้ประกอบในการทำแผนที่ดินของพื้นที่ที่ใช้เป็นมาตรฐานและทำบริเวณตัวอย่างศึกษาเพิ่มเติม

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9.3 Description of reference soil profiles

9.3.1 Profile 501 Humi-Ferralic Cambisol – Mae Sa Mai*

Classification: Humi-Ferralic Cambisol
Date of examination: 29.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 51 55; E98 51 39
Parent rock: granite
Geology: Palaeozoic
Physiographic position: on linear slope (approx. 25°)
Vegetation: evergreen trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-16	Brownish black (7.5 YR 3/2); clay; moderate very fine and fine granular structure; very friable moist, slightly sticky and slightly plastic; common fine, many very fine vesicular and common fine, many very fine irregular pores; few coarse, common medium, many very fine and fine roots; abrupt and smooth boundary to BA.
BA	16-35	Dark reddish brown (5 YR 3/4); clay; moderate very fine and fine subangular blocky structure; friable moist, slightly sticky and slightly plastic; common fine, many very fine irregular pores; few fine, medium and very coarse, common very fine roots; abrupt and smooth boundary to Bw1.
Bw1	35-59	Reddish brown (5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist; sticky and plastic; clay films on faces of voids; common fine, many very fine vesicular and common fine, many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw2.
Bw2	59-79	Reddish brown (5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine, many very fine vesicular and few fine, many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw3.

Horizon	Depth [cm]	Description
Bw3	79-103	Reddish brown (5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many very fine vesicular and many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw4.
Bw4	103-133	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw5.
Bw5	133-162	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine and fine roots; few angular quartz gravel (0.5 – 1.5cm); clear and smooth boundary to Bw6.
Bw6	162-187	Reddish brown (2.5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many very fine irregular pores; few very fine and fine roots; few angular gravel (4.0cm) of strongly weathered granite; clear and smooth boundary to Bw7.
Bw7	187-200	Reddish brown (2.5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many very fine irregular pores; few very fine roots.

*Slightly modified according to Manajuti et al. (2004).

9.3.2 Profile 502 Humi-Ferralic Cambisol – Mae Sa Mai*

Classification: Humi-Ferralic Cambisol
Date of examination: 22.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 52 13; E98 52 05
Parent rock: granite
Geology: Palaeozoic
Physiographic position: on convex slope near ridge (approx. 27°)
Vegetation: pine trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-8	Dark reddish brown (5 YR 2.5/2); clay; moderate very fine and fine granular structure; very friable moist, slightly sticky and slightly plastic; common fine and many very fine irregular pores; common fine and many very fine roots; abrupt and smooth boundary to AB.
AB	8-20	Dark reddish brown (5 YR 3/4); clay; moderate very fine and fine granular and moderate fine subangular blocky structure; friable moist, sticky and plastic; few medium , common fine and many very fine irregular pores; few very coarse, common very fine and fine roots; abrupt and wavy boundary to Bw1.
Bw1	20-48	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; few fine and medium, many very fine irregular pores; few very fine, fine and very coarse roots; clear and smooth boundary to Bw2.
Bw2	48-66	Reddish brown (2.5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few medium vesicular and few fine roots; few angular quartz gravel (0.2 – 1.5cm); abrupt and smooth boundary to Bw3.

Horizon	Depth [cm]	Description
Bw3	66-83	Reddish brown (2.5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine and fine roots; common angular gravel (0.2 – 2.0cm) of strongly weathered granite, common angular quartz gravel (0.2 – 2.0cm); clear and smooth boundary to Bw4.
Bw4	83-109	Bright reddish brown (2.5 YR 5/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few medium vesicular and few fine, many very fine irregular pores; few very fine and fine roots; many angular gravel (0.2 – 3.0cm); clear and smooth boundary to Bw5.
Bw5	109-130	Bright reddish brown (2.5 YR 5/8); clay; moderate very fine and fine subangular blocky structure; friable moist; sticky and plastic; clay films on faces of voids and peds; many very fine irregular pores; few very fine and fine roots; many angular gravel (0.2 – 3.0cm) of strongly weathered granite, many angular quartz and many muscovite (0.2 – 3.0cm); clear and smooth boundary to Bw6.
Bw6	130-149	Bright reddish brown (2.5 YR 5/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few fine roots; common angular gravel (0.2 – 3.0 cm) of strongly weathered granite, common angular quartz and muscovite (0.2 – 3.0cm); clear and smooth boundary to BC1.
BC1	149-170	Orange (5 YR 6/8); loam; moderate very fine, fine and medium subangular blocky structure; friable moist, sticky and plastic; few fine roots; few angular gravel (0.2 – 0.5 cm) of strongly weathered granite, few angular quartz (0.2 – 0.5cm); clear and smooth boundary to BC2.
BC2	170-200	Orange (5 YR 6/8); loam; moderate very fine, fine and medium subangular blocky structure; friable moist; sticky and plastic; few fine and many very fine irregular pores; few fine roots.

*Slightly modified according to Manajuti et al. (2004).

9.3.3 Profile 503 Humi-Ferralic Cambisol – Mae Sa Mai*

Classification: Humi-Ferralic Cambisol
Date of examination: 29.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 52 13; E98 51 02
Parent rock: paragneiss with marble
Geology: Precambrian
Physiographic position: on linear slope (approx. 37°)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah1	0-13	Dark reddish brown (5 YR 2.5/2); sandy clay loam; moderate very fine, fine and medium granular structure; very friable moist, slightly sticky and slightly plastic; few fine and many very fine irregular pores; common fine and many very fine roots; clear and smooth boundary to Ah2.
Ah2	13-28	Dark reddish brown (5 YR 2.5/2); sandy clay loam; moderate very fine granular and moderate very fine, fine subangular blocky structure; very friable moist, slightly sticky and slightly plastic; few fine and many very fine irregular pores; few fine and many very fine roots; clear and smooth boundary to AB.
AB	28-42	Dark reddish brown (5 YR 2.5/2); sandy clay loam; moderate very fine and fine subangular blocky structure; friable moist, slightly sticky and slightly plastic; few fine and many very fine irregular pores; few fine and common very fine roots; abrupt and smooth boundary to Bw1.
Bw1	42-68	Dark reddish brown (5 YR 3/4); sandy clay loam; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; few fine and many very fine irregular pores; few fine and common very fine roots; few angular gravel (0.5 - 4.0cm) of strongly weathered paragneiss, few angular marble gravel (2.0 – 6.0cm); abrupt and smooth boundary to Bw2.

Horizon	Depth [cm]	Description
Bw2	68-97	Brown (7.5 YR 4/4); sandy clay loam; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; many very fine irregular pores; few fine and common very fine roots; common angular gravel (0.2 – 6.0cm) of strongly weathered gneiss; abrupt and smooth boundary to Bw3.
Bw3	97-120	Brown (7.5 YR 4/4); sandy loam; moderate very fine and fine subangular blocky structure; friable moist; slightly sticky and slightly plastic; many very fine irregular pores; few fine and common very fine roots; clear and smooth boundary to Bw4.
Bw4	120-145	Brown (7.5 YR 4/4); with dark yellowish brown (10 YR 4/4); sandy loam; moderate very fine subangular blocky and moderate very fine, fine angular blocky structure; very friable moist, non sticky and non plastic; many very fine irregular pores; few fine and common very fine roots; clear and smooth boundary to BC1.
BC1	145-176	Brown (7.5 YR 4/4) with yellowish brown (10 YR 5/4); sandy loam; weak very fine and fine angular blocky structure; very friable moist, non sticky and non plastic; many very fine irregular pores; few fine and very fine roots; clear and smooth boundary to BC2.
BC2	176-200	Brown (7.5 YR 4/4) with yellowish brown (10 YR 5/4); sandy loam; weak very fine and fine angular blocky structure; very friable moist, non sticky and non plastic; many very fine irregular pores; few fine and very fine roots.

*Slightly modified according to Manajuti et al. (2004).

9.3.4 Profile 504 Profondi-Humic Acrisol – Mae Sa Mai*

Classification: Profondi-Humic Acrisol
Date of examination: 28.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 53 10; E98 53 10
Parent rock: paragneiss
Geology: Precambrian
Physiographic position: on linear slope (approx. 28°)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-10	Brownish black (7.5 YR 3/2); sandy clay loam; moderate very fine granular structure; very friable moist, slightly sticky and slightly plastic; common fine vesicular and few medium, many very fine irregular pores; few medium, many very fine and fine roots; abrupt and smooth boundary to AB.
AB	10-23	Reddish brown (5 YR 4/6); sandy clay loam; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; common fine and many very fine irregular pores; few coarse, common medium, many very fine and fine roots; abrupt and smooth boundary to Bt1.
Bt1	23-42	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine vesicular and many very fine irregular pores; few medium and coarse, common fine, many very fine roots; few angular gravel (1.0 – 1.5 cm) of strongly weathered paragneiss; gradual and smooth boundary to Bt2.
Bt2	42-67	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few coarse, common fine and medium, many very fine roots; few angular gravel (2.0 – 4.0cm) of strongly weathered paragneiss; gradual and smooth boundary to Bt3.

Horizon	Depth [cm]	Description
Bt3	67-109	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and medium vesicular and many very fine irregular pores; few coarse and medium, common fine, many very fine roots; clear and smooth boundary to Bt4.
Bt4	109-131	Reddish brown (2.5 YR 4/8); clay; moderate very fine, fine and medium subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine vesicular and many very fine irregular pores; few fine and common very fine roots; gradual and smooth boundary to Bt5.
Bt5	131-150	Reddish brown (2.5 YR 4/8); clay; moderate very fine, fine and medium subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine vesicular and many very fine irregular pores; few very fine, fine and medium roots; clear and smooth boundary to Bt6.
Bt6	150-173	Reddish brown (2.5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many very fine irregular pores; few very fine and fine roots; gradual and smooth boundary to Bt7.
Bt7	173-198	Reddish brown (2.5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bt8.
Bt8	198-200	Reddish brown (2.5 YR 4/8); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores.

*Slightly modified according to Manajuti et al. (2004).

9.3.5 Profile 505 Profondi-Humic Acrisol – Mae Sa Mai*

Classification: Profondi-Humic Acrisol
Date of examination: 21.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 53 43; E98 51 32
Parent rock: paragneiss
Geology: Precambrian
Physiographic position: on linear slope (approx. 28°)
Vegetation: evergreen trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-9	Brownish black (7.5 YR 3/2); clay; moderate very fine and fine granular structure; very friable moist; slightly sticky and slightly plastic; common fine and many very fine irregular pores; common medium, many very fine and fine roots; abrupt and smooth boundary to BA.
BA	9-22	Dull reddish brown (5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; common fine and many very fine irregular pores; common medium, many very fine and fine roots; abrupt and smooth boundary to Bt1.
Bt1	22-39	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many very fine irregular pores; few medium, common fine, many very fine roots; clear and smooth boundary to Bt2.
Bt2	39-65	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few medium, common fine, many very fine roots; clear and smooth boundary to Bt3.

Horizon	Depth [cm]	Description
Bt3	65-96	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; common fine and medium, many very fine roots; clear and smooth boundary to Bt4.
Bt4	96-119	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few medium, common very fine and fine roots; clear and smooth boundary to Bt5.
Bt5	119-143	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine, fine and medium roots; clear and smooth boundary to Bt6.
Bt6	143-164	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine, fine and medium roots; few angular gravel (0.5 – 2.0cm) of strongly weathered paragneiss; clear and smooth boundary to Bt7.
Bt7	164-189	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine, fine and medium roots; few angular gravel (0.5 – 2.0cm) of strongly weathered paragneiss; clear and smooth boundary to Bt8.
Bt8	189-200	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine, fine and medium roots.

*Slightly modified according to Manajuti et al. (2004).

9.3.6 Profile 506 Humi-Ferralic Cambisol – Mae Sa Mai*

Classification: Humi-Ferralic Cambisol
Date of examination: 28.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 51 45; E98 51 25
Parent rock: granite
Geology: Palaeozoic
Physiographic position: on linear slope (approx. 26˚)
Vegetation: fruit trees, vegetables
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ap	0-15	Brownish black (7.5 YR 3/2); clay loam; moderate very fine, fine and medium granular structure; very friable moist, slightly sticky and slightly plastic; many very fine and fine irregular pores; few fine and many very fine roots; few angular gravel (0.2 – 2.0cm)of weathered granite; abrupt and smooth boundary to BA.
BA	15-27	Dark reddish brown (5 YR 3/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; common fine vesicular and many very fine irregular pores; few fine and many very fine roots; abrupt and smooth boundary to Bw1.
Bw1	27-42	Reddish brown (5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; common fine vesicular and many very fine irregular pores; few coarse and common very fine roots; common angular gravel and stone (3.0 – 12.0cm) of fresh and weathered granite; clear and smooth boundary to Bw2.
Bw2	42-61	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; many very fine irregular pores; common very fine roots; few angular gravel (1.0 – 8.0cm) of fresh and weathered granite; clear and smooth boundary to Bw3.

Horizon	Depth [cm]	Description
Bw3	61-92	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; common fine vesicular and many very fine irregular pores; few very fine roots; common angular gravel and stone (1.0 – 23.0cm) of fresh weathered granite; gradual and smooth boundary to Bw4.
Bw4	92-129	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; few fine and many very fine irregular pores; few medium and coarse roots; many angular gravel and stone (1.0 – 15.0cm) of fresh weathered granite; abrupt and smooth boundary to Bw5.
Bw5	129-146	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; many very fine irregular pores; no roots; few angular quartz gravel (2.0 – 6.0 cm); abrupt and smooth boundary to Bw6.
Bw6	146-168	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; many very fine irregular pores; no roots; abrupt and smooth boundary to Bw7.
Bw7	168-200	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids; few fine and many very fine irregular pores; no roots; few angular quartz gravel (2.0 – 4.0 cm).

*Slightly modified according to Manajuti et al. (2004).

9.3.7 Profile 507 Profondi-Humic Acrisol – Mae Sa Mai*

Classification: Profondi-Humic Acrisol
Date of examination: 21.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 52 33; E98 51 40
Parent rock: Paragneiss
Geology: Precambrian
Physiographic position: on convex slope near ridge (approx. 29˚)
Vegetation: fruit trees, vegetables
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ap	0-20	Brownish black (7.5 YR 3/2); clay loam; moderate very fine and fine granular structure; very friable moist, slightly sticky and slightly plastic; many medium vesicular and many very fine and fine irregular pores; few medium, common fine and many very fine roots; abrupt and wavy boundary to Bt1.
Bt1	20-45	Dark reddish brown (5 YR 3/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; few medium vesicular and many very fine and fine irregular pores; few medium, common very fine and fine roots; clear and smooth boundary to Bt2.
Bt2	45-62	Reddish brown (5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic, many very fine and fine irregular pores; few very fine, fine and medium roots; abrupt and smooth boundary to Bt3.
Bt3	62-78	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; few medium vesicular and many very fine and fine irregular pores; few very fine and fine roots; abrupt and smooth boundary to Bt4.

Horizon	Depth [cm]	Description
Bt4	78-105	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; common medium vesicular and many very fine and fine irregular pores; few very fine, fine and medium roots; few angular quartz gravel (0.2 – 0.6 cm); abrupt and smooth boundary to Bt5.
Bt5	105-133	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; common medium vesicular and many very fine and fine irregular pores; few very fine and fine roots; common angular quartz and muscovite (0.2 – 3.0cm); clear and smooth boundary to Bt6.
Bt6	133-159	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; many very fine and fine irregular pores; few fine roots; common angular gravel (0.2 – 3.0cm) of strongly weathered paragneiss, common angular quartz and muscovite (0.2 – 2.0cm); abrupt and smooth boundary to Bt7.
Bt7	159-187	Reddish brown (2.5 YR 4/6); clay loam; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; many very fine and fine irregular pores; few fine roots; common angular gravel (02. – 2.5cm) of strongly weathered paragneiss, common angular quartz and muscovite (0.2 – 2.0 cm); abrupt and smooth boundary to Bt8.
Bt8	187-200	Reddish brown (2.5 YR 4/6); clay loam; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; many very fine and fine irregular pores; no roots; few angular gravel (0.2 – 6.0cm) of strongly weathered paragneiss.

*Slightly modified according to Manajuti et al. (2004).

9.3.8 Profile 508 Dystri-Humic Cambisol – Mae Sa Mai*

Classification: Dystri-Humic Cambisol
Date of examination: 15.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 52 50; E98 51 27
Parent rock: granite
Geology: Palaeozoic
Physiographic position: on convex slope (approx. 24°)
Vegetation: fruit trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ap	0-14	Dark reddish brown (5 YR 3/4); clay; moderate very fine and fine granular structure; very friable moist, sticky and plastic; many very fine and fine irregular pores; few medium, common fine and many very fine roots; abrupt and smooth boundary to Bw1.
Bw1	14-32	Reddish brown (5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic, common fine and many very fine irregular pores; few fine, common very fine and medium roots; clear and smooth boundary to Bw2.
Bw2	32-53	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine and many very fine irregular pores; few very fine, fine and coarse, common medium roots; clear and smooth boundary to Bw3.
Bw3	53-73	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine and many very fine irregular pores; few very fine, fine, medium and coarse roots; clear and smooth boundary to Bw4.

Horizon	Depth [cm]	Description
Bw4	73-97	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine and many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw5.
Bw5	97-126	Dull reddish brown (2.5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw6.
Bw6	126-146	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine and many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw7.
Bw7	146-169	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; firm moist, sticky and plastic; clay films on faces of voids and peds; common fine and many very fine irregular pores; few very fine and fine roots; clear and smooth boundary to Bw8.
Bw8	169-190	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; firm moist, sticky and plastic; clay films on faces of voids and peds; common fine and many very fine irregular pores; few fine roots; clear and smooth boundary to Bw9.
Bw9	190-200	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; firm moist, sticky and plastic; clay films on faces of voids and peds; few fine and many very fine irregular pores; few fine roots.

*Slightly modified according to Manajuti et al. (2004).

9.3.9 Profile 509 Humi-Ferralic Cambisol – Mae Sa Mai*

Classification: Humi-Ferralic Cambisol
Date of examination: 14.06.2003
Location: Mae Sa Mai, Mae Rim district, Chiang Mai province
Position: N18 53 12; E98 50 56
Parent rock: granite
Geology: Palaeozoic
Physiographic position: on ridge (approx. 3˚)
Vegetation: under cultivation of agronomy
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ap	0-20	Dull reddish brown (5 YR 4/4); clay; moderate weak very fine and fine granular structure; very friable moist, sticky and plastic; many very fine and fine irregular pores; few very fine and fine roots; abrupt and smooth boundary to Bw1.
Bw1	20-40	Dark reddish brown (2.5 YR 3/6) with reddish brown (5 YR 4/4); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine and many very fine irregular pores; few very fine roots; abrupt and smooth boundary to Bw2.
Bw2	40-62	Reddish brown (2.5 YR 4/6) with dark reddish brown (5 YR 3/4); clay; moderate very fine and fine subangular blocky structure, friable moist, sticky and plastic; clay films on faces of voids and peds; common fine and very fine irregular pores; no roots; abrupt and smooth boundary to Bw3.
Bw3	62-85	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine and many fine irregular pores; no roots; abrupt and smooth boundary to Bw4.

Horizon	Depth [cm]	Description
Bw4	85-107	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine vesicular and many very fine irregular pores; no roots; abrupt and smooth boundary to Bw5.
Bw5	107-130	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine vesicular and many very fine irregular pores; no roots; abrupt and smooth boundary to Bw6.
Bw6	130-156	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; common fine vesicular and many very fine irregular pores; no roots; clear and smooth boundary to Bw7.
Bw7	156-179	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many fine vesicular and many very fine irregular pores; no roots; clear and smooth boundary to Bw8.
Bw8	179-200	Reddish brown (2.5 YR 4/6); clay; moderate very fine and fine subangular blocky structure; friable moist, sticky and plastic; clay films on faces of voids and peds; many fine vesicular and many very fine irregular pores; no roots.

*Slightly modified according to Manajuti et al. (2004).

9.3.10 Profile 971 (1766) Cutani-Abruptic Luvisol – Huay Bong

Classification: Cutani-Abruptic Luvisol
Date of examination: 29.12.2004
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 43 20.56; E98 15 24.05
Parent rock: Breccia (ruby coloured)
Geology: Upper Carboniferous
Physiographic position: on convex slope (approx. 5˚)
Vegetation: upland rice between dead trees of the former forest
Remark: site is since 1999 under cultivation

Profile description:

Horizon	Depth [cm]	Description
Ah	0-7	Very dark brown (7.5 YR 2/3); sandy loam; weak granular structure; common coarse fragments; fine interstitial voids; few fine roots; abrupt and smooth boundary to E.
E	7-22	Reddish brown (5 YR 4/6); sandy loam, single grains; many coarse fragments; very fine interstitial voids; very few fine roots; abrupt and smooth boundary to Bt1.
Bt1	22-43	Bright reddish brown (2.5 YR 5/8); clay; moderate subangular blocky structure; common coarse fragments; fine planes; very few fine roots; diffuse and smooth transition to Bt2.
Bt2	43-62	Bright reddish brown (2.5 YR 5/8); clay; moderate subangular blocky to blocky structure; clay skins; few coarse fragments; fine interstitial voids; very few fine roots, abrupt and irregular boundary to Bt3.
Bt3	62-81	Bright reddish brown (2.5 YR 5/8); clay; moderate subangular blocky structure; clay skins; dominant coarse fragments (breccia ruby coloured); fine interstitial voids; no roots; abrupt and irregular boundary to Bt4.
Bt4	81-99	Bright reddish brown (2.5 YR 5/8); clay; weak subangular blocky structure; clay skins; single orange (7.5 YR 6/8) silt concretions very few coarse fragments; very fine interstitial voids; no roots; clear and smooth boundary to Bt5.

Horizon	Depth [cm]	Description
Bt5	99-128	Bright reddish brown (2.5 YR 5/8) matrix, dark red (10 R 3/4) mottles, light reddish grey (2.5 YR 7/1) mottles; clay; weak subangular blocky structure; common coarse fragments; very fine interstitial voids; no roots; gradual and smooth boundary to Bt6.
Bt6	128-162	Matrix reddish brown (2.5 YR 4/8), mottles reddish grey (2.5 YR 6/1); clay loam; weak subangular blocky structure; no coarse fragments; very few interstitial voids; no roots; diffuse and smooth transition to Bt7.
Bt7	162-200	Matrix dark red (10 R 3/6), mottles reddish grey (2.5 YR 6/1); clay loam; weak subangular blocky structure; no coarse fragments; very few interstitial voids; no roots.

9.3.11 Profile 973 (1767) Endoskeleti-Profondic Luvisol – Huay Bong

Classification: Endoskeleti-Profondic Luvisol
Date of examination: 30.12.2004
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 42 45.01; E98 14 47.39
Parent rock: Sandstone
Geology: Upper Carboniferous
Physiographic position: linear slope (approx. 15˚)
Vegetation: upland rice
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-14	Very dark brown (7.5 YR 2/3); sandy clay loam; strong fine subangular blocky structure; very few coarse fragments; fine interstitial voids; few fine roots; charcoal; abrupt and wavy boundary to E.
E	14-30	Dark reddish brown (5 YR 3/6); sandy clay loam, weak fine subangular blocky structure; very few coarse fragments; very fine interstitial voids; very few fine roots; clear and wavy boundary to Bt1.
Bt1	30-43	Dark reddish brown (5 YR 3/6); sandy clay loam; weak fine subangular blocky structure; abundant coarse fragments consisting of sandstone with a prominent fringe of Fe- and Mn-oxides; very fine interstitial voids; very few fine roots; clear and wavy transition to Bt2.
Bt2	43-68	Dark reddish brown (5 YR 3/6); clay loam; weak subangular blocky structure; abundant coarse fragments consisting of sandstone with a prominent fringe of Fe- and Mn-oxides; very fine interstitial voids; very few fine roots, clear and wavy boundary to Bt3.
Bt3	68-87	Reddish brown (2.5 YR 4/8); sandy clay loam; weak subangular blocky structure; abundant coarse fragments consisting of sandstone with a faint fringe of Fe- and Mn-oxides; very fine interstitial voids; no roots; clear and wavy boundary to Bt4.

Horizon	Depth [cm]	Description
Bt4	87-107	Reddish brown (2.5 YR 4/8); clay loam; weak subangular blocky structure; common coarse fragments consisting of sandstone with a faint fringe of Fe- and Mn-oxides; very fine interstitial voids; no roots; gradual and wavy boundary to Bt5.
Bt5	107-135	Reddish brown (2.5 YR 4/8); clay loam; weak subangular blocky structure; common coarse fragments consisting of sandstone; very fine interstitial voids; no roots; clear and wavy boundary to Bt6.
Bt6	135-156	Orange (5 YR 6/8); clay loam; weak subangular blocky structure; common coarse fragments consisting of sandstone; very fine interstitial voids; no roots; clear and wavy boundary to Cw.
Cw	>156	Sandstone with joints filled by orange (5YR 6/8) clay loam; joint distance is smaller than 10cm.

9.3.12 Profile 974 (1768) Humi-Stagnic Cambisol – Huay Bong

Classification: Humi-Stagnic Cambisol
Date of examination: 30.12.2004
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 43 25.46; E98 15 25.46
Parent rock: Alluvium
Geology: Quaternary
Physiographic position: valley bottom (approx. 0˚)
Vegetation: maize
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-20	Dark brown (7.5 YR 3/3); clay loam; strong medium subangular blocky structure; very few coarse fragments; many medium vughs, channels of around one cm diameter, termite nest of around 7cm diameter ; very few fine roots; common charcoal; abrupt and wavy boundary to Bw.
Bw	20-33	Brown (7.5 YR 4/4); loam, moderate medium subangular blocky structure; very few coarse fragments; common fine vughs; very few fine roots; few charcoal; abrupt and smooth boundary to Bg.
Bg	33-56	Dull reddish brown (5 YR 4/3); loam; weak medium subangular blocky structure; no coarse fragments; very fine interstitial voids; no roots; many Fe- and Mn-concretions of around 4mm diameter, prominent contrast to matrix; gradual and smooth transition to Bgw.
Bgw	56-88	Dull reddish brown (5 YR 4/4); clay loam; weak fine subangular blocky structure; no coarse fragments; very fine interstitial voids; no roots, many Fe- and Mn-concretions of around 4mm diameter, distinct contrast to matrix; diffuse and smooth boundary to Bwg.

Horizon	Depth [cm]	Description
Bwg	88-120	Dull reddish brown (5 YR 4/4); sandy clay loam; weak fine subangular blocky structure; very few coarse fragments sandstone coated with Fe- and Mn-oxides; very fine interstitial voids; common Fe- and Mn-concretions of around 4mm diameter, faint contrast to matrix; few roots on lower horizon boundary; abrupt and smooth boundary to CR.
CR	>120	Conglomerate with some sandy loam; abundant coarse fragments; no roots.

9.3.13 Profile 980 (1769) Dystri-Skeletic Regosol – Huay Bong

Classification: Dystri-Skeletic Regosol
Date of examination: 23.01.2005
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 44 03.88; E98 15 21.03
Parent rock: sandstone
Geology: Upper Carboniferous
Physiographic position: on linear slope (approx. 60˚)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-3	Dark brown (7.5 YR 3/4); sandy loam; weak granular structure; common coarse fragments; fine interstitial voids; many fine roots; clear and wavy boundary to CR.
Bw	>3	Dark reddish brown (5 YR 3/6); loam, single grains; dominant coarse fragments (sandstone); medium interstitial voids; many fine roots.

9.3.14 Profile 981 (1770) Dystri-Skeletic Regosol – Huay Bong

Classification: Dystri-Skeletic Regosol
Date of examination: 23.01.2005
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 44 07.72; E98 15 12.30
Parent rock: claystone (red coloured)
Geology: Upper Carboniferous
Physiographic position: on convex slope (approx. 20°)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-7	Reddish brown (2.5 YR 4/6); silty clay; single grains; abundant coarse fragments; fine interstitial voids; very few fine roots; gradual and smooth boundary to CB1.
CB1	7-25	Reddish brown (2.5 YR 4/6) clay; single grains, abundant coarse fragments; fine interstitial voids; very few fine roots; gradual and smooth boundary to CB2.
CB2	25-34	Bright reddish brown (2.5 YR 5/6) clay; single grains; abundant coarse fragments; fine interstitial voids, very few fine roots; gradual and smooth boundary to CR.
CR	>34	Weathered red claystone.

9.3.15 Profile 982 (1771) Dystri-Skeletic Regosol – Huay Bong

Classification: Dystri-Skeletic Regosol
Date of examination: 23.01.2005
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 44 01.33; E98 15 08.78
Parent rock: sandstone
Geology: Upper Carboniferous
Physiographic position: on summit (approx. 0˚)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-4	Reddish brown (5 YR 4/6); sandy loam; single grains; abundant coarse fragments; fine interstitial voids; few fine roots; abrupt and smooth boundary to C.
C	>4	Dull reddish brown (2.5 YR 5/4) sandy loam; single grains, abundant coarse fragments; fine interstitial voids; few fine roots.

9.3.16 Profile 991 (1772) Ferri-Abruptic Luvisol – Huay Bong

Classification: Ferri-Abruptic Luvisol
Date of examination: 24.01.2005
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 43 02.03; E98 15 19.79
Parent rock: sandstone
Geology: Upper Carboniferous
Physiographic position: on linear slope (approx. 7°)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-5	Brown (7.5 YR 4/4); sandy loam; single grains; abundant coarse fragments; fine interstitial voids; few fine roots; abrupt and smooth boundary to E.
E	5-20	Brownish red (5 YR 5/6) loam; single grains, abundant coarse fragments consisting of sandstone impregnated with hematite; fine interstitial voids, coarse vughs consisting of termite nests; very few fine roots; abrupt and smooth boundary to Bt1.
Bt1	20-49	Red (10 R 5/8); clay, weak fine subangular blocky structure; many coarse fragments consisting of sandstone impregnated with hematite; fine interstitial voids, coarse vughs consisting of termite nests, no roots; clear and smooth boundary to Bt2.
Bt2	49-68	Red (10 R 5/8); clay; weak fine subangular blocky structure; common coarse fragments consisting of sandstone impregnated with hematite; fine interstitial voids, coarse vughs consisting of termite nests, no roots; diffuse and clear and smooth boundary to Bt3.
Bt3	68-93	Orange (2.5 YR 6/8); silty clay; weak fine subangular blocky structure; many coarse fragments consisting of sandstone impregnated with hematite; fine interstitial voids, coarse vughs consisting of termite nests, channels from termites; red (10 R 4/6) hematite mottles with a distinct matrix contrast; no roots; abrupt and wavy boundary to Bt4.

Horizon	Depth [cm]	Description
Bt4	93-101	Orange (2.5 YR 6/8); silty clay; weak fine subangular blocky structure; many coarse fragments consisting of sandstone impregnated with hematite; fine interstitial voids; red (10 R 4/6) hematite mottles with a distinct matrix contrast; no roots; abrupt and wavy boundary to R.
R	>101	Sandstone.

9.3.17 Profile 1093 (1837) Dystri-Humic Cambisol – Huay Bong

Classification: Dystri-Humic Cambisol
Date of examination: 09.04.2005
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 42 47.91; E98 15 38.09
Parent rock: sandstone
Geology: Upper Carboniferous
Physiographic position: on linear slope (approx. 10˚)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-9	Dark brown (7.5 YR 3/4); loam; weak medium granular structure; few coarse fragments consisting of sandstone; fine interstitial voids and vughs; few fine roots; clear and wavy boundary to AB.
AB	9-24	Dark reddish brown (5 YR 3/6); clay loam; weak medium granular structure; few coarse fragments consisting of sandstone; in interstitial voids and vughs; common medium roots; clear and wavy boundary to Bw1.
Bw1	24-36	Dark reddish brown (5 YR 3/6); clay loam; weak medium granular structure; abundant coarse fragments consisting of sandstone; fine interstitial voids; few medium roots; clear and wavy boundary to Bw2.
Bw2	36-56	Reddish brown (5 YR 4/8); clay loam; weak medium granular to subangular blocky structure; few coarse fragments consisting of sandstone; fine interstitial voids; very few medium roots; diffuse boundary to Bw3.
Bw3	56-81	Reddish brown (5 YR 4/8); clay loam; weak medium subangular blocky structure; few coarse fragments consisting of sandstone; fine interstitial voids; very few medium roots; diffuse boundary to Bw4.
Bw4	81-102	Dark reddish brown (5 YR 3/6); clay loam; weak medium subangular blocky structure; few coarse fragments consisting of sandstone; fine interstitial voids; very few medium roots; clear and wavy boundary to Cw1.

Horizon	Depth [cm]	Description
Cw1	102-132	Reddish brown (5 YR 4/6); clay loam; weak fine subangular blocky structure; abundant coarse fragments consisting of sandstone; fine interstitial voids; very few medium roots; gradual and wavy boundary to Cw2.
Cw2	132-140	Reddish brown (5 YR 4/6); clay loam; weak fine subangular blocky structure; many coarse fragments consisting of sandstone; fine interstitial voids; no roots.

9.3.18 Profile 1094 Skelti-Stagnic Cambisol – Huay Bong

Classification: Skeleti-Stagnic Cambisol
Date of examination: 04.09.2005
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 43 16.74; E98 14 39.88
Parent rock: claystone
Geology: Upper Carboniferous
Physiographic position: on convex slope (approx. 3˚)
Vegetation: deciduous trees
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-12	Dark reddish brown (2.5 YR 3/2); silty clay loam; weak fine granular to subangular blocky structure; few coarse fragments; few interstitial voids; few fine roots; abrupt and wavy boundary to BA.
BA	12-17	Dull reddish brown (2.5 YR 4/4); silty clay; weak fine subangular structure; dominant coarse fragments consisting of dark purple claystone; common interstitial voids; very few fine roots; abrupt and wavy boundary to Bw1.
Bw1	17-47	Dull reddish brown (2.5 YR 5/4);.clay; weak medium subangular blocky structure; common coarse fragments consisting of light purple claystone with surfaces coated by Fe- and Mn-oxides; few interstitial voids; very few fine roots; few red (10 R 4/6) hematite mottles with a faint matrix contrast; clay skins; gradual and wavy boundary to Bw2.
Bw2	47-66	Dull reddish brown (2.5 YR 5/3); silty clay; weak fine subangular blocky structure; few coarse fragments consisting of light purple claystone with surfaces coated by Fe- and Mn-oxides; few interstitial voids; very few fine roots; few red (10 R 4/6) hematite mottles with a faint matrix contrast; clay skins; diffuse boundary to Bw3.

Horizon	Depth [cm]	Description
Bw3	66-85	Dull orange (7.5 YR 6/4); silty clay; weak medium angular blocky structure; common coarse fragments consisting of light purple claystone with surfaces coated by Fe- and Mn-oxides; few interstitial voids; very few fine roots; clay skins; clear and wavy boundary to Cw.
Cw	85-100	Greyish red (2.5 YR 5/2); clay; weathered claystone; dominant coarse fragments with a diameter of up to 4 cm, consisting of light purple claystone with surfaces coated by Fe- and Mn-oxides; few interstitial voids; no roots.

9.3.19 Profile 1095 (1839) Dystri-Profondic Luvisol – Huay Bong

Classification: Dystri-Pronfondic Luvisol
Date of examination: 05.09.2005
Location: Huay Bong, Mae Chaem district, Chiang Mai province
Position: N18 43 47.37; E98 14 35.68
Parent rock: sandstone
Geology: Tertiary
Physiographic position: on linear slope (approx. 3˚)
Vegetation: tomato, weeds
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-17	Brown (7.5 YR 4/5); clay; moderate fine subangular blocky and medium granular structure; no coarse fragments; few interstitial voids and vughs; few fine roots; Fe- and Mn-concretions; charcoal; gradual and smooth boundary to AB.
AB	17-33	Reddish brown (5 YR 4/5); clay; weak fine granular structure; no coarse fragments; fine interstitial voids and few vughs consisting mainly of termite nests; few fine roots; Fe- and Mn-concretions; charcoal; gradual and smooth boundary to Bt1.
Bt1	33-63	Dark reddish brown (5 YR 3/5); clay; weak fine granular to subangular blocky structure; no coarse fragments; fine interstitial voids; no roots; brick; gradual and smooth boundary to Bt2.
Bt2	63-86	Dark reddish brown (5 YR 3/5); clay; weak fine granular structure; no coarse fragments; fine interstitial voids and few vughs mainly consisting of termite nests; no roots; Fe- and Mn-concretions; diffuse boundary to Bt3.
Bt3	86-120	Reddish brown (5 YR 4/6); clay; weak fine granular structure; no coarse fragments; fine interstitial voids; no roots; Fe- and Mn-concretions; diffuse boundary to Bt4.

Horizon	Depth [cm]	Description
Bt4	120-155	Reddish brown (5 YR 4/6); clay; weak fine granular to subangular blocky structure; no coarse fragments; fine interstitial voids; no roots; Fe- and Mn-concretions; diffuse boundary to Bt5.
Bt5	155-184	Reddish brown (5 YR 4/6); clay; weak fine granular to subangular blocky structure; no coarse fragments; fine interstitial voids; no roots; Fe- and Mn-concretions; diffuse boundary to Bt6.
Bt6	184-200	Reddish brown (5 YR 4/6); clay; weak fine subangular blocky structure; no coarse fragments; fine interstitial voids; no roots.

9.3.20 Profile 113 (1773) Calcari-Humic Gleysol – Bor Krai

Classification: Calcari-Humic Gleysol
Date of examination: 12.10.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 03.18; E98 12 48.58
Parent rock: alluvial deposits
Geology: Quaternary
Physiographic position: bottom of karst depression (approx. 0˚)
Vegetation: grass and shrubs
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-16	Dull yellowish brown (10 YR 4/3); silty clay loam; weak angular blocky structure; no coarse fragments; fine interstitial voids; contains $CaCO_3$; few medium roots; gradual and smooth boundary to Bg1.
Bg1	16-33	Dull yellowish brown (10 YR 4/3); loam, weak angular blocky structure; no coarse fragments; medium interstitial voids; contains CaCO3; no roots; oximorhic colour pattern; charcoal; clear and smooth boundary to Bg2.
Bg2	33-55	Dull yellowish brown (10 YR 4/3); loam, weak angular blocky structure; no coarse fragments; medium interstitial voids; contains CaCO3; no roots; oximorphic colour pattern; charcoal; abrupt and smooth boundary to Br1.
Br1	55-80	Olive black (7.5 Y 3/2); loam; no structure, few coarse fragments; medium interstitial voids; contain $CaCO_3$; no roots; reductimorphic colour pattern; clear and smooth boundary to Br2.
Br2	>80	Greyish olive (7.5 Y 4/2); loam; no structure; few coarse fragments; medium interstitial voids; contain $CaCO_3$; no root; reductimorphic colour pattern.

9.3.21 Profile 449 (1774) Humi-Stagnic Fluvisol – Bor Krai

Classification: Humi-Stagnic Fluvisol
Date of examination: 19.08.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 34 02.25; E98 12 54.78
Parent rock: alluvial deposits
Geology: Quaternary
Physiographic position: valley, close to Mae Lana cave (approx. 0˚)
Vegetation: trees and shrubs
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-2	Brown (7.5 YR 4/4); loam; single grain; no coarse fragments; medium interstitial voids; few medium roots; charcoal; abrupt and wavy boundary to Bu1.
Bu1	2-12	Brown (7.5 YR 4/4); sandy loam, single grain; no coarse fragments; medium interstitial voids; few medium roots; charcoal; abrupt and wavy boundary to Bg1.
Bg1	12-20	Brown (7.5 YR 4/3); silty clay loam, weak subangular blocky to angular blocky structure; no coarse fragments; fine interstitial voids; few medium roots; oximorphic colour pattern, rusty root channels and ped surfaces; abrupt and wavy boundary to Bu2.
Bu2	20-23	Dull reddish Brown (5 YR 4/4); sandy loam, single grain; no coarse fragments; medium interstitial voids; few medium roots; abrupt and wavy boundary to Bg2.
Bg2	23-35	Brown (7.5 YR 4/3); silty clay loam, weak angular blocky structure; no coarse fragments; fine interstitial voids; few medium roots; oximorphic colour pattern, rusty root channels and ped surfaces; abrupt and wavy boundary to Bu3.
Bu3	35-53	Dull brown (7.5 YR 5/4); loam, single grain; few coarse fragments, amount increase towards the stream; medium interstitial voids; few medium roots; charcoal; abrupt and wavy boundary to Bg3.

Horizon	Depth [cm]	Description
Bg3	53-63	Dark brown (7.5 YR 3/3); clay loam, weak subangular blocky; no coarse fragments; fine interstitial voids; few medium roots; rusty ped surfaces; abrupt and wavy boundary to Bu4.
Bu4	63-89	Brown (7.5 YR 4/4); loam, weak subangular blocky structure; no coarse fragments; fine interstitial voids; few medium roots; abrupt and wavy boundary to Bu5.
Bu5	89-97	Brown (7.5 YR 4/4); loam, weak subangular blocky structure; no coarse fragments; fine interstitial voids; few medium roots; abrupt and wavy boundary to Bu6.
Bu6	97-109	Brown (7.5 YR 4/4); sandy loam, single grain; no coarse fragments; medium interstitial voids; few medium roots; abrupt and wavy boundary to C.
C	>109	Dark brown (7.5 YR 3/4); loam, single grain; abundant coarse fragments (subrounded to rounded); medium interstitial voids; few medium roots.

9.3.22 Profile 450 (1777) Humi-Anthric Umbrisol – Bor Krai

Classification: Humi-Anthric Umbrisol
Date of examination: 21.08.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 24.47; E98 12 38.49
Parent rock: limestone
Geology: Permian
Physiographic position: karst depression (approx. 0˚)
Vegetation: trees and shrubs
Remark: fallow since 3 years

Profile description:

Horizon	Depth [cm]	Description
Ah1	0-15	Dark reddish brown (10 R 3/2); silty clay; moderate crumb structure; no coarse fragments; medium interstitial voids; few fine roots; charcoal; brick; Fe-, Mn-concretions up to 2 mm diameter; gradual and smooth boundary to Ah2.

Horizon	Depth [cm]	Description
Ah2	15-40	Dark reddish brown (10 R 3/3); clay; moderate subangular blocky structure; no coarse fragments; medium interstitial voids, channels from termites; few fine roots; charcoal; brick; Fe-, Mn-concretions up to 2 mm diameter; gradual and smooth boundary to Ah3.
Ah3	40-62	Dark reddish brown (10 R 3/3); clay, moderate subangular blocky structure; no coarse fragments; medium interstitial voids; very few fine roots; termite nests; charcoal; brick; Fe-, Mn-concretions of 2 mm diameter; gradual and smooth boundary to Ah4.
Ah4	62-80	Dark reddish brown (5 YR 3/3); clay, moderate subangular blocky structure; no coarse fragments; medium interstitial voids; channels from termites; very few medium roots; brick; Fe-, Mn-concretions up to 2 mm diameter; gradual and smooth boundary to Ah5.
Ah5	80-100	Dark reddish brown (10 R 3/3); clay; moderate subangular blocky structure; no coarse fragments; medium interstitial voids; termite nests; few medium roots; brick; Fe-, Mn-concretions up to 2 mm diameter; gradual and smooth boundary to AB1.
AB1	100-125	Dark red (10 R 3/4); clay, moderate subangular blocky structure; no coarse fragments, medium interstitial voids; few medium roots; charcoal; brick;; gradual and smooth boundary to AB2.
AB2	125-150	Dark red (10 R 3/4); clay, moderate subangular blocky structure; no coarse fragments; fine interstitial voids; few medium roots; charcoal; Fe-, Mn-concretions up to 2 mm diameter.

9.3.23 Profile 452 (1775) Dystri-Ferric Luvisol – Bor Krai

Classification: Dystri-Ferric Luvisol
Date of examination: 16.08.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 09.86; E98 13 07.29
Parent rock: claystone, siltstone
Geology: Permian
Physiographic position: on upper convex slope (approx. 3˚)
Vegetation: mango and banana
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-17	Brown (10 YR 4/4); clay loam; moderate medium subangular blocky structure; very few coarse fragments; fine interstitial voids, few vughs mainly consisting of termite nests; few termite channels filled with subsoil material; very few fine roots; charcoal; abrupt and smooth boundary to Bt1.
Bt1	17-35	Orange (2.5 YR 6/8); clay; moderate medium subangular blocky structure; no coarse fragments; fine interstitial voids, few vughs mainly consisting of termite nests; few termite channels filled with dark topsoil material; very few fine roots; clay skins; common distinct bright reddish brown (2.5 YR 5/8) hematite mottles; gradual and smooth boundary to Bt2.
Bt2	35-47	Orange (2.5 YR 6/8); clay; weak medium subangular blocky structure; common coarse fragments, fine interstitial voids; no roots; clay skins; common distinct dark red (10 R 3/4) hematite mottles; clear and smooth boundary to Bt3.
Bt3	47-74	Orange (5 YR 7/8); silty clay; weak medium subangular blocky structure; common coarse fragments, consisting of yellow silt concretions and a stone layer, the silt concretions are located below the stone layer, the stone layer shows an slope equivalent inclination; fine interstitial voids; no roots; clay skins; common distinct red (10 R 4/6) hematite mottles; clear and smooth boundary to BCw.

Horizon	Depth [cm]	Description
BCw	74-104	Bright yellowish brown (10 YR 7/6); clay loam; weak fine subangular blocky structure; abundant coarse fragments; fine interstitial voids; no roots; common distinct red (10 R 4/6) hematite mottles; diffuse boundary to Cw1.
Cw1	104-132	Bright yellowish brown (10 YR 7/6); silty clay; weak fine subangular blocky structure; abundant coarse fragments; fine interstitial voids; no roots; common prominent bright reddish brown (2.5 YR 5/8) hematite mottles; diffuse boundary Cw2.
Cw2	132-150	Orange (2.5 YR 7/6); silty clay; weak fine subangular blocky structure; abundant coarse fragments; fine interstitial voids; no roots; common prominent reddish brown (10 R 4/4) hematite mottles; diffuse boundary to Cw3.
Cw3	>150	Dull orange (5 YR 7/4); silty clay loam; weak fine subangular blocky structure; abundant coarse fragments; fine interstitial voids; no roots; common prominent reddish brown (10 R 4/4) hematite mottles.

9.3.24 Profile 453 (1778) Ferri-Profondic Luvisol – Bor Krai

Classification: Ferri-Profondic Luvisol
Date of examination: 12.10.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 08.73; E98 13 09.69
Parent rock: claystone, siltstone
Geology: Permian
Physiographic position: on concave slope (approx. 1°)
Vegetation: mango
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-27	Dark brown (10 YR 3/4); silty clay loam; moderate crumb structure; very few coarse fragments; fine interstitial voids; few fine roots; charcoal; brick; abrupt and smooth boundary to E.
E	27-43	Brown (7.5 YR 4/4); silty clay; weak fine subangular blocky structure; no coarse fragments; fine interstitial voids; few fine roots; abrupt and smooth boundary to Bt1.
Bt1	43-71	Bright reddish brown (5 YR 5/8); clay; weak fine subangular blocky structure; no coarse fragments; fine interstitial voids; no roots; abrupt and smooth boundary to Bt2.
Bt2	71-100	Bright reddish brown (5 YR 5/8); clay; weak fine subangular blocky structure; no coarse fragments; fine interstitial voids; no roots; common distinct reddish brown (2.5 YR 4/8) mottles.

9.3.25 Profile 456 (1779) Dystri-Profondic Luvisol – Bor Krai

Classification: Dystri-Profondic Luvisol
Date of examination: 12.10.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 32 59.49; E98 11 54.95
Parent rock: limestone
Geology: Permian
Physiographic position: on linear slope (approx. 40˚)
Vegetation: maize
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-19	Dark reddish brown (2.5 YR 3/4); clay; fine strong crumb structure; no coarse fragments; many medium interstitial voids; few fine roots; abrupt and smooth boundary to AB.
AB	19-37	Dark reddish brown (10R 3/3); clay; fine strong crumb structure; no coarse fragments; many medium interstitial voids; few fine roots; clear and smooth boundary to Bt1.
Bt1	37-65	Dark reddish brown (10R 3/3); clay; fine strong crumb to subangular blocky structure; no coarse fragments; many medium interstitial voids; very few roots; gradual and smooth boundary to Bt2.
Bt2	65-87	Dark reddish brown (10R 3/3); clay; fine strong crumb to subangular blocky structure; no coarse fragments; many medium interstitial voids; no roots; gradual and smooth boundary to Bt3.
Bt3	87-100	Dark red (10R 3/4); clay; fine strong crumb to subangular blocky structure; no coarse fragments; many medium interstitial voids; no roots.

9.3.26 Profile 457 (1780) Profondi-Humic Acrisol – Bor Krai

Classification: Profondi-Humic Acrisol
Date of examination: 14.10.2004
Location: Jabo, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 48.29; E98 12 01.03
Parent rock: limestone
Geology: Permian
Physiographic position: on concave slope (approx. 1°)
Vegetation: rice
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah1	0-20	Dark reddish brown (2.5 YR 3/4); clay; moderate crumb structure; no coarse fragments; fine interstitial voids; medium porosity; few medium roots; gradual and smooth boundary to Ah2.
Ah2	20-40	Dark reddish brown (2.5 YR 3/4); clay; moderate crumb structure; no coarse fragments; fine interstitial voids; medium porosity; few medium roots; clear and smooth boundary to Bt1.
Bt1	40-62	Dark reddish brown (10 R 3/3); clay, moderate subangular blocky structure; no coarse fragments; fine interstitial voids; medium porosity; very few fine roots; gradual and smooth boundary to Bt2.
Bt2	62-86	Dark reddish brown (10 R 3/3); clay, moderate subangular blocky structure; no coarse fragments, fine interstitial voids; medium porosity; very few fine roots; abrupt and smooth boundary to Bt3.
Bt3	86-100	Dark red (10 R 3/4); clay, weak subangular blocky structure; no coarse; very fine interstitial voids; low porosity; no roots.

9.3.27 Profile 479 (1762) Chromi-Eutric Cambisol – Bor Krai

Classification: Chromi-Eutric Cambisol
Date of examination: 15.01.2005
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 48.29; E98 12 01.03
Parent rock: latite
Geology: Triassic (?)
Physiographic position: on linear slope (approx. 50˚)
Vegetation: deciduous trees
Remark: contact zone between latite and limestone

Profile description:

Horizon	Depth [cm]	Description
Ah	0-22	Dull reddish brown (2.5 YR 4/3); clay; strong medium angular blocky and prismatic structure; no coarse fragments; many planes; very low porosity; very few medium roots; clay skins; clear and wavy boundary to Bw1.
Bw1	22-44	Dark reddish brown (5 YR 3/3); silty clay; strong medium subangular blocky and prismatic structure; no coarse fragments; common planes; very low porosity; very few medium and coarse roots; clay skins; clear and wavy boundary to Bw2.
Bw2	44-76	Dark reddish brown (5 YR 3/3); silty clay, moderate subangular blocky structure; abundant coarse fragments consisting of green minerals; common planes; low porosity; very medium and coarse roots; gradual and wavy boundary to Bw3.
Bw3	76-106	Dark reddish brown (5 YR 3/3); silty clay loam, moderate subangular blocky structure; many coarse fragments consisting of green minerals, few planes; low porosity; no roots; gradual and wavy boundary to Bw4.
Bw4	106-120	Dark red (10 R 3/4); silty clay, weak subangular blocky structure; many coarse fragments consisting of green minerals; very fine interstitial voids; very low porosity; no roots.

9.3.28 Profile 1550 Umbri-Gibbsic Ferralsol – Bor Krai

Classification:	Umbri-Gibbsic Ferralsol
Date of examination:	20.08.2004
Location:	Jabo, Pang Ma Pha district, Mae Hong Son province
Position:	N19 33 55.39; E98 12 11.39
Parent rock:	limestone, iron ore and bauxite
Geology:	Permian, Triassic
Physiographic position:	slope convex (approx. 5˚)
Vegetation:	deciduous trees
Remark:	at one part of the profile a rounded, smooth and cone shaped limestone was detected; its upper part started 20 cm below the surface

Profile description:

Horizon	Depth [cm]	Description
Ah	0-10	Dark reddish brown (5 YR 3/3); silty clay; moderate crumb structure; very few coarse fragments; medium interstitial voids; high porosity; very few medium roots; gradual and wavy boundary to AB1.
AB1	10-35	Dark reddish brown (2.5 YR 3/3); clay; moderate subangular blocky structure; very few coarse fragments; medium interstitial voids; high porosity; very few medium roots; diffuse and smooth boundary to AB2.
AB2	35-60	Dark reddish brown (2.5 YR 3/3); clay, moderate subangular blocky structure; very few coarse fragments; medium interstitial voids; high porosity; very few medium and coarse roots; diffuse and smooth boundary to Bs1.
Bs1	60-100	Dark red (10 R 3/4); clay, strong subangular blocky structure; very few coarse fragments, medium interstitial voids; high porosity; very few medium roots; diffuse and smooth boundary to Bs2.
Bs2	100-140	Dark red (10 R 3/4); clay, strong subangular blocky structure; very few coarse; medium interstitial voids; high porosity; very few medium roots; diffuse and smooth boundary to Bs3.
Bs3	>140	Dark red (10 R 3/4); clay; strong subangular blocky structure; medium interstitial voids; high porosity; very few coarse fragments; medium interstitial voids; very few medium roots.

9.3.29 Profile 1627 (1758) Glossi-Calcic Chernozem – Bor Krai

Classification: Glossi-Calcic Chernozem
Date of examination: 12.06.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 15.02; E98 13 41.03
Parent rock: freshwater limestone
Geology: Quaternary
Physiographic position: slope linear (approx. 3˚)
Vegetation: maize
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ahk1	0-18	Black (7.5 YR 1.7/1); silty clay; strong crumb structure; few coarse fragments consisting of freshwater limestone with up to 5 mm diameter; medium interstitial voids, channels; high porosity; few fine roots; diffuse and smooth boundary to Ahk2.
Ahk2	18-40	Black (7.5 YR 1.7/1); silty clay; strong crumb structure; few coarse fragments consisting of freshwater limestone with up to 5 mm diameter; medium interstitial voids, channels; high porosity; few fine and medium roots; clear and smooth boundary to ABk.
ABk	40-55	Brownish black (2.5 Y 3/2); silty clay, moderate subangular blocky structure; common coarse fragments consisting of freshwater limestone with up to 1 cm diameter; medium interstitial voids, channels; high porosity; very few medium and coarse roots; abrupt and irregular boundary to R.
R	>55	Dull yellow (2.5 Y 6/3); massive freshwater limestone to more than 98 vol% with some silty clay in between; medium porosity; no roots.

9.3.30 Profile 1629 (1759) Dystri-Profondic Luvisol – Bor Krai

Classification: Dystri-Profondic Luvisol
Date of examination: 26.10.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 32.23; E98 13 41.16
Parent rock: iron ore, limestone
Geology: Triassic (?), Permian
Physiographic position: karst depression between two sinkholes (approx. 0˚)
Vegetation: maize
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah	0-17	Dark brown (7.5 YR 3/4); silty clay; weak medium crumb to fine subangular blocky structure; few coarse fragments consisting of iron ore; medium interstitial voids, common vughs and channels, medium porosity; common medium and coarse roots; charcoal; brick; clear and wavy boundary to Bt1.
Bt1	17-31	Dark reddish brown (5 YR 3/4); clay; weak medium subangular blocky to fine angular blocky structure; very few coarse fragments consisting of iron ore; medium interstitial voids, few vughs and channels; low porosity; very few medium and coarse roots; charcoal; brick; gradual and smooth boundary to Bt2.
Bt2	31-56	Reddish brown (5 YR 4/8); weak, medium to fine subangular blocky structure; very few coarse fragments consisting of iron ore and silt concretions; fine interstitial voids, few vughs and channels of termites, termite nests; low porosity; very few medium and coarse roots; gradual and smooth boundary to Bt3.

Horizon	Depth [cm]	Description
Bt3	56-76	Dark reddish brown (5 YR 3/6); weak fine subangular blocky structure; very few coarse fragments consisting of iron ore; fine interstitial voids; few vughs and channels of termites; low porosity; very few medium and coarse roots; diffuse boundary to Bt4.
Bt4	76-100	Reddish brown (5 YR 4/8); weak, medium subangular blocky to fine angular blocky structure; no coarse fragments; fine interstitial voids, few vughs and channels of termites; low porosity; very few medium and coarse roots; diffuse boundary to Bt5.
Bt5	>100	Dark reddish brown (5 YR 3/6); moderate, medium subangular blocky to angular blocky structure; no coarse fragments; fine interstitial voids, few vughs and channels of termites; low porosity; very few medium to coarse roots; precipitation of Fe- and Mn-oxides in soil matrix.

9.3.31 Profile 1677 Profondi-Endostagnic Luvisol – Bor Krai

Classification: Profondi-Endostagnic Luvisol
Date of examination: 20.08.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 33 20.93; E98 13 20.93
Parent rock: claystone
Geology: Permian
Physiographic position: slope linear (approx. 4˚)
Vegetation: shrubs and trees
Remark: stagnant water 100 cm below surface

Profile description:

Horizon	Depth [cm]	Description
Ah	0-17	Dark reddish brown (5 YR 3/2); clay loam; moderate crumb to subangular blocky structure; very few coarse fragments consisting of silt stones, brick; medium interstitial voids; medium porosity; common fine roots; slightly calcareous; charcoal; clear and wavy boundary to AB.
AB	17-34	Brown (7.5 YR 4/3); clay; moderate subangular blocky structure; very few coarse fragments, consisting of siltstone; medium interstitial voids; medium porosity; common fine roots; charcoal; abrupt and wavy boundary to Bt.
Bt	34-77	Dull reddish brown (5 YR 4/4); clay, moderate subangular blocky to angular blocky structure; common coarse fragments; medium interstitial voids; medium porosity; very few fine roots; hematite mottles; slightly calcareous; gradual and wavy boundary to BCtg.
BCtg	77-95	Yellowish brown (2.5 Y 5/6); clay, moderate subangular blocky structure; many coarse fragments consisting of siltstones with Fe-Mn enrichment in the centre, medium interstitial voids; low porosity; no roots; hematite mottles; Fe-, Mn-concretions; diffuse and smooth boundary to BCg.

Horizon	Depth [cm]	Description
BCg	95-130	Olive yellow (7.5 Y 6/3); clay, weak subangular blocky structure; many coarse fragments; medium interstitial voids; low porosity; no roots; hematite mottles; Fe-, Mn- concretions; clear and smooth boundary to Cw1.
Cw1	130-165	Bright yellowish brown (10 YR 6/8); silty clay loam; massive; dominant coarse fragments consisting of claystone; fine interstitial voids; very low porosity; no roots; gradual and smooth boundary to Cw2.
Cw2	165-200	Bright yellowish brown (2.5 Y 6/8); silty clay; massive; dominant coarse fragments consisting of claystone; fine interstitial voids; very low porosity; no roots.

9.3.32 Profile 1678 Ferri-Stagnic Luvisol – Bor Krai

Classification: Ferri-Stagnic Luvisol
Date of examination: 04.12.2003
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 32 59.46; E98 13 16.29
Parent rock: sandstone, siltstone, claystone
Geology: Permian
Physiographic position: on linear slope (approx. 15˚)
Vegetation: shrubs and trees
Remark: 3 years fallow

Profile description:

Horizon	Depth [cm]	Description
Ah	0-16	Greyish yellow brown (10 YR 4/2); clay loam; moderate crumb to subangular blocky structure; few coarse fragments; medium interstitial voids; medium porosity; few fine roots; charcoal; brick; clear and smooth boundary to AB.
AB	16-30	Dull yellowish brown (10 YR 4/3); silty clay; moderate medium subangular blocky structure; very few coarse fragments; medium interstitial voids, few vughs and channels of termites; medium porosity; very few medium and coarse roots; charcoal, brick; abrupt and smooth boundary to Btg1.
Btg1	30-52	Brown (7.5 YR 4/4); clay; moderate medium subangular to fine angular blocky structure; very few coarse fragments; fine interstitial voids, planes; Fe-, Mn-concretions; few faint red (10 R 5/6) hematite mottles; clear and smooth boundary to Btg2.
Btg2	52-75	Yellowish brown (10 YR 5/6); clay; moderate angular blocky to subangular blocky structure; few coarse fragments; fine interstitial voids, planes; common faint red (10 R 5/6) hematite mottles; clear and smooth boundary to Btg3.
Btg3	75-89	Brown (10 YR 4/6); clay; weak medium subangular blocky structure; few coarse fragments; fine interstitial voids; Fe-, Mn-concretions; many prominent red (10 R 5/6) hematite mottles; abrupt and wavy boundary to Bg.

Horizon	Depth [cm]	Description
Bg	89-119	Brown (7.5 YR 4/3); clay; weak fine subangular blocky structure; many coarse fragments consisting of yellow (10 YR 7/8) siltstones with Fe-, Mn-oxide in the centre; fine interstitial voids; common faint red (10 R 4/8) hematite mottles; clear and discontinuous boundary to BCg.
BCg	119-152	Greyish brown (7.5 YR 4/2); clay; weak fine subangular blocky structure; abundant coarse fragments consisting of yellow orange (10 YR 7/8) siltstone with a maximum diameter of 3 cm; fine interstitial voids; Fe-, Mn- concretions; clear and smooth boundary to Cw.
Cw	152-171	Dark greyish yellow (2.5 Y 5/2) soil matrix with black (10YR 2/1) veins; clay loam; massive; abundant coarse fragments consisting of yellow orange (10 YR 7/8) siltstone and claystone, claystone fragments show precipitation of Fe-, Mn-oxides in the centre; fine interstitial voids; abrupt and smooth boundary to C.
C	171-200	Yellow orange (10 YR 7/8) to brown (7.5 YR 4/4) siltstone and sandstone with black (10 YR 2/1) veins and some yellowish brown (2.5 Y 5/4) claystone layers; soil material in between consists of sandy loam.

9.3.33 Profile 1679 (1757) Dystri-Profondic Luvisol – Bor Krai

Classification: Dystri-Profondic Luvisol
Date of examination: 21.04.2004
Location: Bor Krai, Pang Ma Pha district, Mae Hong Son province
Position: N19 32 51.96; E98 13 50.31
Parent rock: latite
Geology: Triassic (?)
Physiographic position: slope linear (approx. 10°)
Vegetation: maize
Remark: -

Profile description:

Horizon	Depth [cm]	Description
Ah1	0-14	Dark brown (7.5 YR 3/4); silty clay; medium crumb to subangular blocky structure; very few coarse fragments; fine interstitial voids; low porosity; few fine roots; charcoal; brick; abrupt and smooth boundary to Ah2.
Ah2	14-27	Brown (7.5 YR 4/4); clay; medium crumb to subangular blocky structure; common coarse fragments consisting of latite; fine interstitial voids; low porosity; very few fine roots; charcoal; abrupt and smooth boundary to Bt1.
Bt1	27-53	Reddish brown (5 YR 4/6); clay; angular blocky to prismatic structure; common coarse fragments consisting of altered yellowish latite; fine interstitial voids, planes; very few fine roots; clay skins; abrupt and wavy boundary to Bt2.
Bt2	53-67	Reddish brown (5 YR 4/6); clay; angular blocky to prismatic structure; common coarse fragments mainly within a stone layer consisting of yellow orange (10YR 7/8) latite with Fe-, Mn- oxides in the centre; fine interstitial voids, planes; very few fine roots; Fe-, Mn-concretions; clay skins; abrupt and wavy boundary to Bt3.
Bt3	67-94	Dull reddish brown (2.5 YR 4/4); clay; prismatic structure; very few coarse fragments consisting of yellow latite; planes; no roots; Fe-, Mn- concretions; slickensides; abrupt and wavy boundary to Bt4.

Horizon	Depth [cm]	Description
Bt4	94-104	Greyish red (7.5 YR 6/2); clay; prismatic structure; few coarse fragments consisting of yellow weathered latite; planes; no roots; Fe-, Mn- concretions; slickensides; clear and smooth boundary to Bt5.
Bt5	104-142	Greyish red (7.5 YR 6/2); clay; fine weak subangular blocky structure; very few coarse fragments consisting of yellow weathered latite; planes; no roots; slickensides; clear and smooth boundary to Bt6.
Bt6	142-169	Greyish brown (7.5 YR 5/2); clay; fine weak subangular blocky structure; very few coarse fragments consisting of yellow weathered latite; planes; no roots; slickensides; clear and smooth boundary to Bt7.
Bt7	169-200	Greyish brown (7.5 YR 6/2); clay; fine weak subangular blocky to angular blocky structure; no coarse fragments; slickensides; planes; no roots.

9.4 Figures

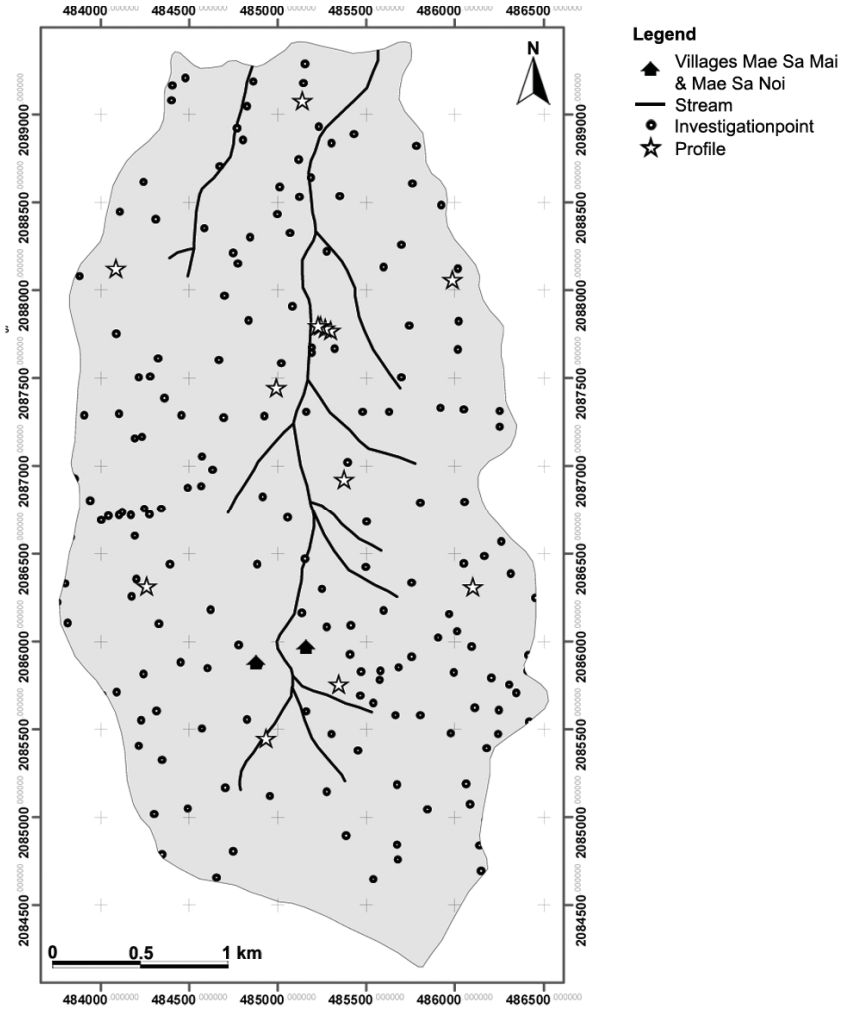

Figure 9-1: Soil probes and soil profiles in the Mae Sa Mai area

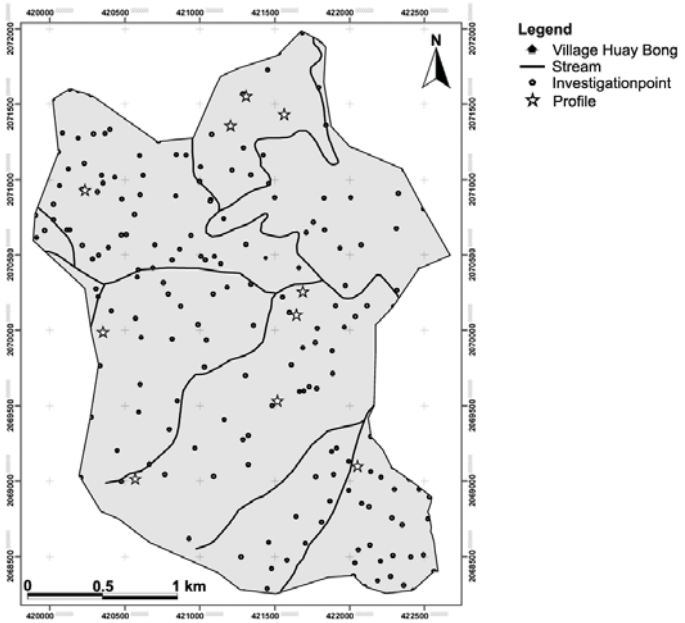

Figure 9-2: Soil probes and soil profiles in the Huay Bong area

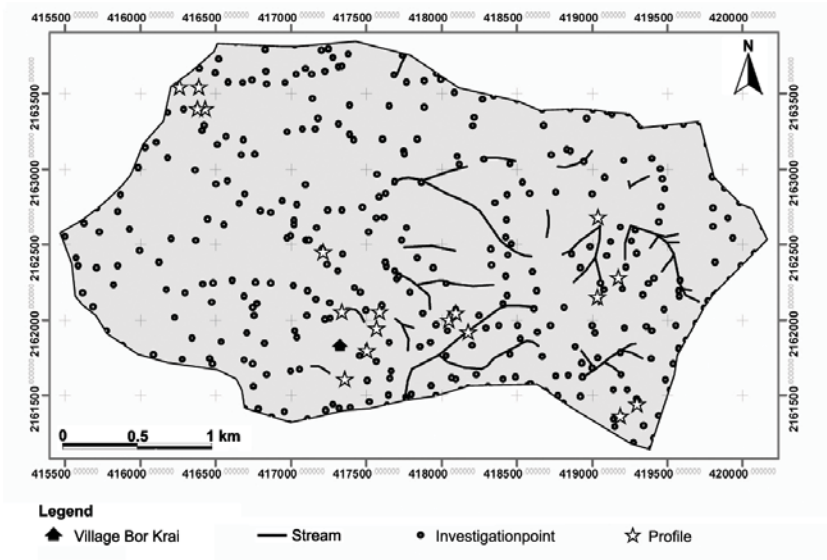

Figure 9-3: Soil probes and soil profiles in the Bor Krai karst area

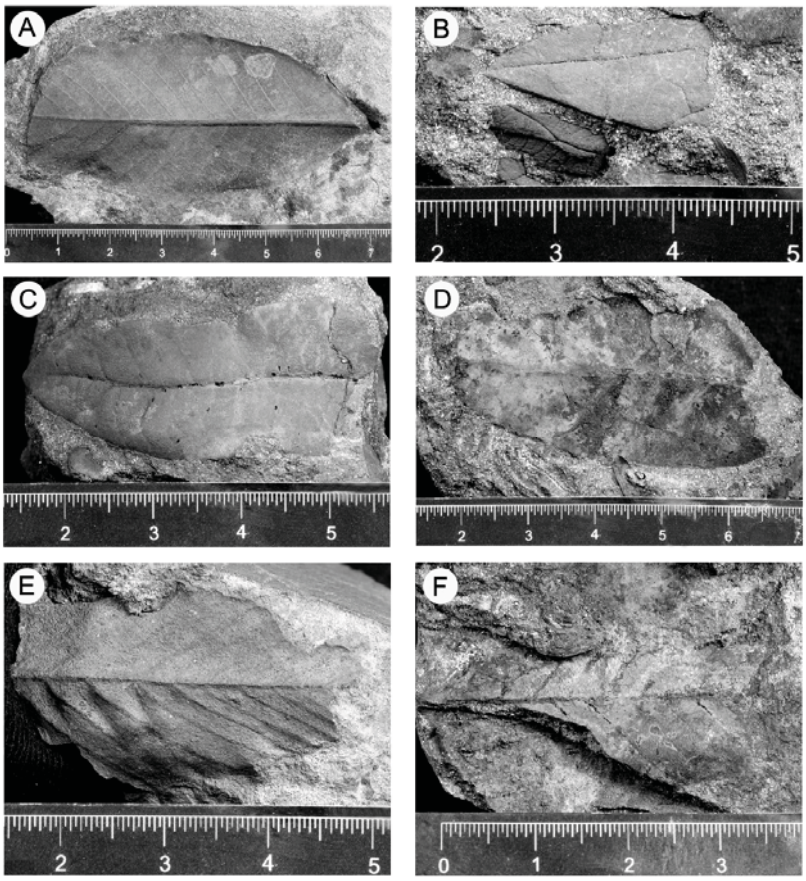

Figure 9-4: Fossil leaves in the Huay Bong area. (A), (C)-(F) *Alnus sp.* (Betulaceae), (B) *Ficus sp.* (Moraceae)

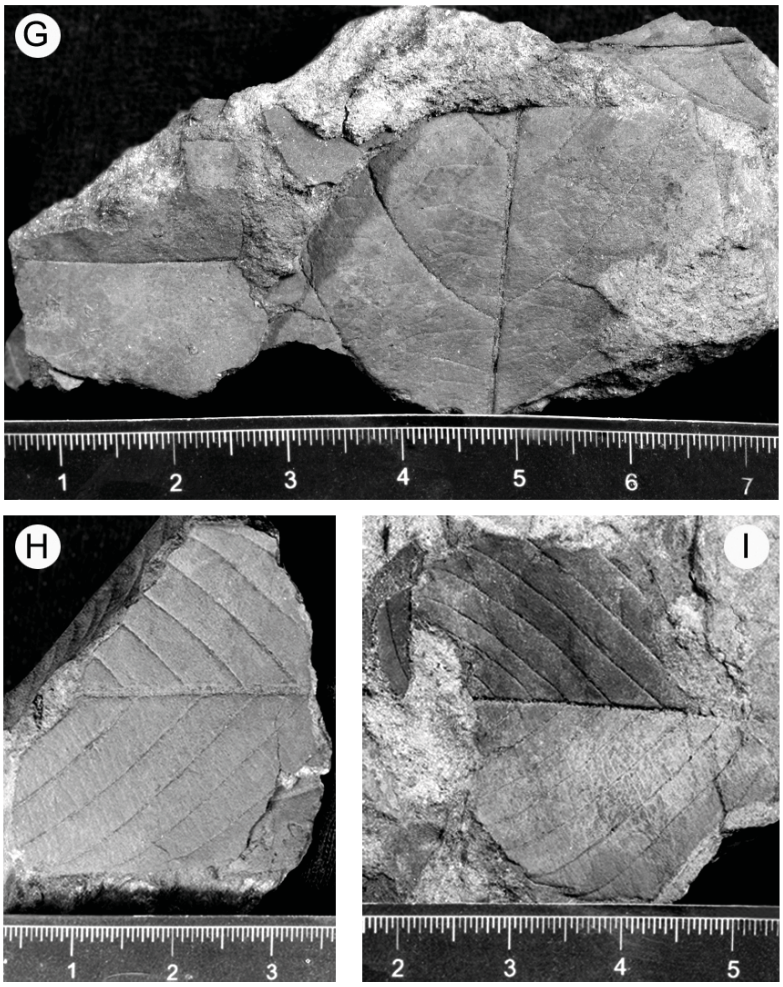

Figure 9-5: Fossil leaves of the Huay Bong area. (G)-(I) *Alnus sp.*

9.5 Analytical data of reference profiles

Table 9-1: Soil profile 501* – Mae Sa Mai: Humi-Ferralic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 51 55	E98 51 39	1120	Granite	Palaeozoic	29.06.2003	Forest	Evergreen trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	16	Ah	7.5 YR 3/2	0.8	38.1	17.1	44.8	Clay
2	35	BA	5 YR 3/4	4.2	39.0	12.2	48.8	Clay
3	59	Bw1	5 YR 4/6	2.3	37.6	11.2	51.2	Clay
4	79	Bw2	5 YR 4/8	1.4	37.3	9.9	52.8	Clay
5	103	Bw3	5 YR 4/8	1.4	36.5	9.9	53.6	Clay
6	133	Bw4	5 YR 4/8	2.3	35.4	9.4	55.2	Clay
7	162	Bw5	2.5 YR 4/6	2.1	35.3	9.5	55.2	Clay
8	187	Bw6	2.5 YR 4/8	1.9	35.1	9.7	55.2	Clay
9	200	Bw7	2.5 YR 4/8	2.0	35.0	9.7	55.3	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	37.57	32.87	12.27	0.04	1.92	6.20	3.77	0.09	31.73
2	21.98	25.07		0.01	0.64	0.54	0.54		7.83
3	20.81	28.89	3.30	0.00	0.53	0.47	0.49	1.65	7.14
4	16.63	26.45	2.69	0.00	0.42	0.33	0.44	1.43	6.82
5	14.76	23.17	2.48	0.00	0.27	0.13	0.35	1.54	4.83
6	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	49.8	0.0	3.40	2.95	677	5.88	4.17	0.80
2	NA	NA	NA	21.2	0.0	1.70	0.22	579	5.74	4.15	1.06
3	NA	NA	NA	13.1	0.0	1.00	0.22	452	5.80	4.12	1.07
4	NA	NA	NA	5.8	0.0	0.50	0.20	460	5.63	4.10	1.07
5	NA	NA	NA	5.1	0.0	0.40	0.21	455	5.60	4.20	1.20
6	NA	NA	NA	4.4	0.0	0.30	0.22	534	5.68	4.35	1.22
7	NA	NA	NA	4.1	0.0	0.30	0.21	465	5.70	4.40	1.23
8	NA	NA	NA	4.1	0.0	0.30	0.22	391	5.93	4.55	1.24
9	NA	NA	NA	4.1	0.0	0.20	0.20	260	5.90	4.60	1.25

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-2: Soil profile 502* – Mae Sa Mai: Humi-Ferralic Cambisol

Latitude	Longitude	Elevation [m a.m.s.l.]	Rock	Geology	Sampling date	Land use	Vegetation
N18 52 13	E98 52 05	1140	Granite	Palaeozoic	22.06.2003	Forest	Pine trees

No.	Depth	Horizon	Colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	8	Ah	5 YR 2.5/2	1.1	36.5	20.3	43.2	Clay
2	20	AB	5 YR 3/4	5.7	38.3	13.7	48.0	Clay
3	48	Bw1	2.5 YR 4/6	3.4	35.5	14.1	50.4	Clay
4	66	Bw2	2.5 YR 4/8	4.9	34.9	14.7	50.4	Clay
5	83	Bw3	2.5 YR 4/8	4.5	34.5	14.3	51.2	Clay
6	109	Bw4	2.5 YR 5/8	35.0	35.9	20.9	43.2	Clay
7	130	Bw5	2.5 YR 5/8	30.0	34.0	19.5	46.5	Clay
8	149	Bw6	2.5 YR 5/8	5.0	32.0	20.5	47.5	Clay
9	170	BC1	5 YR 6/8	2.7	46.1	27.5	26.4	Sandy clay loam
10	200	BC2	5 YR 6/8	2.8	45.0	27.1	27.9	Sandy clay loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	25.62	5.01	7.51	0.18	0.74	3.64	2.18	0.58	26.32
2	17.76	19.63	NA	0.11	0.73	0.47	1.11	NA	13.59
3	15.47	21.52	NA	0.07	0.55	0.31	0.62	NA	9.94
4	12.21	25.87	NA	0.13	0.37	0.00	0.08	NA	4.73
5	8.68	20.37	NA	0.00	0.33	0.01	0.08	NA	4.49
6	7.31	13.91	1.50	0.00	0.31	0.04	0.12	1.03	5.80
7	NA	13.32	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	51.1	0.0	2.70	3.88	646	5.00	4.15	0.83
2	NA	NA	NA	22.2	0.0	1.20	0.22	800	5.63	4.20	1.05
3	NA	NA	NA	7.3	0.0	0.50	0.22	524	5.47	4.14	1.26
4	NA	NA	NA	5.8	0.0	0.40	0.22	401	5.88	4.20	1.29
5	NA	NA	NA	4.6	0.0	0.30	0.22	300	5.80	4.10	1.30
6	NA	NA	NA	4.6	0.0	0.30	0.22	287	5.85	4.05	1.45
7	NA	NA	NA	3.5	0.0	0.20	0.22	300	5.82	4.10	1.47
8	NA	NA	NA	3.5	0.0	0.20	0.22	450	5.83	4.14	1.51
9	NA	NA	NA	3.5	0.0	0.20	0.22	487	5.86	4.10	1.52
10	NA	NA	NA	2.9	0.0	0.10	0.20	350	5.80	4.10	1.53

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-3: Soil profile 503* – Mae Sa Mai: Humi-Ferralic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 52 13	E98 51 02	1100	Paragneiss (with marble)	Precambrian	29.06.2003	Forest	deciduous trees

No.	Depth [cm]	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
				[% m]				
1	13	Ah1	5 YR 2.5/2	1.4	49.2	22.8	28.0	Sandy clay loam
2	28	Ah2	5 YR 2.5/2	0.8	46.8	23.6	29.6	Sandy clay loam
3	42	AB	5 YR 2.5/2	2.2	50.0	22.0	28.0	Sandy clay loam
4	68	Bw1	5 YR 3/4	4.5	55.5	20.5	24.0	Sandy clay loam
5	97	Bw2	7.5 YR 4/4	4.0	52.5	19.5	28.0	Sandy clay loam
6	120	Bw3	7.5 YR 4/4	3.8	66.8	14.8	18.4	Sandy loam
7	145	Bw4	7.5 YR 4/4	3.5	67.5	14.0	18.5	Sandy loam
8	176	BC1	7.5 YR 4/4	2.1	72.3	14.1	13.6	Sandy loam
9	200	BC2	7.5 YR 4/4	2.1	70.1	14.0	15.9	Sandy loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	30.42	21.08	16.52	0.00	0.78	12.48	3.23	0.02	54.14
2	25.69	32.03	13.65	0.00	0.56	10.19	2.85	0.06	52.80
3	22.19	22.99	10.71	0.00	0.35	7.62	2.69	0.07	47.94
4	13.67	23.61	6.20	0.00	0.28	3.83	1.94	0.16	43.97
5	13.65	30.66	5.92	0.00	0.20	3.39	1.96	0.37	40.66
6	12.86	45.11	5.52	0.08	0.22	3.41	1.34	0.43	39.28
7	5.47	7.66	4.91	0.00	0.34	2.97	1.03	0.57	79.27
8	11.62	63.09	5.10	0.00	0.60	2.93	1.33	0.19	41.65
9	10.28	48.72	4.67	0.01	0.61	2.59	1.24	0.14	43.24

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	28.1	0.0	2.3	2.03	793	6.38	5.30	1.08
2	NA	NA	NA	18.6	0.0	1.5	0.22	673	6.46	5.23	1.20
3	NA	NA	NA	18.0	0.0	1.5	0.22	761	6.15	5.07	1.24
4	NA	NA	NA	9.2	0.0	0.8	0.22	420	6.17	4.99	1.45
5	NA	NA	NA	5.8	0.0	0.5	0.31	400	6.10	4.60	1.40
6	NA	NA	NA	5.2	0.0	0.4	0.67	510	6.04	4.52	1.36
7	NA	NA	NA	4.6	0.0	0.3	0.22	500	6.05	4.60	1.37
8	NA	NA	NA	3.5	0.0	0.3	0.22	484	6.11	4.57	1.35
9	NA	NA	NA	2.9	0.0	0.2	0.22	350	6.12	4.70	1.36

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-4: Soil profile 504* – Mae Sa Mai: Profondi-Humic Acrisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 53 10	E98 52 01	890	Gneiss	Precambrian	28.06.2003	Forest	Dry deciduous trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	10	Ah	7.5 YR 3/2	1.2	54.1	19.5	26.4	Sandy clay loam
2	23	AB	5 YR 4/6	1.3	48.5	17.9	33.6	Sandy clay loam
3	42	Bt1	2.5 YR 4/4	0.2	37.5	12.1	50.4	Clay
4	67	Bt2	2.5 YR 4/6	0.4	37.5	12.9	49.6	Clay
5	109	Bt3	2.5 YR 4/6	0.4	35.0	12.0	53.0	Clay
6	131	Bt4	2.5 YR 4/8	0.5	43.3	11.9	44.8	Clay
7	150	Bt5	2.5 YR 4/8	0.5	43.5	12.0	44.6	Clay
8	173	Bt6	2.5 YR 4/8	4.5	38.9	17.1	44.0	Clay
9	198	Bt7	2.5 YR 4/8	4.1	37.5	18.1	44.4	Clay
10	200	Bt8	2.5 YR 4/8	4.0	36.5	18.0	45.5	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	19.70	15.22	8.92	-0.03	0.85	5.01	3.07	0.00	45.18
2	12.34	18.26	NA	0.08	0.65	0.19	0.52	NA	11.67
3	13.21	20.29	2.54	0.08	0.43	0.10	0.60	1.19	9.08
4	11.55	20.17	2.24	0.14	0.32	0.08	0.62	0.86	10.05
5	5.41	8.30	1.82	0.05	0.27	0.06	0.53	0.66	16.85
6	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	34.2	0.0	1.40	7.12	301	5.00	4.00	1.09
2	NA	NA	NA	13.5	0.0	0.70	4.02	153	5.11	4.10	1.36
3	NA	NA	NA	6.5	0.0	0.40	2.30	102	4.85	4.00	1.35
4	NA	NA	NA	3.4	0.0	0.30	2.39	90	4.99	4.00	1.37
5	NA	NA	NA	2.2	0.0	0.20	2.29	82	5.20	4.10	1.35
6	NA	NA	NA	2.1	0.0	0.20	2.87	90	5.11	4.20	1.31
7	NA	NA	NA	1.7	0.0	0.20	2.50	85	5.20	4.20	1.34
8	NA	NA	NA	1.2	0.0	0.10	2.00	75	5.30	4.30	1.42
9	NA	NA	NA	0.6	0.0	0.10	2.00	75	5.40	4.40	1.43
10	NA	NA	NA	0.6	0.0	0.10	2.00	70	5.50	4.50	1.45

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-5: Soil profile 505* – Mae Sa Mai: Profondi-Humic Acrisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 53 43	E98 51 32	670	Gneiss	Precambrian	21.06.2003	Forest	Evergreen trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	9	Ah	7.5 YR 3/2	0.7	34.1	22.7	43.2	Clay
2	22	BA	5 YR 4/4	0.3	26.3	17.7	56.0	Clay
3	39	Bt1	2.5 YR 4/4	0.3	21.3	15.5	63.2	Clay
4	65	Bt2	2.5 YR 4/4	0.2	22.9	17.1	60.0	Clay
5	96	Bt3	2.5 YR 4/4	0.2	23.5	17.5	59.0	Clay
6	119	Bt4	2.5 YR 4/6	0.3	25.3	17.9	56.8	Clay
7	143	Bt5	2.5 YR 4/6	0.4	25.2	18.0	56.8	Clay
8	164	Bt6	2.5 YR 4/6	0.6	25.4	19.4	55.2	Clay
9	189	Bt7	2.5 YR 4/6	0.7	25.0	19.3	55.7	Clay
10	200	Bt8	2.5 YR 4/6	0.8	26.0	19.5	54.5	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	16.35	26.05	8.93	0.04	1.00	5.30	2.57	0.01	54.45
2	4.39	4.07	NA	0.03	0.68	0.47	0.62	NA	40.94
3	10.50	14.80	NA	0.18	0.62	0.07	0.13	NA	9.53
4	9.82	14.69	2.31	0.01	0.50	0.17	0.24	1.31	9.44
5	10.32	15.96	7.00	-0.02	0.38	0.13	0.20	6.30	6.75
6	9.98	16.17	2.00	0.33	0.15	0.30	0.33	0.72	11.08
7	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	27.8	0.0	2.50	2.49	179	4.84	4.63	0.90
2	NA	NA	NA	11.5	0.0	1.10	0.67	259	5.48	4.06	1.26
3	NA	NA	NA	6.3	0.0	0.60	0.22	226	5.41	4.13	1.18
4	NA	NA	NA	5.5	0.0	0.50	0.22	200	5.68	4.50	1.16
5	NA	NA	NA	4.9	0.0	0.40	0.22	190	5.70	4.55	1.25
6	NA	NA	NA	4.4	0.0	0.40	0.22	167	6.14	4.18	1.27
7	NA	NA	NA	3.8	0.0	0.40	0.22	150	6.10	5.00	1.25
8	NA	NA	NA	2.9	0.0	0.30	3.41	128	6.01	4.10	1.23
9	NA	NA	NA	2.3	0.0	0.30	1.00	100	6.00	4.95	1.24
10	NA	NA	NA	1.7	0.0	0.20	2.00	90	6.00	5.00	1.26

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-6: Soil profile 506* – Mae Sa Mai: Humi-Ferralic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 51 45	E98 51 25	1090	granite	Palaeozoic	28.06.2003	Agriculture	Fruit trees, vegetables

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	15	Ap	7.5 YR 3/2	6.3	41.3	20.3	38.4	Clay loam
2	27	BA	5 YR 3/4	6.8	43.3	15.1	41.6	Clay
3	42	Bw1	5 YR 4/6	45.2	41.6	13.6	44.8	Clay
4	61	Bw2	2.5 YR 4/4	13.6	39.1	15.3	45.6	Clay
5	92	Bw3	2.5 YR 4/6	15.0	39.5	15.2	45.3	Clay
6	129	Bw4	2.5 YR 4/6	67.6	39.9	14.5	45.6	Clay
7	146	Bw5	2.5 YR 4/6	20.0	38.0	17.0	45.0	Clay
8	168	Bw6	2.5 YR 4/6	11.5	37.9	18.1	44.0	Clay
9	200	Bw7	2.5 YR 4/6	5.0	37.5	18.0	44.5	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	22.70	25.49	5.00	0.01	0.65	2.94	0.45	0.75	17.83
2	16.90	23.66	3.86	0.01	0.33	0.56	0.05	0.65	5.64
3	20.45	35.43	3.04	0.09	0.28	0.53	0.08	2.06	4.81
4	12.41	21.38	3.55	0.13	0.34	2.56	0.41	0.02	27.72
5	9.89	16.54	3.36	0.08	0.42	2.27	0.57	0.00	33.63
6	10.84	19.10	3.45	0.26	0.26	2.12	0.76	0.00	31.39
7	8.64	15.06	3.48	0.20	0.25	1.88	0.97	0.01	38.24
8	10.18	19.51	4.00	0.15	0.25	2.14	1.45	0.00	39.30
9	8.94	17.10	2.69	0.00	0.25	1.22	1.21	0.00	30.05

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	28.1	0.0	2.70	13.77	1222	4.71	4.33	1.05
2	NA	NA	NA	15.4	0.0	1.50	0.22	646	5.10	4.00	1.12
3	NA	NA	NA	10.0	0.0	1.00	0.22	586	5.02	4.13	1.16
4	NA	NA	NA	5.8	0.0	0.60	0.22	450	5.18	4.00	1.20
5	NA	NA	NA	5.2	0.0	0.40	0.22	300	5.50	4.15	1.23
6	NA	NA	NA	4.6	0.0	0.40	0.22	233	6.35	5.46	1.24
7	NA	NA	NA	4.1	0.0	0.30	0.22	150	5.80	4.12	1.35
8	NA	NA	NA	3.5	0.0	0.30	1.12	120	5.72	5.51	1.40
9	NA	NA	NA	2.9	0.0	0.30	0.90	100	5.70	4.35	1.41

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-7: Soil profile 507* – Mae Sa Mai: Profondi-Humic Acrisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 52 33	E98 51 40	865	Gneiss	Precambrian	21.06.2003	Agriculture	Fruit trees, vegetables

No.	Depth [cm]	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
				[% m]				
1	20	Ap	7.5 YR 3/2	0.1	45.8	18.2	36.0	Sandy clay
2	45	Bt1	5 YR 3/4	4.3	40.0	16.0	44.0	Clay
3	62	Bt2	5 YR 4/6	10.7	38.8	12.4	48.8	Clay
4	78	Bt3	2.5 YR 4/6	1.6	34.2	18.2	47.7	Clay
5	105	Bt4	2.5 YR 4/6	1.7	35.0	17.0	48.0	Clay
6	133	Bt5	2.5 YR 4/6	16.2	38.1	17.1	44.8	Clay
7	159	Bt6	2.5 YR 4/6	17.0	39.5	18.5	42.0	Clay
8	187	Bt7	2.5 YR 4/6	30.5	41.5	20.9	37.6	Clay loam
9	200	Bt8	2.5 YR 4/6	20.0	41.2	20.5	38.3	Clay loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	15.84	10.72	4.23	-0.05	0.84	1.71	0.94	0.71	21.72
2	11.36	11.36	2.65	0.03	0.25	0.54	0.39	1.40	10.60
3	8.31	9.01	1.89	-0.01	0.12	0.42	0.32	0.87	10.30
4	8.65	13.37		0.06	0.17	0.67	0.50		16.25
5	7.67	10.99	1.55	-0.04	0.13	0.32	0.41	0.57	10.77
6	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	26.1	0.0	2.00	10.18	548	6.15	4.74	0.97
2	NA	NA	NA	13.9	0.0	1.10	0.22	117	5.00	3.97	1.31
3	NA	NA	NA	8.5	0.0	0.70	0.22	83	5.26	3.96	1.43
4	NA	NA	NA	5.8	0.0	0.50	0.22	70	5.57	4.10	1.37
5	NA	NA	NA	5.2	0.0	0.50	0.22	60	5.40	4.10	1.42
6	NA	NA	NA	4.6	0.0	0.40	0.22	57	5.31	4.12	1.45
7	NA	NA	NA	4.1	0.0	0.40	0.22	80	5.50	4.20	1.45
8	NA	NA	NA	3.5	0.0	0.30	0.22	143	5.76	4.19	1.46
9	NA	NA	NA	2.9	0.0	0.30	0.22	120	5.80	4.50	1.45

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-8: Soil profile 508* – Mae Sa Mai: Dystri-Humic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 52 50	E98 51 27	850	Granite	Palaeozoic	15.06.2003	Agriculture	Fruit trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	14	Ap	5 YR 3/4	0.1	41.2	18.04	40.8	Clay
2	32	Bw1	5 YR 4/6	0.2	28.2	11.80	60.0	Clay
3	53	Bw2	2.5 YR 4/4	0.3	28.9	11.12	60.0	Clay
4	73	Bw3	2.5 YR 4/4	0.3	31.1	12.86	56.0	Clay
5	97	Bw4	2.5 YR 4/4	0.3	30.9	12.50	56.6	Clay
6	126	Bw5	2.5 YR 4/4	0.5	30.8	12.42	56.8	Clay
7	146	Bw6	2.5 YR 4/6	0.3	32.5	12.30	55.2	Clay
8	169	Bw7	2.5 YR 4/6	0.3	33.3	12.26	54.4	Clay
9	190	Bw8	2.5 YR 4/6	0.4	33.1	12.30	54.6	Clay
10	200	Bw9	2.5 YR 4/6	0.5	33.2	12.40	54.4	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	19.21	36.68	11.06	-0.03	1.17	8.41	1.41	0.00	57.07
2	17.29	24.83	8.41	-0.01	0.42	6.93	0.96	0.00	48.00
3	17.30	26.29	7.10	0.00	0.27	5.85	0.94	0.00	40.80
4	15.71	25.88	NA	0.00	0.28	5.15	0.93	NA	40.50
5	15.96	26.17	5.25	0.00	0.26	4.06	0.86	0.03	32.49
6	16.02	26.54	5.95	-0.01	0.32	4.71	0.85	0.07	36.70
7	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	18.2	0.0	1.50	5.77	462	6.44	5.25	1.18
2	NA	NA	NA	10.3	0.0	1.00	0.22	500	6.11	4.92	1.29
3	NA	NA	NA	6.6	0.0	0.80	0.22	351	5.99	5.00	1.22
4	NA	NA	NA	5.2	0.0	0.60	0.22	250	6.28	5.10	1.21
5	NA	NA	NA	4.9	0.0	0.50	0.22	200	5.80	4.70	1.20
6	NA	NA	NA	4.1	0.0	0.40	0.22	102	5.32	4.29	1.20
7	NA	NA	NA	3.5	0.0	0.30	0.22	110	5.42	4.10	1.25
8	NA	NA	NA	3.5	0.0	0.30	0.22	125	5.52	4.16	1.32
9	NA	NA	NA	2.9	0.0	0.30	0.22	126	5.60	4.20	1.35
10	NA	NA	NA	2.9	0.0	0.30	0.22	130	5.70	4.30	1.40

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-9: Soil profile 509* – Mae Sa Mai: Humi-Ferralic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 53 12	E98 50 56	905	Granite	Palaeozoic	14.06.2003	Agriculture	Under cultivation of agronomy

No.	Depth [cm]	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
				[% m]				
1	20	Ap	5 YR 4/4	0.3	34.6	12.6	52.8	Clay
2	40	Bw1	2.5 YR 3/6	0.1	30.3	9.7	60.0	Clay
3	62	Bw2	2.5 YR 4/6	0.1	29.4	7.4	63.2	Clay
4	85	Bw3	2.5 YR 4/6	0.3	29.0	9.4	61.6	Clay
5	107	Bw4	2.5 YR 4/6	0.2	28.0	9.5	62.5	Clay
6	130	Bw5	2.5 YR 4/6	0.2	28.4	9.2	62.4	Clay
7	156	Bw6	2.5 YR 4/6	0.2	27.5	9.1	63.4	Clay
8	179	Bw7	2.5 YR 4/6	0.2	27.0	9.0	64.0	Clay
9	200	Bw8	2.5 YR 4/6	0.2	25.9	9.0	65.1	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	28.53	14.56	9.06	0.00	1.53	4.95	2.37	0.05	30.89
2	22.09	13.03	3.76	0.00	0.32	1.28	0.67	1.16	10.25
3	17.71	16.63	3.02	0.07	0.21	0.59	0.34	1.56	6.78
4	11.29	9.18		0.00	0.13	0.14	0.12		3.09
5	12.87	12.58	1.78	0.03	0.12	0.05	0.09	1.23	2.23
6	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	19.3	0.0	1.40	18.06	238	5.01	4.02	1.01
2	NA	NA	NA	13.2	0.0	0.80	0.22	44	5.30	4.17	1.22
3	NA	NA	NA	6.7	0.0	0.50	0.22	45	5.21	4.51	1.18
4	NA	NA	NA	5.2	0.0	0.50	0.22	46	5.67	4.61	1.21
5	NA	NA	NA	4.6	0.0	0.40	0.22	50	5.50	4.40	1.20
6	NA	NA	NA	4.1	0.0	0.40	0.22	54	4.87	4.41	1.11
7	NA	NA	NA	3.5	0.0	0.30	0.22	46	4.80	4.40	1.25
8	NA	NA	NA	2.9	0.0	0.30	0.22	34	4.72	4.44	1.29
9	NA	NA	NA	2.9	0.0	0.30	0.22	30	4.70	4.40	1.30

*Manajuti et al. 2004 – except analysis of CEC, exchangeable cations

Table 9-10: Soil profile 971 (1766) – Huay Bong: Cutani-Abruptic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 43 20.56	E98 15 24.05	724	Breccia	Upper Carboniferous	29.12.2004	Agriculture	Rice

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	7	Ah	7.5 YR 2/3	15.2	64.7	24.0	11.3	Sandy loam
2	22	E	5 YR 4/6	37.0	58.8	29.4	11.8	Sandy loam
3	43	Bt1	2.5 YR 5/8	24.6	35.3	22.4	42.3	Clay
4	62	Bt2	2.5 YR 5/8	15.7	22.9	18.4	58.7	Clay
5	81	Bt3	NA	99.0	NA	NA	NA	NA
6	99	Bt4	2.5 YR 4/8	9.2	28.0	23.9	48.1	Clay
7	128	Bt5	2.5 YR 4/8	2.1	29.8	26.0	44.3	Clay
8	162	Bt6	2.5 YR 6/1	21.4	34.7	27.0	38.3	Clay loam
9	200	Bt7	2.5 YR 6/1	16.3	37.5	24.5	38.0	Clay loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	15.11	131.28	5.75	0.01	0.31	3.20	2.08	0.03	37.04
2	5.55	46.52	2.21	0.02	0.17	0.22	0.76	0.63	20.77
3	15.74	36.73	7.61	0.02	0.40	0.20	2.45	3.68	19.53
4	22.12	38.01	10.43	0.02	0.56	0.18	2.95	5.58	16.77
5	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	17.80	37.49	8.98	0.02	0.41	0.10	2.13	5.05	14.93
7	17.07	38.92	7.97	0.02	0.31	0.11	1.48	4.94	11.24
8	14.07	37.29	7.47	0.02	0.19	0.09	0.86	5.34	8.23
9	14.20	37.84	7.14	0.02	0.13	0.06	0.52	5.40	5.10

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	20.1	0.0	0.95	17.11	91	5.92	NA	NA
2	NA	NA	NA	3.8	0.0	0.20	7.75	43	5.82	NA	NA
3	NA	NA	NA	3.6	0.0	0.33	0.62	76	5.26	NA	NA
4	NA	NA	NA	2.9	0.0	0.38	0.26	96	5.38	NA	NA
5	NA	NA	NA	NA	0.0	NA	NA	NA	5.49	NA	NA
6	NA	NA	NA	1.4	0.0	0.28	0.06	72	5.60	NA	NA
7	NA	NA	NA	0.9	0.0	0.19	0.05	48	5.44	NA	NA
8	NA	NA	NA	0.3	0.0	0.12	0.05	19	5.31	NA	NA
9	NA	NA	NA	0.0	0.0	0.06	0.00	6	5.36	NA	NA

Table 9-11: Soil profile 973 (1767) – Huay Bong: Endoskeleti-Profondic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 42 45.01	E98 14 47.39	902	Sandstone	Upper Carboniferous	30.12.2004	Agriculture	Rice

No.	Depth [cm]	Horizon	Soil colour	Skeleton [% m]	Sand [% m]	Silt [% m]	Clay [% m]	Texture
1	14	Ah	7.5 YR 2/3	2.8	55.3	24.1	20.5	Sandy clay loam
2	30	E	5 YR 4/6	21.6	48.4	24.2	27.5	Sandy clay loam
3	43	Bt1	5 YR 3/6	5.1	44.5	22.1	33.4	Sandy clay loam
4	68	Bt2	5 YR 3/6	59.3	43.5	20.9	35.7	Clay loam
5	87	Bt3	5 YR 3/6	76.4	44.0	21.4	34.5	Sandy clay loam
6	107	Bt4	2.5 YR 4/8	64.3	48.4	22.0	29.7	Sandy clay loam
7	135	Bt5	2.5 YR 4/8	36.7	41.8	27.3	31.0	Clay loam
8	156	Bt6	5 YR 6/8	54.1	39.3	28.1	32.6	Clay loam
9	200	Cw	5 YR 6/8	75.0	39.9	28.6	31.5	Clay loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	18.17	59.82	7.26	0.01	0.99	4.02	2.10	0.00	39.23
2	11.73	36.88	4.02	0.03	0.19	0.10	0.19	2.48	4.33
3	13.48	36.72	4.54	0.01	0.19	0.07	0.14	3.41	3.03
4	13.55	35.44	5.33	0.03	0.17	0.18	0.15	3.59	3.90
5	13.73	38.03	6.17	0.05	0.16	0.18	0.35	3.30	5.42
6	11.79	38.40	5.41	0.03	0.11	0.17	0.35	3.03	5.57
7	12.18	38.06	5.62	0.04	0.10	0.20	0.40	3.41	6.10
8	12.93	38.34	6.34	0.05	0.09	0.26	0.47	3.15	6.72
9	12.75	40.46	5.68	0.02	0.09	0.24	0.50	4.17	6.65

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	20.9	0.0	1.38	3.46	307	6.20	NA	NA
2	NA	NA	NA	6.1	0.0	0.52	0.35	31	4.99	NA	NA
3	NA	NA	NA	4.5	0.0	0.46	0.10	22	4.92	NA	NA
4	NA	NA	NA	3.4	0.0	0.43	0.10	17	4.90	NA	NA
5	NA	NA	NA	2.2	0.0	0.34	0.20	20	4.83	NA	NA
6	NA	NA	NA	1.5	0.0	0.30	0.15	13	5.01	NA	NA
7	NA	NA	NA	1.6	0.0	0.38	0.00	10	5.05	NA	NA
8	NA	NA	NA	0.0	0.0	4.14	0.00	8	4.84	NA	NA
9	NA	NA	NA	0.0	0.0	4.14	0.10	11	4.99	NA	NA

Table 9-12: Soil profile 974 (1768) – Huay Bong: Humi-Stagnic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 43 25.61	E98 15 25.46	692	Alluvium	Quaternary	30.12.2004	Agriculture	Maize

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	20	Ah	7.5 YR 3/3	0.0	23.4	48.0	28.6	Clay loam
2	33	Bw	7.5 YR 4/4	1.5	39.3	37.0	24.0	Loam
3	56	Bg	5 YR 4/3	0.6	34.2	40.0	26.3	Loam
4	88	Bgw	5 YR 4/4	7.7	32.2	41.0	27.3	Clay loam
5	120	Bwg	5 YR 4/4	3.9	49.4	29.0	21.6	Sandy clay loam
6	121	CR	NA	84.5	77.5	7.0	15.5	Sandy loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	25.58	32.87	17.88	0.03	0.71	15.35	1.79	0.03	69.89
2	14.12	34.72	8.61	0.01	0.32	6.82	1.25	0.02	59.43
3	16.13	45.09	9.03	0.01	0.42	6.95	1.56	0.01	55.39
4	14.95	43.02	7.80	0.03	0.40	5.63	1.54	0.00	50.87
5	10.49	40.38	5.60	0.03	0.29	3.82	1.28	0.04	51.65
6	9.13	52.59		0.03	0.22	3.32	1.19		52.22

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	21.3	0.0	1.65	36.83	206	8.26	NA	NA
2	NA	NA	NA	7.7	0.0	0.74	1.42	85	7.58	NA	NA
3	NA	NA	NA	6.0	0.0	0.57	0.56	103	7.40	NA	NA
4	NA	NA	NA	4.2	0.0	0.51	0.76	101	7.13	NA	NA
5	NA	NA	NA	2.3	0.0	0.30	1.47	75	6.59	NA	NA
6	NA	NA	NA	1.3	0.0	0.26	1.96	62	6.38	NA	NA

Table 9-13: Soil profile 980 (1769) – Huay Bong: Dystri-Skeletic Regosol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 44 03.88	E98 15 21.03	788	Sandstone	Upper Carboniferous	23.01.2005	Forest	Deciduous trees, bamboo

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	3	Ah	7.5 YR 3/4	70.4	53.0	31.0	16.0	Sandy loam
2	4	CR	7.5 YR 3/6	48.1	48.8	30.6	20.5	Loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	15.82	74.23		0.05	0.34	7.90	1.14		59.57
2	13.39	52.79	6.83	0.01	0.18	5.35	1.05	0.06	49.21

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA		NA	24.1	0.0	1.34	3.39	92	6.66	NA	NA
2	NA		NA	13.8	0.0	1.00	2.09	29	6.43	NA	NA

Table 9-14: Soil profile 981 (1770) – Huay Bong: Dystri-Skeletic Regosol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 44 07.72	E98 15 12.30	822	Claystone	Upper Carboniferous	23.01.2005	Forest	deciduous trees

No.	Depth [cm]	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
				[% m]				
1	7	A	2.5 YR 4/6	46.4	7.1	47.1	45.8	Silty clay
2	25	CB1	2.5 YR 4/6	63.9	20.8	21.0	58.3	Clay
3	34	CB2	2.5 YR 5/6	>70.0	22.5	22.5	55.0	Clay
4	35	CR	NA	>95.0	NA	NA	NA	NA

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	19.31	42.19	9.13	0.02	0.59	0.96	1.07	5.48	13.63
2	24.89	42.71	11.33	0.03	0.73	0.33	0.57	8.28	6.68
3	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	9.4	0.0	0.74	1.45	100	5.16	NA	NA
2	NA	NA	NA	4.3	0.0	0.66	0.96	99	5.04	NA	NA
3	NA	NA	NA	NA	0.0	NA	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	0.0	NA	NA	NA	NA	NA	NA

Table 9-15: Soil profile 982 (1771) – Huay Bong: Dystri-Skeletic Regosol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 44 01.33	E98 15 08.78	842	Sandstone	Upper Carboniferous	23.01.2005	Forest	Deciduous trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	4	A	5 YR 2/2	63.8	69.9	24.0	6.2	Sandy loam
2	5	C	2.5 YR 5/4	65.4	61.9	30.7	7.4	Sandy loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	11.96	193.84	4.07	0.03	0.20	2.40	1.20	0.00	32.02
2	3.96	53.66	1.78	0.02	0.08	0.23	0.69	0.55	25.78

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	21.1	0.0	1.16	9.99	62	5.39	NA	NA
2	NA	NA	NA	8.6	0.0	0.12	1.26	19	5.62	NA	NA

Table 9-16: Soil profile 991 (1772) – Huay Bong: Ferri-Abruptic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 43 02.03	E98 15 19.79	843	Sandstone	Upper Carboniferous	24.01.2005	Forest	Deciduous trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	5	Ah	7.5 YR 4/4	63.2	55.9	35.1	9.0	Sandy loam
2	20	E	5 YR 5/6	72.4	46.3	37.5	16.2	Loam
3	49	Bt1	10 R 5/8	49.6	16.7	31.7	51.6	Clay
4	68	Bt2	10 R 5/8	30.8	9.4	37.5	53.1	Clay
5	93	Bt3	2.5 YR 6/8	52.6	7.9	44.1	48.0	Silty clay
6	101	Bt4	2.5 YR 5/8	52.5	10.6	40.4	49.0	Silty clay
7	102	R	NA	NA	NA	NA	NA	NA

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	10.47	116.33	4.11	0.01	0.24	2.44	1.20	0.06	37.21
2	7.24	44.72	3.10	0.02	0.20	0.34	0.68	1.38	17.12
3	24.31	47.15	9.94	0.01	0.33	0.23	1.34	6.81	7.85
4	27.09	51.02	10.82	0.01	0.31	0.37	1.45	7.30	7.89
5	22.38	46.63	9.89	0.05	0.21	0.28	1.07	7.93	7.19
6	23.03	47.05	10.27	0.01	0.19	0.23	0.90	8.18	5.80
7	NA	NA	NA	NA	NA	NA	NA	NA	NA

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	14.1	0.0	0.80	2.67	74	5.91	NA	NA
2	NA	NA	NA	4.9	0.0	0.29	1.21	55	5.30	NA	NA
3	NA	NA	NA	3.9	0.0	0.47	0.43	54	5.19	NA	NA
4	NA	NA	NA	1.9	0.0	0.35	0.38	48	5.29	NA	NA
5	NA	NA	NA	1.1	0.0	0.29	0.32	26	5.34	NA	NA
6	NA	NA	NA	1.4	0.0	0.31	0.16	21	5.20	NA	NA
7	NA	NA	NA	NA	0.0	NA	NA	NA	NA	NA	NA

Table 9-17: Soil profile 1093 (1837) - Huay Bong: Dystri-Humic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 42 47.91	E98 15 38.09	764	Sandstone	Upper Carboniferous	04.09.2005	Forest	Deciduous trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	9	Ah	7.5 YR3/4	3.0	40.4	40.8	18.9	Loam
2	24	AB	5 YR 3/6	3.0	34.2	37.2	28.6	Clay loam
3	36	Bw1	5 YR 3/6	>50.0	33.1	35.7	31.2	Clay loam
4	56	Bw2	5 YR 4/8	3.0	31.2	36.5	32.3	Clay loam
5	81	Bw3	5 YR 4/8	3.0	28.7	37.9	33.4	Clay loam
6	102	Bw4	5 YR 3/6	3.0	26.3	40.0	33.7	Clay loam
7	132	Cw1	5 YR 4/6	>50.0	26.1	39.5	34.4	Clay loam
8	140	Cw2	5 YR 4/6	40.0	26.0	39.3	34.7	Clay loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	18.53	NA	7.64	0.19	0.47	4.77	2.03	0.00	40.26
2	13.45	NA	3.62	0.10	0.35	1.44	0.87	0.53	20.52
3	11.98	NA	2.78	0.11	0.35	0.34	0.73	0.86	12.77
4	11.78	NA	2.72	0.14	0.40	0.34	0.77	1.04	14.01
5	12.41	NA	3.32	0.08	0.43	0.69	0.80	1.13	16.12
6	12.31	NA	3.68	0.10	0.36	1.37	0.91	0.76	22.26
7	13.04	NA	4.30	0.09	0.35	2.59	1.05	0.06	31.29
8	13.18	NA	4.53	0.11	0.28	2.90	1.14	0.00	33.61

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	21.1	0.0	1.45	2.30	115	5.27	4.74	NA
2	NA	NA	NA	9.9	0.0	0.90	1.10	60	5.06	4.05	NA
3	NA	NA	NA	6.5	0.0	0.75	0.85	56	4.91	4.02	NA
4	NA	NA	NA	4.9	0.0	0.57	0.55	66	4.97	4.07	NA
5	NA	NA	NA	3.8	0.0	0.47	0.35	78	5.03	4.10	NA
6	NA	NA	NA	3.5	0.0	0.45	0.20	61	5.04	4.19	NA
7	NA	NA	NA	2.7	0.0	0.38	0.10	65	5.29	4.49	NA
8	NA	NA	NA	4.3	0.0	0.50	0.20	52	5.30	4.51	NA

Table 9-18: Soil profile 1094 - Huay Bong: Skeleti-Stagnic Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 43 16.74	E98 14 39.88	752	Claystone	Upper Carboniferous	04.09.2005	Forest	Deciduous trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	12	Ah	2.5 YR 3/2	3.0	10.1	50.3	39.6	Silty clay loam
2	17	BA	2.5 YR 4/4	90.0	8.6	43.8	47.6	Silty clay
3	47	Bw1	2.5 YR 5/4	15.0	6.7	38.0	55.3	Clay
4	66	Bw2	2.5 YR 5/3	5.0	5.4	44.1	50.5	Silty clay
5	85	Bw3	7.5 YR 6/4	15.0	4.0	42.9	53.1	Silty clay
6	100	Cw	2.5 YR 5/2	90.0	10.0	37.7	52.6	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	24.49	61.77	10.30	0.05	0.51	5.14	2.08	2.53	31.77
2	27.21	56.99	14.31	0.07	0.74	9.79	3.70	0.00	52.55
3	28.60	51.66	15.72	0.07	0.43	10.38	3.74	1.02	51.12
4	27.65	54.72	14.63	0.04	0.32	10.01	3.48	0.69	50.09
5	27.57	51.89	16.90	0.04	0.29	12.43	3.86	0.16	60.28
6	27.62	52.46	19.95	0.05	0.31	15.27	4.32	0.00	72.23

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	7.2	0.0	0.31	2.80	110	4.92	3.77	NA
2	NA	NA	NA	12.1	0.0	0.95	4.05	172	5.20	4.26	NA
3	NA	NA	NA	3.1	0.0	0.22	0.35	64	5.53	4.05	NA
4	NA	NA	NA	1.9	0.0	0.32	0.10	41	5.60	4.00	NA
5	NA	NA	NA	2.6	0.0	0.35	0.20	28	5.89	4.19	NA
6	NA	NA	NA	2.2	0.0	0.38	0.35	27	NA	4.30	NA

Table 9-19: Soil profile 1095 (1839) - Huay Bong: Dystri-Profondic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N18 43 47.37	E98 14 35.68	776	Sandstone	Tertiary	05.09.2005	Agriculture	Tomato

No.	Depth [cm]	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
				[% m]				
1	17	Ah	7.5 YR 4/5	<1.0	22.4	29.5	48.1	Clay
2	33	AB	5 YR 4/5	<1.0	20.9	28.0	51.0	Clay
3	63	Bt1	5 YR 3/5	<1.0	18.8	24.2	57.0	Clay
4	86	Bt2	5 YR 3/5	<1.0	20.0	25.3	54.7	Clay
5	120	Bt3	5 YR 4/6	<1.0	21.0	23.7	55.3	Clay
6	155	Bt4	5 YR 4/6	<1.0	20.1	24.2	55.8	Clay
7	184	Bt5	5 YR 4/6	<1.0	18.7	25.6	55.7	Clay
8	200	Bt6	5 YR 4/6	<1.0	18.3	26.6	55.2	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	19.62	40.62	6.11	0.01	0.44	0.33	0.42	4.91	6.12
2	18.75	36.62	4.52	0.10	0.37	0.17	0.49	3.39	6.03
3	17.98	31.48	5.55	0.08	0.34	0.06	0.55	4.52	5.73
4	17.95	32.79	5.03	0.11	0.32	0.11	0.29	3.88	4.62
5	16.65	30.09	4.36	0.12	0.31	0.06	0.24	3.63	4.38
6	17.14	30.74	4.56	0.10	0.21	0.07	0.24	3.80	3.62
7	17.49	31.37	5.05	0.11	0.19	0.55	0.55	3.29	8.00
8	17.62	31.91	5.26	0.07	0.17	0.21	0.64	3.95	6.19

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	Bulk density
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	3.62	0.20	0.06	14.9	0.0	1.17	0.40	36	4.52	3.78	NA
2	3.73	0.18	0.05	9.8	0.0	0.92	0.30	42	4.12	3.96	NA
3	3.75	0.17	0.05	4.8	0.0	0.88	0.00	33	4.32	3.99	NA
4	3.41	0.16	0.05	3.7	0.0	2.83	0.10	32	4.76	4.03	NA
5	4.20	0.13	0.03	2.5	0.0	0.39	0.15	36	4.56	3.99	NA
6	4.49	0.12	0.03	1.6	0.0	0.32	0.05	14	4.87	4.19	NA
7	3.98	0.11	0.03	2.7	0.0	0.42	0.05	10	4.46	4.09	NA
8	4.35	0.11	0.02	2.5	0.0	0.43	0.00	6	4.80	3.95	NA

Table 9-20: Soil profile 113 (1773) – Bor Krai: Calcari-Humic Gleysol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 03.18	E98 12 48.58	713	Alluvium	Quaternary	12.10.2004	None	Grasses, shrubs

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	16	A	10 YR 4/3	0.0	14.8	56.8	28.3	Silty clay loam
2	33	Bg1	10 YR 4/3	0.0	31.9	42.5	25.6	Loam
3	55	Bg2	10 YR 4/3	0.0	34.9	42.1	23.1	Loam
4	80	Br1	7.5 Y 3/2	0.0	42.7	35.1	22.2	Loam
5	100	Br2	7.5 Y 4/2	0.0	43.3	33.7	23.1	Loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	24.67	6.57		0.28	0.32	22.40	0.08	NA	93.56
2	21.26	11.49	18.56	0.00	0.24	18.26	0.06	0.00	87.29
3	19.28	5.63	19.15	0.33	0.26	18.49	0.06	0.00	99.31
4	18.08	8.43	16.57	0.05	0.35	16.09	0.08	0.05	91.63
5	19.74	4.48	19.74	0.59	0.58	18.46	0.11	0.04	100.00

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	27.6	1.1	2.27	23.13	96	7.92	NA	NA
2	NA	NA	NA	22.5	1.0	1.65	18.78	71	7.79	NA	NA
3	NA	NA	NA	22.2	0.6	1.62	22.39	82	7.99	NA	NA
4	NA	NA	NA	18.7	0.7	1.31	26.54	108	8.05	NA	NA
5	NA	NA	NA	21.8	1.2	1.43	42.53	196	8.19	NA	NA

Table 9-21: Soil profile 449 (1774) – Bor Krai: Humi-Stagnic Fluvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 34 02.25	E98 12 54.78	558	Alluvium	Quaternary	19.08.2004	Forest	Trees and shrubs

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	2	A	7.5 YR 4/4	0.0	49.7	34.0	16.3	Loam
2	12	Bu1	7.5 YR 4/4	11.1	65.8	20.9	13.4	Sandy loam
3	20	Bg1	7.5 YR 4/3	5.1	9.4	56.7	33.9	Silty clay loam
4	23	Bu2	5 YR 4/4	0.0	80.0	5.0	15.0	Sandy loam
5	35	Bg2	7.5 YR 4/3	0.0	16.6	52.8	30.7	Silty clay loam
6	53	Bu3	7.5 YR 5/4	0.0	37.3	41.4	21.4	Loam
7	63	Bg3	7.5 YR 3/3	0.0	24.5	47.5	28.0	Clay loam
8	89	Bu4	7.5 YR 4/4	0.0	40.3	43.5	16.2	Loam
9	97	Bu5	7.5 YR 4/4	7.8	31.6	42.1	26.3	Loam
10	109	Bu6	7.5 YR 4/4	72.5	63.2	24.2	12.6	Sandy loam
11	>109	C	NA	>80.0	66.2	18.8	15.0	Sandy loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	23.50	45.92	11.52	0.00	0.46	10.78	0.21	0.09	48.63
2	13.75	48.00	6.78	0.09	0.21	6.26	0.19	0.08	49.12
3	38.70	25.90	18.55	0.00	0.38	18.13	0.04	0.05	47.83
4	25.14		16.71	0.04	0.23	12.85	3.54	0.06	66.27
5	46.46	18.34	24.20	0.00	0.37	23.79	0.04	0.03	52.04
6	22.65	35.08	11.41	0.00	0.23	10.88	0.26	0.01	50.13
7	31.37	40.33	15.55	0.02	0.28	15.21	0.03	0.00	49.57
8	17.70	37.08	9.62	0.00	0.16	9.15	0.31	0.00	54.06
9	37.72	47.16	19.57	0.01	0.19	19.33	0.04	0.04	51.87
10	11.69	41.21	6.38	0.00	0.08	6.16	0.14	0.04	54.43
11	13.15	48.28	7.12	0.01	0.11	6.86	0.15	0.02	54.15

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	24.1	0.0	1.50	NA	NA	6.75	NA	NA
2	NA	NA	NA	6.9	0.0	0.40	NA	NA	7.34	NA	NA
3	NA	NA	NA	24.5	0.0	1.78	NA	NA	7.21	NA	NA
4	NA	NA	NA	NA	0.0	NA	NA	NA	7.57	NA	NA
5	NA	NA	NA	32.2	0.0	1.98	NA	NA	7.45	NA	NA
6	NA	NA	NA	12.6	0.0	0.89	NA	NA	7.32	NA	NA
7	NA	NA	NA	16.2	0.0	1.21	NA	NA	7.24	NA	NA
8	NA	NA	NA	9.7	0.0	0.61	NA	NA	7.95	NA	NA
9	NA	NA	NA	20.9	0.0	1.29	NA	NA	7.69	NA	NA
10	NA	NA	NA	5.4	0.0	0.41	NA	NA	7.72	NA	NA
11	NA	NA	NA	5.5	0.0	0.40	NA	NA	7.65	NA	NA

Table 9-22: Soil profile 450 (1777) – Bor Krai: Humi-Anthric Umbrisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 24.47	E98 12 38.49	712	Limestone	Permian	21.08.2004	Agriculture	Fallow, 3 years with shrubs and small trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	15	Ah1	10 R 3/2	0.0	9.2	40.3	50.6	Silty clay
2	40	Ah2	10 R 3/3	0.9	9.1	35.5	55.5	Clay
3	62	Ah3	10 R 3/3	0.0	8.5	34.0	57.5	Clay
4	80	Ah4	10 R 3/3	0.0	10.2	36.0	53.8	Clay
5	100	Ah5	10 R 3/3	0.0	14.1	37.5	48.4	Clay
6	125	AB1	10 R 3/4	0.0	8.6	41.0	50.4	Clay
7	>125	AB2	10 R 3/4	6.0	7.2	34.3	58.5	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	54.08	60.48	20.72	0.03	1.01	19.35	0.29	0.00	38.23
2	46.52	52.90	14.26	0.00	0.25	13.72	0.26	0.00	30.58
3	40.48	48.62	9.79	0.00	0.25	9.23	0.23	0.08	23.98
4	39.64	52.75	8.38	0.00	0.24	7.75	0.24	0.11	20.75
5	36.47	50.18	7.10	0.00	0.24	6.51	0.21	0.12	19.05
6	40.68	57.82	8.53	0.00	0.20	7.85	0.21	0.13	20.32
7	40.26	53.24	8.58	0.18	0.20	7.60	0.16	0.33	20.22

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	31.2	0.0	2.14	26.13	168	6.27	5.41	NA
2	NA	NA	NA	18.7	0.0	1.19	28.19	9	6.25	4.94	NA
3	NA	NA	NA	11.4	0.0	0.86	12.08	13	6.07	4.83	NA
4	NA	NA	NA	10.0	0.0	0.73	7.32	16	5.83	4.73	NA
5	NA	NA	NA	5.5	0.0	0.64	5.16	10	5.93	4.73	NA
6	NA	NA	NA	6.3	0.0	0.63	0.00	5	5.98	4.65	NA
7	NA	NA	NA	8.7	0.0	0.72	3.30	6	5.88	4.50	NA

Table 9-23: Soil profile 452 (1775) – Bor Krai: Dystri-Ferric Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 09.86	E98 13 07.29	795	Claystone, siltstone	Permian	16.08.2004	Agriculture	Mango, banana

No.	Depth [cm]	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
				[% m]				
1	17	Ah	10 YR 4/4	0.0	24.7	42.7	32.6	Clay loam
2	35	Bt1	2.5 YR 6/8	0.1	11.5	32.3	56.2	Clay
3	47	Bt2	2.5 YR 6/8	26.3	11.5	38.7	49.9	Clay
4	74	Bt3	5 YR 7/8	19.0	32.0	39.5	28.5	Clay loam
5	104	BCw	10 YR 7/6	8.4	4.5	50.9	44.6	Silty clay
6	132	Cw1	10 YR 7/6	9.5	4.0	55.6	40.3	Silty clay
7	150	Cw2	2.5 YR 7/4	0.0	3.6	54.8	41.6	Silty clay
8	>150	Cw3	5 YR 7/4	15.6	2.6	58.2	39.2	Silty clay loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	18.98	57.00	8.56	0.20	1.49	4.42	2.44	0.01	45.04
2	28.37	52.18	9.34	0.11	0.98	4.02	3.61	0.33	30.74
3	27.02	57.28	NA	0.10	0.81	3.07	3.07	NA	26.04
4	13.16	45.60	5.79	0.05	0.45	2.12	1.56	1.46	31.77
5	21.69	43.40	9.49	0.06	0.55	2.71	2.10	3.40	25.03
6	20.38	47.63	9.10	0.05	0.48	2.38	2.11	3.29	24.63
7	24.30	52.39	20.94	0.05	0.51	12.60	2.36	4.25	63.89
8	23.01	58.67	10.67	0.05	0.44	1.54	2.16	6.27	18.17

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	12.0	0.0	1.09	NA	NA	6.50	NA	NA
2	NA	NA	NA	5.9	0.0	0.88	NA	NA	5.10	NA	NA
3	NA	NA	NA	8.8	0.0	0.85	NA	NA	7.35	NA	NA
4	NA	NA	NA	0.9	0.0	0.38	NA	NA	4.96	NA	NA
5	NA	NA	NA	1.2	0.0	0.64	NA	NA	5.13	NA	NA
6	NA	NA	NA	0.6	0.0	0.56	NA	NA	5.28	NA	NA
7	NA	NA	NA	1.1	0.0	0.63	NA	NA	5.32	NA	NA
8	NA	NA	NA	0.4	0.0	0.55	NA	NA	5.31	NA	NA

Table 9-24: Soil profile 453 (1778) – Bor Krai: Ferri-Profondic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 08.73	E98 13 09.69	791	Claystone, siltstone	Permian	12.10.2004	Agriculture	Mango

No.	Depth [cm]	Horizon	Soil colour	Skeleton [% m]	Sand [% m]	Silt [% m]	Clay [% m]	Texture
1	27	Ah	10 YR 3/4	0.0	15.5	52.8	31.8	Silty clay loam
2	43	E	7.5 YR 4/4	0.0	13.3	44.84	41.8	Silty clay
3	71	Bt1	5 YR 5/8	0.0	7.5	32.34	60.1	Clay
4	100	Bt2	5 YR 5/6	0.0	8.5	36.01	55.5	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	25.68	80.58	10.26	0.01	0.66	9.28	0.26	0.02	39.79
2	18.56	43.22	5.43	0.00	0.64	4.38	0.26	0.03	28.43
3	24.79	39.92	6.99	0.08	0.78	3.97	0.28	1.44	20.63
4	23.86	41.66	7.21	0.01	0.68	4.77	0.27	1.20	23.98

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	22.9	0.0	1.61	NA	NA	6.31	5.18	NA
2	NA	NA	NA	7.0	0.0	0.88	NA	NA	6.28	4.80	NA
3	NA	NA	NA	4.5	0.0	0.88	NA	NA	5.30	4.13	NA
4	NA	NA	NA	2.8	0.0	0.71	NA	NA	5.66	4.15	NA

Table 9-25: Soil profile 456 (1779) – Bor Krai: Dystri-Profondic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 32 59.49	E98 11 54.95	766	Limestone	Permian	12.10.2004	Agriculture	Maize

No.	Depth [cm]	Horizon	Soil colour	Skeleton [% m]	Sand [% m]	Silt [% m]	Clay [% m]	Texture
1	19	Ah	2.5 YR 3/4	0.00	16.48	22.72	60.81	Clay
2	37	AB	10 R 3/3	0.00	13.81	15.82	70.37	Clay
3	65	Bt1	10 R 3/3	0.00	13.96	13.15	72.89	Clay
4	87	Bt2	10 R 3/3	0.00	13.38	12.23	74.40	Clay
5	100	Bt3	10 R 3/4	0.00	13.62	11.63	74.75	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	33.38	36.43	15.79	0.09	1.13	14.23	0.20	0.00	46.89
2	26.10	51.40	8.17	0.07	0.32	7.53	0.17	0.07	30.99
3	22.96	31.66	8.20	0.03	0.14	7.80	0.17	0.09	35.44
4	21.14	30.19	6.95	0.03	0.11	6.56	0.15	0.08	32.36
5	21.47	32.50	6.09	0.06	0.10	5.71	0.14	0.07	27.97

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	23.30	0.00	2.15	NA	NA	7.28	6.12	NA
2	NA	NA	NA	11.70	0.00	1.28	NA	NA	7.06	5.90	NA
3	NA	NA	NA	7.80	0.00	0.93	NA	NA	7.11	5.96	NA
4	NA	NA	NA	6.30	0.00	0.82	NA	NA	6.64	5.95	NA
5	NA	NA	NA	4.80	0.00	0.71	NA	NA	6.64	5.91	NA

Table 9-26: Soil profile 457 (1780) – Bor Krai: Profondi-Humic Acrisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 48.29	E98 12 01.03	877	Limestone	Permian	14.10.2004	Agriculture	Rice

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	20	Ah1	2.5 YR 3/4	0.00	8.13	43.51	48.36	Clay
2	40	Ah2	2.5 YR 3/4	0.00	8.45	24.18	67.37	Clay
3	62	Bt1	10 R 3/3	0.00	7.81	12.71	79.48	Clay
4	86	Bt2	10 R 3/3	0.00	7.27	13.29	79.44	Clay
5	100	Bt3	10 R 3/3	0.00	7.43	11.30	81.27	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	35.59	17.93	13.54	0.22	1.21	11.74	0.22	0.07	37.64
2	24.12	30.67	6.73	0.26	0.37	5.84	0.09	0.05	27.19
3	18.99	18.84	4.83	0.08	0.14	4.39	0.05	0.03	24.48
4	16.54	20.73	3.98	0.00	0.10	3.70	0.02	0.02	23.02
5	16.70	23.39	3.96	0.06	0.10	3.61	0.02	0.01	22.70

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	39.0	0.0	2.35	NA	NA	6.35	5.68	NA
2	NA	NA	NA	17.1	0.0	0.99	NA	NA	6.07	5.35	NA
3	NA	NA	NA	10.1	0.0	0.65	NA	NA	6.17	5.43	NA
4	NA	NA	NA	5.7	0.0	0.51	NA	NA	6.17	5.56	NA
5	NA	NA	NA	5.0	0.0	0.40	NA	NA	6.15	5.62	NA

Table 9-27: Soil profile 479 (1762) – Bor Krai: Chromi-Eutric Cambisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 32 49.31	E98 13 46.51	926	Latite	Triassic (?)	15.01.2005	Forest	Deciduous trees

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	28	Ah	2.5 YR 4/3	0.0	4.7	37.3	58.0	Clay
2	44	Bw1	5 YR 3/3	0.0	6.4	46.3	47.2	Silty clay
3	71	Bw2	5 YR 3/3	42.1	13.8	42.2	44.0	Silty clay
4	86	Bw3	5 YR 3/3	30.9	17.0	43.3	39.7	Silty clay loam
5	100	Bw4	5 YR 3/3	29.3	14.1	44.9	41.1	Silty clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	64.65	77.43	42.00	0.04	0.96	34.14	6.57	0.00	64.51
2	48.86	99.30	28.78	0.06	0.35	24.96	3.28	0.00	58.65
3	50.38	120.69	31.35	0.05	0.48	27.05	3.48	0.00	61.63
4	46.34	128.09	29.54	0.05	0.39	25.47	3.44	0.09	63.33
5	46.38	137.25	29.78	0.06	0.45	25.12	3.86	0.09	63.58

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	NA	NA	NA	16.5	0.0	1.22	44.02	172	6.57	NA	NA
2	NA	NA	NA	3.5	0.0	0.39	18.34	49	6.56	NA	NA
3	NA	NA	NA	1.2	0.0	0.23	20.73	60	6.57	NA	NA
4	NA	NA	NA	0.5	0.0	1.87	14.55	43	6.62	NA	NA
5	NA	NA	NA	0.4	0.0	0.18	24.64	51	6.56	NA	NA

Table 9-28: Soil profile 1550 (Sereke 2002 – revised) – Jabo: Umbri-Gibbsic Ferralsol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 55.39	E98 12 11.39	930	Limestone	Permian	14.01.2002	Agriculture	Shrubs, herbs

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	10	Ah	5 YR 3/3	3.0	3.4	39.4	57.3	Silty clay
2	35	AB1	2.5 YR 3/3	3.0	3.2	24.8	72.0	Clay
3	60	AB2	2.5 YR 3/3	3.0	2.7	17.6	79.6	Clay
4	100	Bs1	10 R 3/4	3.0	3.8	19.0	77.3	Clay
5	140	Bs2	10 R 3/4	3.0	3.3	19.0	77.6	Clay
6	>140	Bs3	10 R 3/4	3.0	2.8	20.1	77.1	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	37.60	12.88	18.47	0.07	0.21	16.65	1.44	0.00	49.60
2	25.00	11.92	9.51	0.07	0.10	8.68	0.58	0.03	37.80
3	17.80	12.96	2.97	0.01	0.07	1.75	0.38	0.37	12.40
4	16.10	14.70	2.84	0.01	0.06	1.32	0.25	0.71	10.20
5	16.00	15.13	3.46	0.01	0.05	2.58	0.41	0.08	19.10
6	15.90	15.70	3.01	0.03	0.05	2.41	0.30	0.00	17.70

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	12.37	0.12	0.01	37.0	0.0	2.70	5.33	75	6.80	NA	0.79
2	12.88	0.14	0.01	19.6	0.0	1.50	3.04	14	6.80	NA	0.67
3	12.40	0.19	0.02	8.9	0.0	0.90	3.16	4	5.70	NA	0.76
4	14.31	0.20	0.01	5.3	0.0	0.70	1.64	0	5.30	NA	1.00
5	13.09	0.21	0.02	4.6	0.0	0.60	1.60	0	5.90	NA	1.04
6	12.84	0.22	0.02	4.2	0.0	0.60	0.00	0	6.20	NA	1.18

No.	Kaolinite	Vermiculite	Gibbsite	Quartz	Goethite	Hematite
	Bulk mineral composition (%) of the soil horizon					
2	21,8	6,55	40,5	3,98	14,1	13,12
6	14	7,33	47,8	4,28	14,5	12,16

Table 9-29: Soil profile 1627 (1758) – Bor Krai – Glossi-Calcic Chernozem

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 15.02	E98 13 41.03	810	Freshwater limestone	Permian	10.06.2004	Agriculture	Maize

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	18	Ahk1	7.5 YR 1.7/1	0.0	12.0	43.4	44.6	Silty clay
2	40	Ahk2	7.5 YR 1.7/1	0.0	11.6	42.1	46.4	Silty clay
3	55	ABk	2.5 Y 3/2	1.3	14.3	41.7	44.0	Silty clay
4	>55	R	2.5 Y 6/3	13.5	11.9	40.4	47.8	Silty clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	43.95	86.49	43.95	0.00	0.21	42.59	1.15	0.00	100.00
2	31.43	58.71	31.43	0.00	0.16	30.80	0.47	0.00	100.00
3	18.39	34.13	18.39	0.01	0.13	17.75	0.50	0.00	100.00
4	3.67	0.00	3.66	0.01	0.01	3.47	0.18	0.03	100.00

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	0.85	0.29	0.34	56.8	68.8	5.32	11.44	47	7.97	NA	NA
2	0.93	0.14	0.15	34.1	64.7	2.71	10.21	37	8.09	NA	NA
3	0.63	0.04	0.06	12.7	66.2	1.23	12.17	28	8.28	NA	NA
4	0.26	0.08	0.32			0.08	24.66	9	8.85	NA	NA

Table 9-30: Soil profile 1629 (1759) – Bor Krai: Dystri-Profondic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 32.23	E98 13 41.16	758	Iron ore, limestone	Permian	26.10.2004	Agriculture	Maize

No.	Depth [cm]	Horizon	Soil colour	Skeleton [% m]	Sand [% m]	Silt [% m]	Clay [% m]	Texture
1	17	Ah	7.5 YR 3/4	0.05	15.4	43.7	40.9	Silty clay
2	31	Bt1	5 YR 3/4	0.66	15.6	32.2	52.2	Clay
3	56	Bt2	5 YR 4/8	0.13	15.6	30.2	54.2	Clay
4	76	Bt3	5 YR 3/6	0.24	13.1	26.1	60.8	Clay
5	100	Bt4	5 YR 4/8	0.02	10.9	24.5	64.6	Clay
6	>100	Bt6	5 YR 3/6	0.06	10.2	19.3	70.5	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	32.08	66.95	15.84	0.09	0.95	12.54	2.24	0.00	49.36
2	27.04	46.51	11.38	0.05	0.79	8.57	1.97	0.00	42.09
3	26.55	44.86	9.95	0.04	0.72	6.83	2.19	0.00	36.84
4	26.84	41.57	7.86	0.03	0.76	4.60	1.85	0.41	26.99
5	28.83	42.69	8.14	0.04	0.80	5.00	1.76	0.42	26.36
6	28.08	38.45	8.95	0.04	0.95	5.86	1.76	0.20	30.68

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	7.17	0.41	0.06	24.30	0.00	1.45	1.27	242	6.23	5.36	NA
2	7.52	0.36	0.05	14.20	0.00	1.04	0.00	174	6.13	5.17	NA
3	7.48	0.31	0.04	11.60	0.00	0.95	0.00	150	5.94	4.96	NA
4	7.55	0.28	0.04	8.00	0.00	0.82	0.00	148	5.61	4.38	NA
5	7.51	0.22	0.03	6.50	0.00	0.84	0.00	161	5.45	4.37	NA
6	7.39	0.20	0.03	5.00	0.00	0.80	0.00	213	5.44	4.43	NA

Table 9-31: Soil profile 1677 – Bor Krai: Profondi-Endostagnic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 33 13.50	E98 13 20.93	770	Claystone, (limestone)	Permian	01.12.2003	Agriculture	Shrubs, weeds

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	17	Ah	5 YR 3/2	1.2	22.9	39.9	37.2	Clay loam
2	34	AB	7.5 YR 4/3	1.1	19.6	36.8	43.6	Clay
3	77	Bt	5 YR 4/4	0.3	13.9	32.3	53.8	Clay
4	95	BCtg	2.5 YR 5/6	8.9	17.0	33.2	49.9	Clay
5	130	BCg	10 YR 6/8	9.0	12.8	41.5	45.7	Clay
6	165	Cw1	2.5 Y 6/8	22.9	12.0	47.0	41.1	Silty clay loam
7	200	Cw2	2.5 Y 6/8	34.4	6.7	52.1	41.1	Clay loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	33.53	78.18	16.18	0.00	0.59	13.27	2.21	0.00	47.87
2	30.36	63.87	15.41	0.00	0.44	12.08	2.89	0.02	50.75
3	30.70	55.83	13.82	0.03	0.38	10.88	2.09	0.29	43.55
4	28.24	56.56	15.07	0.06	0.30	12.02	2.45	0.01	52.47
5	30.58	68.38	16.22	0.08	0.25	13.19	2.68	0.00	52.97
6	31.06	77.31	16.57	0.13	0.20	13.25	2.99	0.00	53.36
7	33.77	83.49	18.58	0.16	0.19	14.71	3.52	0.00	55.02

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	1.86	0.25	0.14	27.6	0.0	2.21	0.41	149	6.19	5.20	1.46
2	2.80	0.23	0.08	16.6	0.0	1.66	0.00	97	6.11	4.96	1.40
3	3.27	0.13	0.04	8.8	0.0	1.23	0.00	84	6.06	4.66	1.43
4	3.30	0.14	0.04	5.2	0.0	0.91	0.00	65	6.54	5.13	1.50
5	2.88	0.11	0.04	3.0	0.0	0.73	0.00	58	6.53	5.04	1.52
6	3.26	0.08	0.02	2.2	0.0	0.69	0.00	54	6.65	5.05	NA
7	2.82	0.06	0.02	0.7	0.0	0.63	0.00	58	6.45	4.88	NA

Table 9-32: Soil profile 1678 – Bor Krai: Ferri-Stagnic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 32 59.46	E98 13 16.29	780	Sandstone, siltstone	Permian	04.12.2003	Agriculture	Shrubs, weeds

No.	Depth [cm]	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
				[% m]				
1	16	Ah	10 YR 4/2	0.1	20.0	45.8	34.1	Clay loam
2	30	AB	10 YR 4/3	0.0	14.8	41.0	44.2	Silty clay
3	52	Btg1	7.5 YR 4/4	0.4	9.1	28.8	62.2	Clay
4	75	Btg2	10 YR 5/6	0.7	9.5	30.8	59.7	Clay
5	89	Btg3	10 YR 4/6	0.0	11.4	31.6	57.0	Clay
6	119	Bg	7.5 YR 4/3	10.4	16.0	37.2	47.0	Clay
7	152	BCg	7.5 YR 4/2	9.1	29.3	30.6	40.2	Clay
8	171	Cw	2.5 Y 5/2	55.9	39.4	33.5	27.1	Clay loam
9	200	C	10 YR 7/8	41.6	62.9	18.1	19.0	Sandy loam

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c\ kg^{-1}$]								[%]
1	34.08	84.76	21.52	0.00	0.82	17.72	2.90	0.01	62.85
2	30.01	61.32	19.00	0.01	0.40	16.22	2.37	0.00	63.31
3	32.86	52.91	20.90	0.02	0.36	17.82	2.67	0.00	63.51
4	33.70	57.81	20.25	0.02	0.29	17.29	2.61	0.00	59.94
5	32.88	57.26	21.18	0.04	0.27	18.41	2.42	0.00	64.31
6	31.10	62.28	20.74	0.02	0.23	18.40	2.09	0.00	66.71
7	31.25	79.03	18.01	0.03	0.19	16.04	1.66	0.00	57.37
8	29.45	110.37	17.50	0.06	0.13	15.62	1.58	0.00	59.04
9	19.66	161.92	13.88	0.02	0.09	12.48	1.18	0.00	70.15

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	3.31	0.10	0.03	33.7	0.0	2.53	0.72	223	6.44	5.46	1.34
2	2.32	0.44	0.19	18.2	0.0	1.64	0.00	82	6.51	5.50	1.43
3	2.62	0.33	0.13	9.9	0.0	1.24	0.00	61	6.98	5.59	1.42
4	3.41	0.12	0.03	6.6	0.0	1.03	0.00	45	6.35	5.28	1.43
5	3.62	0.09	0.02	6.0	0.0	0.93	0.00	48	6.43	5.37	1.44
6	3.38	0.09	0.03	4.7	0.0	0.88	0.00	43	6.42	5.25	1.48
7	3.10	0.07	0.02	3.1	0.0	0.55	0.00	37	6.88	5.45	NA
8	2.46	0.05	0.02	1.9	0.0	0.49	0.00	30	6.72	5.40	NA
9	2.32	0.05	0.02	1.4	0.0	0.37	0.00	24	6.76	5.44	NA

Table 9-33: Soil profile 1679 (1757) – Bor Krai: Dystri-Profondic Luvisol

Latitude	Longitude	Elevation [m asl]	Rock	Geology	Sampling date	Land use	Vegetation
N19 32 51.96	E98 13 50.31	880	Latite	Triassic (?)	21.04.2004	Agriculture	Shrubs. weeds

No.	Depth	Horizon	Soil colour	Skeleton	Sand	Silt	Clay	Texture
	[cm]			[% m]				
1	14	Ah1	7.5 YR 3/4	4.5	18.5	40.5	41.0	Silty clay
2	27	Ah2	7.5 YR 4/4	1.4	10.1	39.0	50.9	Clay
3	53	Bt1	5 YR 4/6	2.1	8.5	31.4	60.1	Clay
4	67	Bt2	5 YR 4/6	0.0	9.4	38.2	52.4	Clay
5	94	Bt3	2.5 YR 4/4	2.9	7.0	30.2	62.9	Clay
6	104	Bt4	7.5 YR 6/2	3.4	10.4	24.3	65.3	Clay
7	142	Bt5	7.5 YR 6/2	2.4	10.7	29.4	60.0	Clay
8	169	Bt6	7.5 YR 5/2	9.0	5.3	33.5	61.1	Clay
9	200	Bt7	7.5 YR 6/2	1.9	5.1	37.1	57.8	Clay

No.	CEC_{soil}	$CEC_{clay(f)}$	ECEC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS
	[$cmol_c$ kg^{-1}]								[%]
1	44.84	109.44	19.28	0.06	1.02	11.98	6.04	0.00	42.59
2	40.49	79.55	16.69	0.20	0.67	8.27	6.36	1.09	38.24
3	44.25	73.65	20.89	0.31	0.64	10.10	8.62	1.08	44.47
4	49.56	94.55	25.04	0.19	0.70	12.33	10.88	0.73	48.64
5	45.64	72.60	23.73	0.23	0.90	11.82	10.12	0.45	50.56
6	47.75	73.10	24.43	0.18	0.87	12.14	10.38	0.52	49.36
7	51.60	86.05	24.18	0.22	0.89	11.99	10.27	0.49	45.30
8	54.24	88.71	27.08	0.26	0.88	13.27	11.67	0.73	48.08
9	53.10	91.81	25.82	0.24	0.83	12.53	11.18	0.69	46.68

No.	Fe_d	Fe_o	Fe_o/Fe_d	C_{org}	C_{carb}	N_t	P_{CAL}	K_{CAL}	pH H_2O	pH KCl	BD
	[% m]			[g kg^{-1}]			[mg kg^{-1}]				[g cm^{-3}]
1	6.02	1.00	0.17	23.3	0.0	1.55	24.99	256	5.73	4.75	1.50
2	6.63	0.67	0.10	15.2	0.0	1.09	12.00	139	5.49	4.17	1.50
3	6.62	0.37	0.06	8.2	0.0	0.80	0.41	107	5.39	4.18	1.50
4	6.08	0.37	0.06	3.7	0.0	0.49	0.83	123	5.44	4.21	1.50
5	6.33	0.35	0.06	4.2	0.0	0.61	0.31	138	5.59	4.39	1.30
6	6.47	0.35	0.05	5.4	0.0	0.67	0.00	132	5.59	4.31	1.30
7	6.41	0.32	0.05	5.5	0.0	0.67	0.00	130	5.42	4.32	1.50
8	5.90	0.26	0.04	4.8	0.0	0.67	0.00	131	5.39	4.24	1.50
9	6.07	0.22	0.04	4.6	0.0	0.62	0.00	126	5.55	4.25	1.50

Acknowledgments

This research was conducted within the framework of the Special Research Program 564, and was funded by the Deutsche Forschungsgemeinschaft (DFG) whose support is gratefully acknowledged. This work was mainly carried out at the Faculty of Agriculture, Chiang Mai University and at the Department of Soil Science and Land Evaluation of Hohenheim University, to whom I am very grateful for the logistical and scientific support.

My special thanks go to Prof. Dr. Karl Stahr, who offered me the subject and supervised my work throughout many years. His expert advice and the numerous objective discussions are highly acknowledged. Thankfully acknowledged is Dr. Ludger Herrmann for his valuable expert advice and for accompanying my work over the whole time.

A very cordial thank is due to Petra Erbe for improving the design of all the figures, for critical reviewing of the manuscript and for giving me her expert advice. Thankfully acknowledged also is Dirk Euler for giving me his expert advice regarding statistical questions and fruitful discussions about sustainability. Thanks go to Dr. J.F. Maxwell for critical reviewing of the manuscript and for giving me his expert advice. Special thanks go to Dr. Joachim Ingwersen for giving me the hint about the maximum likelihood method, for his expert advice and numerous constructive discussions. Thanks go to Dr. Andreas Neef for discussions and his expert advice. Thanks goes to Peter Elstner for many fruitful discussion and the helpful cooperation during all those years.

At the Department of Soil Science and Land Evaluation of the Hohenheim University I am indebted to Karin Breuer for carrying out most of the analyses, but also to Annerose Boettcher, Andrea Zipp, Detlef Frobel, Conny Ruf, and Dr. Mehdi Zarei.

At the Faculty of Agriculture of the Chiang Mai University I am grateful to Niwat Anongrak for his helpful support with secondary data and his expert advice and also to Dr. Mattiga Panomtaranichagul for many helpful discussions. At the Faculty of Science of the Chiang Mai University I am indebted to Dr. Benjavun Ratanasthien for the identification of the plant fossils from Huay Bong.

Thanks go to Cindy Hugenschmidt for constructive discussion and for supporting the measurements of pH and electrical conductivity in the Mae Sa Noi stream. Special thanks are due to Chalathon Choocharoen, Gunnar Kahl, Anne Weiß, Torsten Hüller, Wolfram Spreer, and Klaus Spohrer for all the fruitful discussions. Thanks go to Dr. Oliver Frör for his expert advice about statistical methods and to Paweena Prachasuksanti for translating the summary into Thai.

I am very grateful to the villagers of Bor Krai, Huay Bong, and Mae Sa Mai for their support. A very cordial thank is due to the villagers of Bor Krai for their hospitality. Thanks go to Wirod for his guidance in the Huay Bong area and for his expertise.
Last, but not least, I am very grateful to Jajoy, who guided me in all the years on my field trips and who never gave up to join my struggle through all my difficulties.