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SOIL SALINIZATION IN NORTH-EAST THAILAND

With 5 figures and 6 photos

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Zusammenfassung: Bodenversalzung in Nordost-Thailand

Sekundäre Bodenversalzung ist nicht allein ein Problem der Bewässerungsgebiete, sondern kann auch als „dryland salting" in nicht bewässerten Böden auftreten. Aus dem im monsunalen Klimabereich gelegenen Khorat Plateau in NE-Thailand wird eine weitverbreitete sekundäre Bodenversalzung beschrieben. In den vergangenen Jahrzehnten wurde eine drastische Zunahme der versalzten Areale beobachtet. Geomorphologische Untersuchungen zeigen, daß die Quelle des Salzes in den marinen Gesteinen der mesozoischen Mahasarakham Formation und einem im Pleistozän angelegten, stark salzhaltigen Grundwasservorrat in den Alluvialebenen gegeben ist. Die Ursache der zunehmenden Versalzung ist in der weitflächigen Abholzung in den Grundwassererneuerungsgebieten zu suchen, die in direktem Zusammenhang mit der rapiden Zunahme des „cash crop"-Anbaus steht. Durch die Abholzung der tiefwurzelnden, stark wasserverbrauchenden Waldvegetation (Monsunwald und Dipterocarpus-Trockenwald) kam es zur verstärkten Infiltration des Niederschlagswassers und zur Anhebung des Grundwasserspiegels sowohl in den Grundwassererneuerungsgebieten selbst als auch in den benachbarten Tälern und Ebenen. Die gelösten Salze gelangten zum einen durch seichten „interflow", zum anderen durch längeren Transport über das oft gespannte Grundwasser in den Bereich der Wurzelzone. Hierbei ist der seichte „interflow" für die Versalzungserscheinungen am unmittelbaren Hangfuß von kleinen Erhebungen, der längere Grundwassertransport für die Versalzung in den weitgespannten Ebenen verantwortlich. Zusätzlich kommt es zum kapillaren Aufstieg von salzhaltigem Grundwasser.

Alle Maßnahmen zur Bekämpfung der Bodenversalzung müssen davon ausgehen, daß es sich um einen quasinatürlichen Prozeß handelt, der weder völlig unterbunden noch schlagartig beseitigt werden kann. Eine entscheidende Verbesserung kann nur durch eine längerfristige Senkung des Grundwasserspiegels erreicht werden, denn nur dadurch kann der Aufstieg des Grundwassers bis in die Wurzelzone unterbunden werden. Zu den wichtigsten Maßnahmen gehören der Schutz der noch vorhandenen Waldgebiete und vor allem die Änderung der Landnutzung in den Grundwassererneuerungsgebieten durch Aufforstung und Anbau von Baumkulturen.

Introduction

The problem of secondary soil salinization is not new; it is probably as old as the agricultural activity of man in the drier parts of the world and it is likely that some ancient civilisations collapsed or at least declined due to the spread of salinity in formerly productive fields (JACOBSEN a. ADAMS 1958). However, soil salinization remained a relatively localized phenomenon until about a century ago, when large irrigation projects came into existence and resulted in the rapid expansion of irrigated land. Although not immediately apparent, this eventually caused a rise in watertable, a mobilisation of salts and a gradual transport of salts to the root zone or even to the soil surface. It has been estimated that presently an area of about 200 000 km^2 worldwide is affected by soil salinization and the annual loss in productivity is in the order of 4000 Million Deutschmark.

Soil salinization is often seen exclusively in connection with irrigation in arid and semi-arid areas, and it is certainly here where it is most widespread and occurs in its most severe form. However, under certain conditions soil salinization also affects non-irrigated land. This is usually referred to as dryland salting and it has been most extensively studied in Australia where it is widespread in the south-east and south-west of the continent (PECK et al. 1983).

The general cause of dryland salting is - as with salting on irrigated land - an excess of water leading to rising water-tables. In the case of dryland salting this surplus water, however, does not result from water brought into the area from far away storage areas through irrigation but is simply the result of a drastic change in land use, usually the removal of deep rooting trees with a high water consumption and their replacement by shallow rooting vegetation such as cereal crops or pasture grasses and legumes.

In addition to this, other conditions such as an ultimate salt source, a mechanism of salt accumulation, impeded drainage and leaching also have to be met. These conditions are usually closely linked with the geomorphological history of an area, and it is therefore essential to develop an understanding of these factors before one is able to explain the process of soil salinization for a particular area.

The following account is based on the senior author's involvement with the Thai Australian Tung Kula Ronghai Project (TATKR), a bilateral rural development project that aimed at improving the agricultural productivity of one of the poorest areas of north-east Thailand. This area constitutes a vast tract of alluvial plain land about 3000 km² in area and because of its poverty it bears its name "Tung Kula Ronghai", which means the "plain of the weeping Kula people". In addition to the senior author's direct participation in this project, field studies were carried by both authors throughout the North East.

Geology of the North East

North-east Thailand is virtually identical with the Khorat Plateau, an extensive, low lying undulating to low hilly plain that deserves its name plateau only through the fact that it is bordered along its southern and western margin by prominent cuestas (Schichtstufen) and hogbacks (Schichtrippen). Structurally the plateau represents a saucer-shaped basin developed over a sequence of Mesozoic to early Tertiary rocks. These strata overlay a folded Paleozoic basement and are sub-horizontal over much of the plateau except along the margin, where they have been warped to give rise to cuestas and hogbacks. In the centre of the plateau uplift along a south-easterly trending axis has produced a prominent anticline which has clear surface expression as the Phu Phan Range.

The Mesozoic sequence consists of beds of sandstone and shale of varying thickness and degree of interbedding. The oldest sedimentary rocks are lower Jurassic siltstones and sandstones, which form localized outcrops along the western hogback. The most important rock sequences for the Khorat Plateau and its margins are the middle-upper Jurassic Phu Phan Formation, a series of resistant, thick, cross-bedded sandstones and conglomeratic sandstones, the lower-upper Cretaceous conglomerates of the Khok Kruat Formation and the Mahasarakham Formation a series of sandstones, siltstones and shales frequently interbedded with rock salt and gypsum (HAHN 1982).

The Mahasarakham Formation covers about 25% of the Khorat Plateau and represents the most important formation with respect to soil and groundwater salinity since it constitutes the ultimate source of the salt. This formation is about 500 m thick and is made up of layers of rock salt and clastic sediments (YUMUANG 1983). In the lower half of the formation three beds of halite, between 80 and 120 m thick, are interbedded with thin layers of clastic sediments. The upper part of the formation (about 180 m in total) contains less salt but is not entirely salt-free, as often stated. It has been claimed that the upper 60 m of the Formation are salt-free due to weathering and solution of the salt. This, however, does not agree with recent drilling results. Veins of salt have been found by the authors at depths of 2.5 m below surface in the Tung Kula Ronghai area and in several road cuts along the Nakhon Ratchasima-Khon Kaen highway and in recently excavated fish ponds.

Landform Development

The most widespread landforms on the Khorat Plateau are low ridges and hills with broad intervening valleys and undulating plains. Along the main rivers extensive alluvial flats are developed. One of the most distinctive features of the Plateau is the relatively thick and uniform sand cover that veneers these ridges, hills and undulating plains. This sand cover may be between 1 and 3 m thick and overlies partly weathered shales and sandstones of the Mahasarakham Formation. In a few places a thicker sand cover was observed during drilling operations; however, it was difficult to establish whether this sand deposit was in fact a true deposit or weathered bedrock (PRAMOJANEE et al. 1985).

Where the sand cover is directly accessible along road cuts and in dug-out ponds, it rarely exeeds 3 m in thickness. It is pale brown, yellow, occasionally light grey in colour and its texture is fine-sandy with some silt which increases slightly down the profile. At

2-3 m depth there is usually a pisolitic horizon, which in depressions may thicken to a lateritic crust and hardens when exposed to the atmosphere.

In striking contrast to these widespread sands are bright red sands which occur in isolated patches throughout the southern and eastern Khorat Plateau. If they occur near the pale sands they always occupy higher positions on the slope or form broad ridge crests. However, they also occur without connection to the pale sands close to the present-day rivers and form broad, usually forested, low ridges. They are relatively prominent along the southern margin of the middle Mun River, near Khorat, Khon Kaen and Yasothon, but isolated patches can be observed in the eastern and central part of the Plateau.

Few studies have been done on the landform development in the North East (Boonsener a. Tassonasorn 1983, Boonsener 1985, Löffler et al. 1984, Pramojanee et al. 1985). The most frequently quoted papers are those of Moormann and collaborators (Moormann et al. 1964, Moormann a. Rajanasoonthon 1972) who try to explain the distribution of the soils in the North East with the aid of a geomorphological model. They suggest that most of the Khorat Plateau was formed by alluvial depostion and constitutes alluvial terraces built up by the Mekong River and its tributaries. They claim to recognize three main terraces called the high, middle and lower terrace, and the main soil groups are classified accordingly into high, middle and lower terrace soils. This model has several shortcomings, as pointed out by Michael (1982) and Löffler et al. (1984), and cannot be accepted as being applicable for the landform development of the Khorat Plateau. The main arguments against the terrace model are: distinct alluvial terraces consisting of water transported horizontally-layered material are rarely developed and in particular the "middle terrace", which according to Moormann et al. is widespread, does not exhibit any geomorphological terrace features; the sand is often continuous from the ridge crest - which often shows a solid core - to the vally bottom, which is inconsistent with a terrace origin as is the great areal extend of this "middle terrace".

The "upper terrace" of Moormann's concept is not simply an old alluvial terrace even though in this case fluvially transported gravel can be found in many locations such as along the Khon Kaen-Udon road north of Khon Kaen University and more widespread on a forest covered low plateau northwest of Kalasin and along the southern margin of the Mun River. In other places, however, there is no evidence of water transport and the red sands appear to represent the remnants of an old weathered land surface.

The landforms of the Khorat Plateau are more easily explained as the result of erosional processes, with the red sands being relicts of an older deeply weathered landscape of low relief which was dissected and much of the weathering mantle stripped off. There is evidence from the Tung Kula Ronghai plain that the Mun River and its tributaries were incised much deeper than the present-day land surface; in fact the base of the alluvial sediments is at 30 m below sea level and 150 m below the present plain surface (Löffler et al. 1984). The base of the Mun River at Tha Tum, for instance, is 130 m below the present plain and the base of the Lam Sieo Yai at Wapi Pathum is at least 40 m below surface (ADAB 1983). Through this incision and stripping the underlying less strongly weathered material and even bedrock were exposed, except for some areas near watersheds and in low-lying positions.

Following this incision was a period of accumulation in the main valleys caused by a rise in base-level at the confluence of the Mun and Mekong rivers. This rise was probably coincident with the volcanic activity during the early Pleistocene. Its main effect on the Mun River system was the ponding of the river system, since the present base-level near the confluence is formed by a series of rapids at an altitude of 100 m above sea-level. This is over 100 m above the base of the alluvial sediments. The Mun River basin thus became an enclosed basin and probably lacustrine conditions prevailed for some time. Eventually the basin became filled up with sediment and the surface of these sediments constitutes the present alluvial plains of the Mun and Chi rivers. So far we have no dates for these events, except for the youngest phases of accumulation. Our bore records and C-14 dates show that there must have been a significant change in climate and associated processes after about 20 000 years BP when deposition of sands rich in organic material was replaced by deposition of sands entirely free of organic matter. There also seems to have been an increased inflow of saline water into the basins since the groundwater in the non-organic sands is always considerably saltier than in the underlying organic sands. Some localized aeolian activity may also have been associated with this. Aeolian activity also seems to have occurred in the Khon Kaen area further west (Boonsener a. Tassanasorn 1983). However, unequivocal evidence for aeolian transport is difficult to find since sand transport can only have operated over short distances out of the flood plain to adjacent hills. The interpretation of this event given by LÖFFLER et al. (1984) is that it represents a dry phase coinciding with the maximum of the last glacial period and a greatly extended land area in the South East Asian region.

The geomorphic evidence thus shows that much of the southern Khorat Plateau constitutes a relatively young erosional landscape with much of the previously existing weathering mantle being stripped off and the little - or only partly - weathered Mahasarakham Formation being brought close to the land surface. The larger valleys are in-filled valleys that were much more deeply incised in previous times. The outlet of the Mun River, which drains much of the Khorat Plateau into the Mekong, was gradually raised so that the middle course of the Mun and the Chi Rivers became enclosed basins and sediment traps. However, they also form traps for the salty groundwater that has accumulated over time in the basins. The degree of salinity was probably accentuated when drier conditions persisted during the height of the last glacial period as a result of reduced temperatures and a greatly extended land area.

Causes of salinization

Soil salinization in north-east Thailand is not a new problem and it is also not a problem entirely caused by man. Apart from the salt-bearing rocks, which are evidently the ultimate cause of salinization, there exists a nearly stationary supply of highly saline groundwater in the larger basins, such as the Tung Kula Ronghai, and through stripping of the old weathering mantle relatively fresh little weathered salt bearing rock occurs close to the surface.

Photo 1: Hill made of spoil from salt making activities near Ban Chiang; according to archaeological evidence and C 14-dating, the salt making at this site dates back 2000 years (E. LÖFFLER, March 1982)

Kulturhügel bestehend aus Auswaschungsdetritus traditioneller Salzgewinnung in der Nähe von Ban Chiang. Der Beginn der Salzgewinnung kann hier aufgrund archäologischer Funde und C 14-Datierungen auf 2000 Jahre vor heute datiert werden

There is also archaeological evidence that localized occurrences of surface salt have been utilized for salt making for two thousand years (Photo 1) in very much the same way as it is still practised today, i. e. highly salinized surface soil is scraped from the ground, collected into a hollow log and by adding water the salt is leached out and the highly saline brine is evaporated by boiling.

However, it is also beyond doubt, that the extent of secondary soil salinization has increased considerably and that many areas formerly salt-free have become saline following forest clearance. This applies in particular to many low-lying areas that have become saline following clearance of nearby uplands. This development was accelerated by the widespread clearance of uplands in the fifties and early sixties in connection with the cultivation of cassava, sugar cane, and kenaf. It has been estimated that today about 26 000 km² of formerly productive land are salinized in varying degrees of severity and about the same area is threatened by salinization (ARUNIN 1984, EL-SWAIFY et al. 1982). Nearly all the areas concerned are rice lands. Since the soils of the North East are generally of low fertility and unfavourable in their physical characteristics (rice yields in the North East are less than half of those in the Central Plain), this additional negative factor has disastrous consequences on productivity.

There is also direct documentation in some areas that clearance was followed by salinization (Photo 2) and interviews with older villagers invariably confirm this. The large extend of salt-affected, abandoned rice fields is also a clear indication of an increase in salinity, since it is unlikely that the fields were originally established in saline soils (Photo 3).

There is little disagreement amongst the researchers on this relationship between deforestation and salinity, and this relationship has been well researched in other countries particulary in Australia (PECK 1978, PECK et al. 1983, WILLIAMSON 1982). However, the main controversies lie in the explanations of how the salt actually reaches the surface.

There are two main lines of thought, each being based on field and partly also experimental and laboratory evidence. The first concept envisages that the salt originates directly from weathering of the Mahasarakham bedrock and is transported from nearby uplands through shallow interflow to lower

Photo 2: Ricefields abandoned and destroyed due to salinization and subsequent soil erosion. Flat topped areas are remnants of old rice fields (E. Löffler, March 1985)
Aufgrund starker Bodenversalzung aufgegebene und durch Bodenerosion zerstörte Reisfelder. Die flachen, herauspräparierten Platten sind Reste der alten Reisfeldoberfläche

lying areas. The second theory denies the significance of shallow interflow because of the high degree of weathering and desalinization of the rocks near the surface and because this interflow occurs in the wet season when the shallow groundwater is constantly recharged with fresh rain water. Instead it is claimed that the main cause of salt reaching the surface is a general rise in groundwater to the capillary fringe and consequently the capillary rise of salt to the surface. Salt is supposed to be brought into the aquifer by long distance groundwater flow from distant salt-bearing rock strata.

According to our observations there can be no doubt that both mechanisms operate but under different geomorphological and hydrogeological conditions. Generally speaking shallow interflow operates mostly on a local scale; it is particularly obvious around the footslopes of low hills and mounds that consist of the spoil of former salt-making activities. These low hills are widely scattered throughout the North East and they are quite frequent in the upper Mun River area north of Nakhon Ratchasima. They are relatively easy to identify because of their roundish shape, their conspicuous occurrence within otherwise flat plain land, and their composition of irregulary-bedded usually still highly saline fine sands (Photo 1). Charcoal from the wood that was used to boil the brine and artefacts such as pottery fragments are invariably found in these mounds. These mounds must not be regarded as the cause of salinity; they are simply the result of the people taking advantage of the already occurring soil salinization.

Photo 3: Severely salt-affected rice fields in the Khorat area (E. Löffler, September 1986)
Stark salzgeschädigte Reisfelder in der Nähe von Khorat

However, natural hills and ridges with bedrock close to the surface also contribute salt by shallow interflow. Indirect evidence for this can be seen along many road cuts where salt crusts occur in gullies at the break of slope between the hill and the plain.

One particularly striking example of shallow interflow associated with rising groundwater occurs some 30 km south-west of Khon Kaen at Ban Phra Yuen and this site is under investigation by the Soil Salinity Division of the Department of Land Development. The area consists of low broad ridges with wide valleys, which are under rice or used to be under rice. The ridges were forested until about 35 years ago, when they were cleared to make place for more rice fields in the lower lying areas and upland crops higher up the slope. Within about ten years after clearing, the rice fields along the foot slopes became saline and salinity has increased ever since, so that today the area is virtually barren and even used for traditional salt making(Photo 2). From the topographic situation it is evident that the salt in this case must have reached the lower slopes by shallow interflow, whereby a rise in groundwater must have brought salt close to the surface and caused shallow salt water seepage. In addition to the surface salinization, severe soil erosion has set in and removed much of the upper soil horizon exposing the even more heavily salinized subsoil (Photo 2).

Another well documented example for salinization by shallow interflow has been reported by Takaya et al. (1984). A small hill formed of partly weathered rocks of the Mahasarakham Formation rises some 10 m above the surrounding plain. The bedrock is overlain, as is common throughout the Khorat Plateau, by 1–1.5 m of fine sand. On top of the hill a pond some 70 × 150 m was excavated for water storage and fish production. The water in the pond is fresh, but the foot of the hill is heavily salinized with the degree of salinization decreasing with increasing distance from the hill. A piezometer installed at the foot of the hill showed a piezometric level slightly above the plain surface and the water was moderately saline with an EC (electric conductivity) of 1100μS/cm. Three pits dug into different levels along the slope indicate that the water is becoming increasingly saline as it moves downslope by shallow interflow, and the only explanation for this is that the water picks up salt as it moves through the weathered Mahasarakham Formation.

Salinization by shallow interflow is thus a process that cannot be denied and it is responsible for a great number of saline areas, and, according to our observations, it is most commonly associated with the situation just described above, namely with seepage of water from man-made ponds that are ubiquitous throughout the North East.

However, shallow interflow cannot explain the great expanse of salinized land in large alluvial plains such as the Tung Kula Ronghai because there is just not sufficient bedrock area in the near vicinity and the salinity effects are spread rather irregularly throughout the plain (Photo 4, 5). The saline areas occur as randomly distributed spots, 5–25 m in diameter and can be well observed on air photos.

Photo 5: Air photo (Orthophoto) of salt-affected area in the Tung Kula Ronghai. Irregular light grey spots are salt-damaged sites (E. Löffler, February 1986)

Luftbild (Orthophoto) der salzgeschädigten Agrarlandschaft im Tung Kula Ronghai. Die hellgrauen Stellen sind salzgeschädigte Areale innerhalb (abgeernteter) Reisfelder

Photo 4: Air photo of salt-affected area in the Tung Kula Ronghai. The damaged areas show up as bare patches within the rice fields (arrows). Note that in some areas (lower centre and centre) rice has already been harvested (C. Lee, November 1985)

Luftbild der salzgeschädigten Agrarlandschaft im Tung Kula Ronghai. Die geschädigten Gebiete erscheinen als kahle Areale innerhalb der Reisfelder (Pfeile). Man beachte, daß in einigen Gebieten (Zentrum und unterer Teil des Bildes) die Reisfelder bereits abgeerntet sind

It is also unlikely that under present climatic conditions salt is brought into the plains by surface flow from salinized areas further upstream, since the salt concentrations in the rivers during the rainy season, when wide spread flooding occurs, are extremely low. The salinity of the plain is undoubtedly linked with the high degree of salinity of the groundwater.

In the Tung Kula Ronghai area the groundwater movements and the shallow and deep stratigraphy of the sediments have been investigated in some detail by the authors and other scienticts belonging to the Thai Australian Tung Kula Ronghai Project (ADAB 1983) and the situation here appears to be representative for the salinization of larger plain lands (Fig. 1). The situation within the upper two metres below surface can be particularly well studied here because of the construction of many kilometres of drainge channels (Photo 6). From these channel exposures a number of soil samples were collected from sites that showed different degrees of salinization.

The most important stratigraphic units of this plain (Fig. 1) are a clay layer, about 1–3 m thick, which

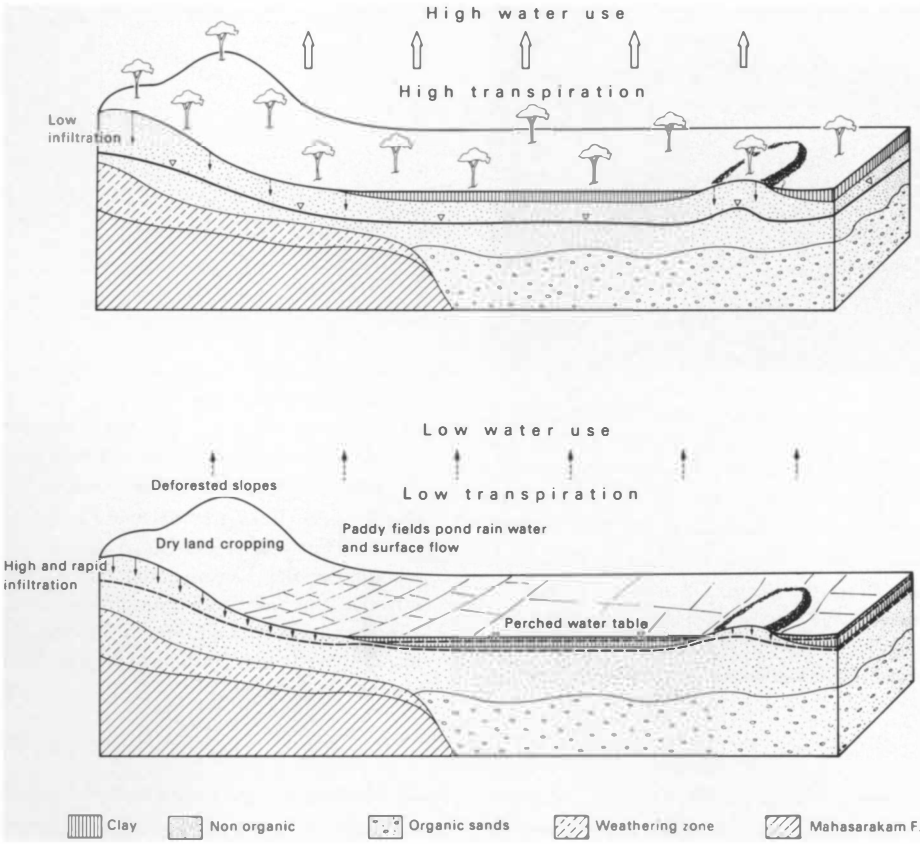

Fig. 1: Idealised block diagram of Tung Kula Ronghai Plain showing stratigraphy and model of soil salinization under natural vegetation (upper diagram)
Water use and evapotranspiration are high and the ground water level is relatively low. With deforestation (lower diagram) ground water use and transpiration are reduced. Due to the presence of a confining clay layer in the plain the ground water here is under artesian pressure. A perched water table develops during the rainy season and is usually not connected with the main aquifer

Idealisiertes Blockdiagramm der stratigraphischen Verhältnisse im Tung Kula Ronghai mit einem Modell der Bodenversalzungsgenese
Bei einem Bewuchs mit natürlicher Vegetation (oberes Diagramm) ist der Grundwasserverbrauch aufgrund der hohen Evapotranspiration hoch und der Grundwasserspiegel liegt relativ tief. Mit der Abholzung (unteres Diagramm) wird der Grundwasserverbrauch aufgrund der gesunkenen Transpiration verringert, die Infiltrationsrate steigt und der Grundwasserspiegel steigt an. Die Tonschicht in der Ebene verhindert ein freies Ansteigen des Grundwassers. Während der Regenzeit bildet sich auf der Tonschicht in der Pflugsohle der Reisfelder ein Stauwasserhorizont aus, welcher in der Regel nicht mit dem Hauptaquifer in Verbindung steht

forms the surface of the plain, and a layer of fine sand, yellow to red in colour and without any trace of organic matter, about 10 m in thickness representing the main aquifer but being highly salinized. In the channels this sand layer is sometimes exposed at the base. This is underlain by sand of great thickness which contains organic material (Löffler et al. 1984). This organic sand contains water that is always less salty than the water in the non-organic sands. The clay layer is only present in the plain proper, and it peters out near hills and sandy rises.

The groundwater levels in the profiles are well defined by pisolitic horizons (Photo 6). Generally the upper, nearly rectilinear, pisolit horizon defines the basis of the plough pan that forms the uppermost part of the clay layer. The iron enrichment can be explained as a result of ponding of water at the boundary of the sandy plough pan and the clay. The drying-up of the perched water table at the beginning of the dry season causes the lowering of the water-saturated zone, and pisolits are formed at the base of the plough pan.

Photo 6: Drainage channel in the Tung Kula Ronghai south of Suwannaphum. Height of the profile 2.2 m. The two pisolitic horizons indicate the levels of the perched and artesian water tables respectively. In the right foreground the two horizons meet (E. LÖFFLER, March 1987)

Entwässerungsgraben im Tung Kula Ronghai südlich Suwannaphum. Höhe des Profils 2,2 m. Die Niveaus des oberflächennahen und des gespannten Grundwasserspiegels werden durch zwei Pisolithhorizonte markiert. Im Vordergrund rechts laufen die beiden Horizonte zusammen

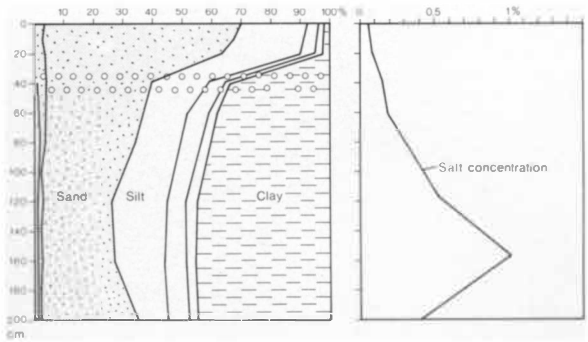

Fig. 2: Granulometric composition (left) and salt distribution (right) of a site in Tung Kula Ronghai little affected by salt damage. The salt is enriched in the lower part of the clay layer while the upper part of the layer and the sandy plough pan are nearly salt free

Korngrößen- (links) und Salzverteilung (rechts) in einem Profil im Tung Kula Ronghai, das nur eine geringfügige Schädigung der Reispflanzen durch Bodenversalzung aufweist. Das Salz ist im unteren Teil der Tonschicht angereichert, während die oberen Teile der Tonschicht und der Pflughorizont deutlich geringere Salzmengen enthalten

The plough pan contains much less clay than the clay horizon below. Otherwise the granulometric composition is similar. Therefore the sandy plough pan is of pedogenic and not of sedimentary origin. Besides a descendant clay displacement a lateral displacement is also possible, as was observed during heavy rainfalls in September 1987. Such rainfalls occur sporadically as a result of cyclones from the Gulf of Tonkin.

The region of the lower groundwater level is defined by a pisolitic mottled zone. The height of this wave-like zone varies between 2.5 m and 0.5 m below surface. Piezometric observations, which started two years ago, show that the lower aquifer is under artesian pressure during the wet season, with the piezometric surface rising above surface in some piezometers. A typical situation representative of sites not affected by salt damage is shown in Fig. 2. In this example, the salt distribution shows a distinct zonation of salt concentrations from the plough pan to the base of the clay layer. It increases from the plough pan where it is 0.1 g salt/100 g soil to 1.0 g/100 g at the base of the clay layer. Despite the high salt concentration at the base of the clay layer the surface salinity is small, the limit of salt damage to rice crops being about 0.2 g/100 g soil (MAAS et al. 1977).

The typical situation of a salt-affected site is shown in Fig. 3. As in Fig. 2 a distinct plough pan is developed. However, the lower mottled zone is compressed to a pisolitic band and is situated 1 m below surface. The salt distribution shows an accumulation zone in the vicinity of the plough pan. The salt content of 0.4 g/100 g soil is similar to a crop yield reduction of 40%. Total crop failure would occur at 0.7 g salt/100 g soil (MAAS et al. 1977).

The clay layer peters out in the vicinity of isolated sandsheets which rise through the clay layer and form

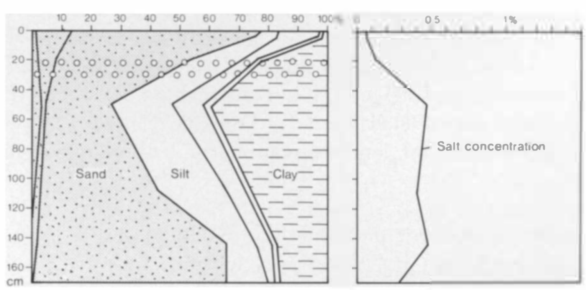

Fig. 3: Granulometric composition (left) and salt distribution (right) of a site in Tung Kula Ronghai affected by salt damage. Salt is enriched in the clay layer about 1 m thick and reaches the root zone through capillary rise

Korngrößen- (links) und Salzverteilung (rechts) in einem Aufschluß im Tung Kula Ronghai mit deutlicher Salzschädigung der Reispflanzen. Das Salz ist in der ca. 1 m mächtigen Tonschicht und im Bereich der Wurzelzone angereichert

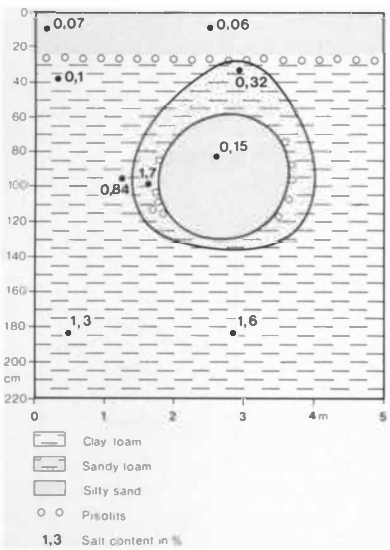

Fig. 4: Salt distribution around a sand lens incorporated in the clay layer. The sand lens facilitates the ascent of the artesian ground water and leads to higher salt concentration in the root zone compared to the profiles nearby

Salzverteilung in der Umgebung einer in der Tonschicht „schwimmenden" Sandlinse. Die Sandlinse fördert den Aufstieg des artesischen Grundwassers und bedingt einen höheren Salzgehalt im Bereich der Wurzelzone, als es in direkt benachbarten Profilabschnitten der Fall ist

low rises 1–2 m above the general level of the plain. Here salt-affected areas were not observed.

A stratigraphic peculiarity are sand lenses incorporated in the clay layer (Fig. 4). On top of the sand lens close to the plough pan the salt content is 2 to 3 times higher than in a 3 m thick clay layer next to it. The salt content in the sand lens itself and in the direct vicinity is up to 1.8 g/100 g soil, and this decreases to 0.3 g salt/100 g soil at the base of the plough pan.

The observations described permit the following reconstruction of the process of soil salinization (Fig. 5). The fact that the highest salt concentrations occur in the lower part of the clay layer underlines the important influence of the artesian aquifer. Near the top of this aquifer and its capillary fringe salt is accumulated. The salty groundwater is enriched in the clay layer during groundwater ascent favoured by artesian pressure and small pore size. During the groundwater lowering the clay still remains wet while the top of the non-organic sand starts to dry out. If the clay layer has a thickness of more than twice the capillary fringe (1–1.5 m), the rice plants which grow in the upper 30 cm are not affected by salting (Fig. 5). However, if the clay layer peters out or is interrupted by sand lenses, the capillary fringe rises close to or into the root zone. In some cases a direct mixing of perched and artesian water can be observed. In these cases the two pisolitic horizons join each other (Photo 6).

During the dry season the paddy fields dry out and, due to the high pore size of the sandy soil in the plough pan and the small pore size in the clay layer underneath, the salt is accumulated near the bottom of the plough pan (Fig. 5) (The samples of the described profiles were taken in April 87, at the end of the dry season!). The process of salt enrichment is interrupted by flooding of the rice paddys and lateral movement of disolved salts. At nearly the same time salt is transported vertically into the upper parts of the salt-affected soils due to the rising artesian ground water. The general model of the salinization process is shown in Fig. 5.

On sand ridges and partly more highly situated areas soil salinization does not occur because the artesian groundwater does not reach the clay layer and/or the capillary pressure in sandy material is not high enough to produce a salt accumulation in the root zone of the rice crops.

One other factor that influences the local occurrence of salinity is land management. Field observations showed that within rice fields those parts that were slightly above the general level of the remainder of the field were most salt-affected. At the end of the rainy season these are the areas which dry out earliest or which dry out repeatedly during dry spells within the wet season while the rest of the field remains water-covered. Because of the early drying-out salt reaches the root zone early, leading to inhibited growth or death of the plants. Also due to the capillary pressure and the slight difference in water table, water and salt from nearby is drawn towards the low rises, increasing the degree of salinity. No capillary pressure can develop as long as the surface is water covered, and it is therefore important for the farmer to maintain a field as level as possible and to keep the water on the field as long as possible. This, of course, is not easy under the relatively simple farming methods with buffalo-drawn ploughs and the lack of efficient water control.

Measures to alleviate salinity

All measures to alleviate salinity have to take into account the fact that soil salinity in the North East is at least partly a natural phenomenon and is unlikely to be eradicated entirely. In some areas, especially

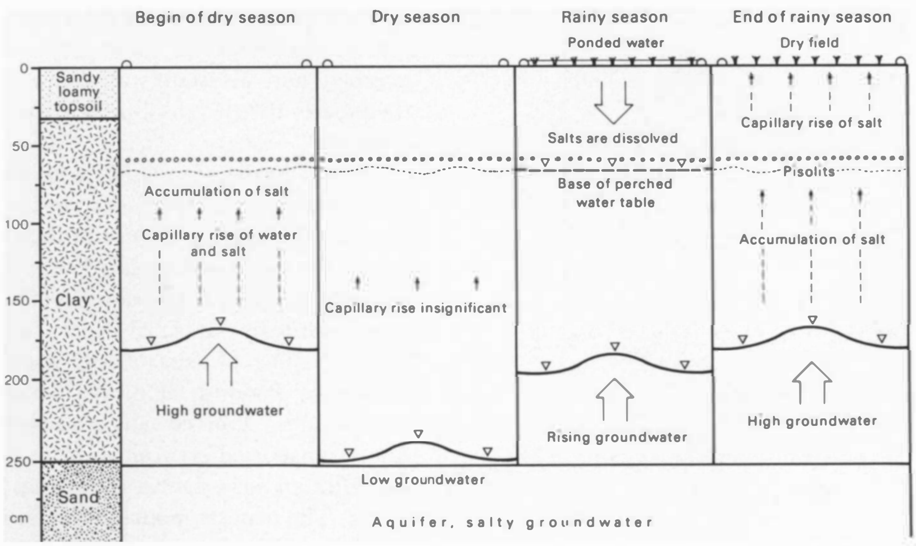

Fig. 5: General model of soil salinization due to changing of groundwater levels during the seasons

Generalisiertes Modell der Bodenversalzung in Beziehung zum Wechsel der Grundwasserstände im Verlauf der hygrischen Jahreszeiten

those that are severly salinized and where there is evidence that salinity has been a long standing occurrence, it may not be possible or worthwhile to combat salinity at all. It also has to be recognized that soil salinization is a long-term problem, and no quick solutions will be possible although short-term measures such as soil amendments will be helpful to some degree, at least in cases that are not yet severe. Regardless of whether salt moves to or near to the surface by shallow interflow or through long and medium distance transport through the deeper groundwater, a long-term improvement of the sitatuion can only be achieved through a lowering of the groundwater-table, since only this can stop the direct or indirect rise of salts to the soil surface.

Other important factors, which so far have not been dealt with but which are of greatest importance, are the standard of agricultural techniques, the natural productivity of the soils and above all the socio-economic conditions of the population. Taking these factors into account it becomes clear that complicated and expensive measures, such as extensive subsurface drainage and the construction of ground water pumping systems as is for instance practised in Australia and the U.S.A., have to be excluded quite apart from the problem of the disposal of the salty groundwater in this heavily populated region.

The most important, but at the same time most difficult, measure for social reasons is reafforestation, including the planting of tree crops in as many groundwater-intake areas as possible. Groundwater-intake areas are basically all the upland areas. This will increase water consumption in the intake areas and hence lower the water-table on the uplands, which in turn will reduce the level of the water-table in the lowlands and also the pressure on the lowland aquifer if an artesian situation is present, as in the Tung Kula Ronghai area. The social acceptance of reafforestation is a major obstacle even on public land, since this land is generally used as grazing land by the villagers. Pure reafforestation will therefore only be possible where large areas of vacant public land are available and this situation is rare in the North East. Therefore agroforestry, with a combination between tree planting and pasture, will be most suitable in order to offset the loss of grazing land. The practice of trying to grow rice in bunded rice fields in upland areas should be discontinued since this, too, increases the recharge. On these fields rice can be grown only during exceptionally wet years, which may be only about one in five and the yields are very low. Replacement with other crops - preferably tree crops - should be encouraged.

Short-term measures, which are already practised by some farmers, are soil amendments through mulching with rice straw, rice husks and manure, intercropping (very rare) during the dry season, and the abandonment of the old practice of burning the rice straw for easier work in the fields. These measures improve soil structure and reduce evaporation from the exposed soil surface and thus also help reducing capillary rise, but they will only have a marginal and localized effect.

The importance of maintaining a level field to prevent parts of the rice field to dry out early was already mentioned. This will require the occasional use of a tractor, but again this will not reduce salinity in the long run.

Water distribution and water management need to be improved. Although the great majority (over 95%) of rice fields in the North East is dependent entirely on rain water, locally including flood water, the distribution of this is not efficient so that some fields receive too much and others too little water. The salinity hazard of those fields with little water is increased through lateral seepage of water and salt from the better-watered neighbouring fields, a situation which also occurs if non-irrigated fields border irrigated fields.

One of the most efficient ways to improve water management would, of course, be irrigation and this would also alleviate the salinity problem since as long as the rice fields are water-covered no capillary rise is possible. However, irrigation in the North East is not an easy task. Nearly all the suitable dam sites have already been utilized, such as the Udonratana Dam near Khon Kaen and the Lam Pao Dam near Kalasin, and there are simply no other feasible sites left. To pond large quantities of water on the plateau itself is not only technologically difficult, but would cause a substantial loss of land that presently belongs to the better watered and slightly more fertile stretches of rice land. There are also considerable ecological and hygiene problems associated with the ponding of large areas of shallow water, and the ponded water would result in a further rise of the water table causing an increase in salinity hazard outside the irrigated area. An irrigation project that would serve most of the plainlands of the North East is also unfeasible because of the limited water supply and the high rates of evaporation during the dry season. Even the setting up of small-scale irrigation schemes needs careful investigation of the local hydrogeolocigal situation since the withdrawal of fresh water may - if it exceeds fresh water recharge - causes salt water incursions at least during the latter part of the dry season when the fresh water supply is low or exhausted and the need for irrigation water is highest.

One of the first large-scale attemps to use reafforestation as an appropriate measure to alleviate soil salinity was undertaken within the Upland Reforestation Component of the Thai Australian Tung Kula Ronghai Project. The aim of this component was to reafforest over a period of 5 years annually 360 ha of uplands in order to reduce the water-table or reduce the piezometric pressure in the adajacent lowlands. This lowering of the water-table should reduce the salinity hazard in the lowlands. With the aid of a piezometer network the fluctuations of the water-table will be monitored over at least a ten year period. Since the piezometer network of 80 piezometers has only been fully operational for about one year, and since the planted trees are still immature, no quantitative results are to hand yet and are unlikely to be so for several years to come.

The principle of the reafforestation programme is worth mentioning. In contrast to many other reafforestation projects, which are purely for the purpose of reafforestation this one is an integrated one and aims at producing timber, creating adequate pasture and lowering the water-table. Initially the main tree used for reafforestation is *Eucalyptus camaldulensis.* This has been done because in the highly impoverished soils native trees are extremely difficult to establish. They are dependent for their growth on an forest ecosystem providing shade and nutrients. *Eucalyptus camaldulensis* does grow well on poor acid soils and is at present the only tree that under the given conditions shows any promise. It is hoped to gradually replace the exotic Eucalypts by native trees.

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SULTRINESS AS A CHARACTERISING FEATURE OF HUMID TROPICAL WARM CLIMATE: WITH SPECIAL REFERENCE TO THE PHILIPPINES

With 5 figures, 5 tables and 1 supplement (IV)

PHILIP TILLEY

Zusammenfassung: Schwüle als charakteristisches Merkmal der warm-feuchten Tropen unter besonderer Berücksichtigung der Philippinen

Die feuchten und trockenen Tropen sind durch das gemeinsame Merkmal der geringsten photoperiodischen und thermischen Saisonalität gekennzeichnet. Eine der charakteristischen Eigenschaften der feuchten Tropen ist jedoch, daß Teile von ihnen dauernd, jahreszeitlich oder täglich feucht und warm genug sind, um schwül zu sein, d. h. klimatische Bedingungen zeigen, die von den Menschen als drückend heiß und feucht empfunden werden. Das Phänomen der Schwüle - obwohl nicht auf die tropische Welt beschränkt - unterscheidet die warm-humiden Tropen stärker von denjenigen tropischen Regionen, die nachts oder permanent zu kühl sind, um schwül zu sein, als von den Gebieten, die jahreszeitlich oder permanent zu trocken sind.

Die meisten Versuche zwischen den feuchten und trockenen Tropen zu unterscheiden, folgten dem Beispiel KÖPPENS (1900) mit der Abgrenzung der ganzjährig und