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Rapid Indicator-Based Soil Mapping for Regional Planning in Northern Thailand

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ABSTRACT

The breakneck speed of development in Thailand has led to ever mounting pressure on the country's natural soil resources. This essential resource for agricultural food production is declining rapidly both in quantity and quality due mainly to uncontrolled urban development.

An illustrate example is the city and valley of Chiang Mai in northern Thailand. The area is rapidly developing into the regional business hub of northern Thailand and neighboring countries. The interactions between the accelerated economic growth, an ever-increasing population, inadequate land-use practices, and the limited land resources present a formidable challenge for sound regional planning. Already, Chiang Mai is facing stiff competition for land and is struggling with pollution and recurrent waste disposal crises.

Against this background and in order to timely support regional planning in Chiang Mai, a rapid appraisal of the area's soil resources was carried out based on available physical and chemical soil indicators such as particle-size distribution, cation exchange capacity, base saturation, and pH among others. Within a period of less than 4 months a dozen indicator-based soil maps were developed at a scale of 1:100,000 as part of a Thai-German technical cooperation project. To planners, the resultant maps provided an adequate and easily readable guide to the distribution of essential soil properties that give the suitabilities and limitations of the soils for various agricultural and non-agricultural uses in the area.

INTRODUCTION

Extensive building schemes are adversely affecting the availability of productive arable soils in the valley of Chiang Mai and neighboring Lamphun, a traditionally agricultural region in northern Thailand. In the absence of zoning laws, private landowners and real-estate agencies are developing housing estates that are scattered all over the valley which is otherwise dominated by paddy rice fields, some are over 1,000 years old.

In order to protect the newly built properties from rainy-season flooding, the former paddy rice fields need to be raised by approximately one meter with soil material excavated from numerous pits opened up across the nearby alluvial river terraces and/or the hillsides. Clearly, the combined effect of excavating soil material and subsequently depositing it onto previously irrigated paddy rice fields causes undue destruction of valuable arable soils.

To appreciate such human impacts on the soil environment and to help solve problems that arise in everyday planning, regional planners need to have access to sufficiently informative and easily readable pedological maps. Unfortunately, much of the information about the distribution and properties of soils in northern Thailand is in a form that is virtually impossible for planners to access and use in a manner convenient to their planning requirements.

An example is the soil series maps available for Chiang Mai (DLD, 1976) and Lamphun (DLD, 1981) at 1:100,000 scale. They contain a lot of specialist pedologic information that requires an expert to extract the particular data that are of interest. As a result, their wealth of information about soils has failed to reach planners, land users, and other government institutions; all of who could greatly benefit from an understanding of the nature and properties of the soil environment on which to formulate environmentally sound development plans.

In their conventional paper form, the soil series maps suffer from other problems too. First, they are static and therefore difficult and expensive to update and, second, because they are static they lose flexibility.

INSTITUTIONAL FRAMEWORK AND PREPARATORY WORK

The mandate of the bilateral Thai-German technical cooperation project, under which soil mapping was executed, was to support regional planning on issues related to environmental geology, that is the interactions between humans and the earth.

The project partners are the Department of Mineral Resources (DMR) of Thailand and the Federal Institute of Geosciences and Natural Resources (BGR) of Germany. As the DMR's mandate does not encompass soil science but is confined to the discipline of geology, the project did not have access to soil data. Hence, possible avenues of cooperation had to be explored between the two project partners and a third party concerned with soil surveying.

The Department of Land Development (DLD), located in Bangkok, was in position and willing to provide the required project support. Discussions with DLD staff yielded a close liaison agreement that not only provided the project with direct access to relevant soil data but also involved active data processing support by DLD staff.

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MATERIALS AND METHODS

The 46 soil profile and laboratory data sets available for the project area were entered into the DLD soil information system (Website http://www.ldd.go.th/Eo0100.htm) on a DOS-based personal computer (PC). Subsequently, all attribute data were further processed and manipulated in a spreadsheet program and later transferred to the ARC/INFO GIS software (Website http://www.esri.com/). The final soil attribute data were stored in sets of table files. For computer-based mapping at 1:100,000 scale, attribute information stored in the digital table files was linked to the geo-referenced digital soil map data (polygons) of the project area organized in the ARC/INFO GIS software environment.

The work was carried out in several consecutive steps. Initially, DMR counterpart staff digitized the four field survey map sheets available at a scale of 1:50,000 that cover the project area (2800 km^2) in Chiang Mai and Lamphun provinces respectively. All four are based upon the interpretation of 1:15.000 scale aerial photographs supported by extensive field checking and sampling. Soil boundaries were input by digitizing and referenced to a plane coordinate system. Soil areas (polygons) were identified by code.

While the field survey maps were digitized at the DMR, counterpart staff from the DLD's soil information section coded the available soil profile descriptions and field soil records according to DLD Soil Information System (SIS) standards. The DLDSIS features an early DOS-operated soil database program that stores information on individual soil series of the DLD's Soil Survey Division collection. This information contains the physiography and lithology of the sites where the soil profiles were surveyed and sampled, soil profile descriptions, and a wealth of soil physical and chemical laboratory data.

Once coding was complete, all soil-chemical and soil-physical laboratory data were entered into the DLDSIS software program. After the data, available on a soil horizon basis, had been entered into the DLDSIS, the soil chemical and physical data were extracted for data computation by means of spreadsheets. For ease of cartographic presentation, the available chemical and physical soil-horizon data were aggregated for the topsoils (defined as 0-25 cm depth) and subsoils (25-100 cm depth) respectively.

Aggregation was done on a proportional basis, which is the thickness of each soil horizon, expressed in percentage, was multiplied with each of the horizon's parameter values. These were then added up for each of the two depth levels to yield the final top- and subsoil values. In the case of the pH values, the original values were used for the aggregation rather than the logarithms, because they constitute the negative logarithm of the value of the H^+ concentration.

Indicator-based soil mapping

Soils are used for many purposes, such as road and building construction, waste disposal, and agricultural crop production. Soil maps, therefore, most commonly are required for areas that have competing land-use interests (USDA-NRCS, 1993). They reveal the nature, distribution, and inter-relationship of soils and are thus essential for assessing their suitability for agricultural and other forms of land use (Bastian and Schreiber, 1994). Although soil suitability, or soil quality for that matter, can not be measured directly, it can be inferred or estimated by measuring certain indicator properties, functions, or conditions (Acton and Gregorich, 1995). Soil quality is the ability of the soil to provide for good environmental quality (water and air quality), to support life and habitation, and to sustain agricultural food production.

Generally, an indicator is a factor that indicates or describes the character of a larger system. Soil indicators are factors that specifically point to a soil's state. These factors may be directly related to the soil, or they may be related to something that is affected by the soil, such as groundwater or crops. They may be in the form of physical, chemical, and/or biological properties, functions, or conditions, and their measurement may be based on simple field tests or elaborate laboratory analyses (USDA-NRCS, 1996).

Regional planning in general and in the project area in northern Thailand in particular deals with land use in broad perspective and appraises large areas. To be applicable to regional planning, soil maps must provide cartographic presentations of useful soil indicators rather than of predominant soil types which provide abstract information in a form only soil scientists are able to decipher. Furthermore, sound interpretation of measured indicator values needs to be based on acceptable value ranges. With Thailand being located within the tropics, ranges were taken from Booker's tropical soil manual (Landon, 1991).

In this context, it is also worth mentioning that soils and thus soil indicators, like other attributes of land, are known for their strong spatial heterogeneity at often very short distances (Becher, 1995). In the absence of soil biological parameters, variation tends to be highest for chemical properties and lowest for physical properties, and these variations can even be found within soils mapped as a single series (Landon, 1991). It should also be noted, that measured values not only reflect variations inherent in the soil but also those attributable to the methods of measurement. In addition, soil survey map units are rarely, if ever, pure. Probably all delineations contain some inclusions, that is minor soils present in such a spatial pattern that they cannot be separated out of the mapped unit.

Soil chemical and physical parameters used

Work concentrated on indicators for soil fertility evaluation in the project area, namely cation exchange capacity (CEC), percent base saturation (% BS), texture (particle size distribution), hydrogen concentration (pH), and organic matter content (% C). The two main reasons for this approach were: (i) project management and regional planners in Chiang Mai were primarily interested in delineating areas endowed with fertile soils from those with less fertile soils, and (ii) no single factor can be used as a universal index of soil quality (Acton and Gregorich, 1995; USDA Natural Resource Conservation Service, 1996).

Cation exchange capacity (CEC): As part of the overall assessment of the potential fertility of a soil, and possible response to fertilizer application, nutrient-retention capacity measurements are commonly made by determining the soil's cation exchange capacity (CEC). CEC or soil exchange sites are the negative sites on the clay particles that are created due to the unsatisfied charges of broken sites at the edge of minerals or internal ionic exchange. The negative sites attract and hold positive ions (cations). The notation of CEC for the SI units is centimoles of positive charge per kilogramme of soil [cmol(+) kg^{-1} soil].

CEC estimates may be derived from the amount of a particular cation that a soil can hold when leached by a buffered solution containing that cation. A commonly used leaching solution is ammonium acetate (NH_4OAc) buffered at pH 7. This method was applied to the samples from which the data available for this mapping exercise were derived.

Percent base saturation (%BS): Percent base saturation (% BS) is a measure of the proportion of exchangeable basic cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) occupying the cation exchange sites of a soil; as opposed to the acid cations (H^+ and Al^{3+}). Base saturation percentage was used as indication of the soil fertility status, as is done in the FAO soil classification system (FAO-Unesco, 1988). It was calculated as SUMBA x 100 divided by SUMBA + EXACID. EXACID (extract acidity) was measured in 0.5 N $BaCl_2$ (barium chloride) with triethanolamine buffered at pH 8.

Soil texture (particle size distribution): Soil texture is the relative proportion of different-sized mineral particles (clay, silt, and sand) in a soil or soil horizon respectively. DLD data are derived from the pipette method and the results are given in percentages by weight of the fine earth fraction (< 2 mm diameter). For mapping purposes the results were grouped into textural classes employing the equilateral textural triangle used in the U.S. system (USDA Soil Taxonomy, 1996).

H^+ concentration *(*pH): Except for extremely weathered and leached soils, hydrogen ions (H^+) are the principal source of soil acidity. Also, because the concentration of H^+ in a soil solution can be measured easily, soil acidity is conventionally identified by means of the soil's pH. A 1:5 soil:water suspension was used to measure the pH value of a soil sample.

Soil acidity is an important soil chemical characteristic primarily because it affects the availability of plant nutrients and plant growth. The pH range of 5.5 to 7.5 seems to allow the best availability of plant nutrients. At pH values below 5.5, aluminum ions are released from clay lattices and become established on the clay complex where they can have toxic effects on plant root growth.

Organic matter (%Org C): In the humid tropics, organic matter plays a key role for the fertility of soils, many of which are strongly weathered with little cation exchange capacity remaining in the mineral soil. For these soils, organic matter is an essential component for enhancement of nutrient storage and plant availability of nutrients.

In practice, soil organic matter is determined as the amount of soil carbon, because carbon, the key component of organic matter, is readily measured in the laboratory. It was measured in percent by weight employing the Walkley-Black method (wet oxidation).

RESULTS AND DISCUSSION

With the limitations of soil mapping and indicator-based soil mapping respectively in mind, several maps were completed, namely a Map of Potential Soil Fertility based on the CEC, a Map of Soil Fertility Status based on percent base saturation, and a Map of Soil Texture based on particle-size distribution. In addition, ready-to-use data sets were prepared for plotting two more indicator-based soil maps, namely a Map of the Degree of Soil Acidity based on soil pH, and a Map of Soil Organic Matter based on organic C content. Finally, a Soil Classification Map at two levels of generalization, soil orders and subgroups, were also completed during the short-term assignment.

Soil Classification Map: The mapped soils in the project area all fell within five soil orders according to the USDA Soil Taxonomy System (USDA-NRCS, 1996): Alfisols, Ultisols, Entisols, Inceptisols, and Mollisol. By far the most common soil order in the project area was the Alfisols. These semi-recent alluvial soils dominate the central basin area. They constitute prime agricultural soils and are characterized by paddy rice cultivation. Within the Alfisols order, Typic Tropaqualfs are the widespread subgroup. Aqualfs (suborder level) are the wet Alfisols.

Along the perimeter of the valley, Ultisols (Aquults) are most common. Like the Alfisols, these old alluvials are characterized by distinct clay accumulations in the subsoil. The translocation of clay particles into the argillic B horizon is greater in these soils than in any other group. Ultisols and Alfisols differ in that the latter are less strongly weathered.

Inceptisols (Aquepts), and a very few diverse Entisols (Aquents, Fluvents, Orthents), occupy large stretches of land in close proximity to the central water courses. It is these recent alluvial soils that are annually flooded and thus have fresh sediments added.

Finally, large areas were surveyed and mapped as alluvial complex. Areas mapped in this way are characterized by highly complex soil distribution patterns that were difficult to survey in detail. Hence, they were surveyed in broad geomorphological terms. This applied both to narrow bands of soils along the main watercourses and the steep slopes in the mountainous areas. In the case of the narrow bands of alluvial soils along the watercourses, only some dominant soils were sampled and constituted the database for the thematic soil maps produced.

The mountainous areas, defined as those areas with slopes steeper than 35%, were mapped as slope complex but were not surveyed.

Soil Texture Map: Soil texture is a fundamental physical property of soil that influences how the soil responds to different stresses, such as compactibility. Similarly, the measurements are also used in correlation studies, for example, to relate plant-available water capacity to texture. In practice, soil texture is often used as a basic indicator of soil chemical properties such as the soil's capacity to store and release plant nutrients. Since it is essentially a property of the colloidal fraction, derived mainly from the clay and the organic matter fraction, a soil's nutrient-retention capacity, expressed in the form of CEC, is related to soil texture.

Map of Potential Soil Fertility: The important relation between soil texture and CEC is clearly highlighted in the case of the project data when comparing the Soil Texture Map (Fig. 1) and the Map of Potential Soil Fertility (Fig. 2). The silty-clay to clayey Inceptisols are characterized by a medium (15-25 cmol kg^{-1}) to high (25-40 cmol kg^{-1}) CEC, while the loamy Alfisols feature a low (5-15 cmol kg^{-1}) CEC. At the bottom end of the scale are the strongly weathered Ultisols which feature sandy-loamy to loamy-sandy textures. As a result, they have a very low (<5 cmol kg^{-1}) CEC.

The obvious correlation between the two maps and indicators respectively corroborates the good quality of the soil physical and chemical data provided by the DLD. Also, bearing in mind that CEC values seem to be lower with NH_4 as compared to using Ba, Sr, Ca or Mg as index cations, the values used for this mapping exercise are underestimates rather than overestimates.

Map of Soil Fertility Status: The results from this mapping exercise clearly highlight that the soils in the project area, in particular the Alfisols and Inceptisols that dominate paddy rice fields, were managed well. Their base saturation is high (>60%) throughout, reflecting a good (and possibly balanced) nutrient (fertilizer) supply. Even the vast majority of Ultisols had a medium base saturation (20-60%), with only a very few, located right at the very edge of the valley, featuring a low base saturation (<20%).

It has often been assumed that for optimum agricultural crop production a neutral soil is required, with all the acidity neutralized by base saturation of the clay complex exchange sites. However, in acid soils in particular, the limiting factor is often the concentration of aluminum ions in the soil solution, which in turn depends on the concentration of the other ions involved in the exchange reaction. It has been shown that some soils are base saturated at pH 5, which may explain why acid-sensitive crops can be grown on some tropical soils with pH values about 5.5.

Map of the Degree of Soil Acidity: The available project data show that most topsoils fall within the favorable pH range of between 5.5 to 7.5, though at the bottom end of the scale or even slightly below. A small number of topsoils are strongly acid with pH values between 4.5 and 5.0. They cut across various soil orders so that no clear spatial pattern is discernible and may be the result of inappropriate fertilizer application.

In contrast, subsoil data do indicate a spatial pattern of soil acidity with only Ultisols featuring slightly (pH 5.6-6.0) to moderately (pH 5.1-5.5) acid subsoils. The bulk of the remaining subsoil data falls within the neutral range (pH 6.1-6.5) that is the preferred range for most crops.

Map of Soil Organic Matter: The data for the project area revealed that virtually all topsoils (0-250 mm depth) were depleted of organic carbon. Measured organic C levels were very (1-2%) to extremely (<1%) low, with only a few soils featuring somewhat higher, yet still low (2-3%) contents of organic carbon. Organic carbon levels of the aggregated subsoil data (250 mm to 1 m) are extremely low throughout.

The low levels of organic carbon content are likely to be due to the historical intensive use of the soils under irrigation. Since the 1970s, irrigation has been further intensified in the form of modern irrigation schemes that now also support crop production during the dry season (November-May); although only on a limited hectarage due to water shortage. In some places, underground water pumping for dry season cropping has become popular. The effects this cropping intensification (including agro-chemical) may have on soils (and water resources) need as yet to be established.

CONCLUSIONS

The indicator-based soil maps prepared were received well by regional planners in Chiang Mai. For the first time, they were given interpretations of their soil environment in an intuitively comprehensible form.

Realizing that specialist soil information is often failing to reach potential users, soil scientists should begin to appreciate the usefulness of indicator-based approaches. These allow assessment of soil resources in a fast, yet reliable way. If an approximate understanding of natural phenomena is acceptable, then, clearly, soil phenomena can be described in this way. By also resorting to parameter data that is readily available, burning issues can be addressed quickly in terms of a few relevant features without having to know all the variables at once. Because the vagaries involved in the indicators are small (provided data collection, computation and interpretation is done with expedience), indicator-based soil mapping approaches are meaningful.

It should be remembered, that even the most elaborate scientific concepts and theories including, for example, sophisticated pedo-transfer functions, are also only approximations to the true nature of natural phenomena. Furthermore, because all natural phenomena are ultimately interrelated, to fully and accurately understand any one of them, precise information would be needed for all of them, which is not possible at this time.

REFERENCES

Acton, D.F. and L.J. Gregorich (ed.) 1995. The Health of Our Soils. Toward sustainable agriculture in Canada. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Publication 1906/E. (Website: res.agr.ca/CANSIS/PUBLICATIONS/HEALTH/_overview.html)

Bastian, O. and K.-F. Schreiber (ed.) 1994. Analyse und ökologische Bewertung der Landschaft. Gustav Fischer Verlag, Jena/Stuttgart, Germany.

Becher, H.H. 1995. On the importance of soil homogeneity when evaluating field trials. Journal of Agronomy and Crop Science, 174: 33-40.

DLD. 1976. Detailed reconnaissance soil map of Chiang Mai province. Province Series No. 27, Scale 1:100,000, Department of Land Development (DLD), Soil Survey &

Classification Division, Bangkok.
DLD. 1981. Detailed reconnaissance soil map of Lamphun province. Province Series No. 317, Scale 1:100,000. Department of Land Development (DLD), Soil Survey & Classification Division, Bangkok (in Thai with English summary plus 3 soil map sheets).
FAO-Unesco. 1988. Soil map of the world. Revised legend. World Soil Resources Report 60, FAO, Rome, Italy.
Landon, J.R. (ed.) 1991. Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. 474 p., Longman Scientific & Technical, England.
USDA-NRCS, Soil Survey Division. 1993. Soil Survey Manual. United States Dept. of Agriculture, Handbook No. 18, U.S. Government Printing Office, Washington, D.C., 437 p.
USDA-NRCS. 1996. Keys to Soil Taxonomy. Seventh Edition, USDA Natural Resources Conservation Service, U.S. Government Printing Office, Washington, D.C., 644 p.
USDA-NRCS. 1996. Soil quality information sheet. Indicators for soil quality evaluation. Prepared by the USDA Natural Resources Conservation Service in cooperation with the USDA-NRCS Soil Quality Institute, and the USDA National Soil Tilth Laboratory, Agricultural Research Service, (http://www.nssc.nrcs.usda.gov/).