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Application of Electromagnetic Induction Terrain Conductivity Meter to salinity assessment in salt-affected soils

—Regional salt-affected soils map in northeastern Thailand—

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Abstract

The electromagnetic induction terrain conductivity meter, "EITCM", has been used for the salinity assessment in salt-affected soils in northeastern Thailand. This paper briefly discusses the applicability of the electromagnetic method for delineating the salt distribution within the landscape and determining the salt content in soil at the depth up to 30 m. This information together with hydrological data and present landuse is useful for the base of the salinity management in northeastern Thailand. A case study presented the results of the use of the electromagnetic terrain conductivity meter in some major salt-affected soils of Nakhonratchasima province. The results of the investigation revealed that the source of salt in the process of soil salinization underlies the salt-affected soils. High-elevated areas play an important role for the water supply in the process of soil salinization. Variations of the reading might be due to the salt content, moisture content and soil type. Accuracy of the reading must be carefully considered when the survey for soil profiles is carried out in the areas where high clay content and low moisture content.

Key words : Electromagnetic induction terrain conductivity meter, electrical conductivity, salt-affected soils map, northeastern Thailand

Introduction

Salt-affected soils in the northeastern Thailand spatially spread in low-lying paddy fields. The affected areas were estimated of seventeen percent of the region or 2.85 million ha (Department of Land Development, 1989). The major soluble salt is NaCl in the soil solution and in the groundwater resulting in the adverse effects to soils and plants as well as environments. The salt derives from rock salt of the Mahasarakram Formation underlying salt-affected lands and contaminates to shallow groundwater (Williamson, *et al.* 1988). The further extension of salt-affected soils is due to deforestation in recharge area, salt making, the construction of reservoirs and the mismanagement of irrigation (Arunin, 1984). Salt-affected soil map was developed through the interpretation of aerial photos, satellite imagery, hydrogeological maps and soil survey. Field checks were done by collected some soil samples for laboratory analysis. Mapping units were classified by degree of salinity into 5 classes as very strongly, strongly, moderately, slightly and non salt-affected areas and potential salt-source areas (Department of Land Development, 1991).

Counter measures for the salinity control in the northeastern Thailand are based on the mapping units of the salt-affected soil map. Agronomic practices and soil amendments including organic and inorganic substance as well as green manuring are recommended for increasing rice yields in slightly and moderately salt-affected soils, while salt tolerant trees and halophytic grasses are cultivated in very strongly and strongly salt-affected soils. Reforestation with trees of salt tolerance, fast-growing, and high water use is recommended for preventing the secondary salinization in potential salt-affected soils (Arunin, 1992).

The salinity assessment is essential to ensure that recommendations for the management of salt-affected soils is fruitful. Mismanagement may cause further expansion of salt-affected soils. Further more, it will be laborious to persuade farmers to acquire new technology (Abrol and Fireman, 1977).

Various methods or techniques can be used for assessing salt-affected soils. Extent of salt patches, native halophytes in landscapes and certain symptoms of crops as a result of stress impound by salt are simple characteristics of salt affected-soils (Arunin, 1984). But the degree of salinity can only be specified by analyzing soil samples for the concentration of soluble salts as electrical conductivity of the saturation paste extract ($Ec_e > 2$ dS/m) (Soil Science Society of America, 1979). Sources of salt underlie salt-affected soils. Subsurface conditions can be investigated at the shallow depth which a hand auger can be drilled. Power augurs or drilling equipment can not be employed. Subsurface conditions can be partly obtained from one hydrogeological map at 1 : 500,000 scale which is only suitable for broad scale purposes (Piancharaen, 1973). Cores drilling for salt, petroleum and groundwater exploitations are available in many places (Krairapanond, *et al.*, 1992 ; Japakasetr and Suwanich, 1984). Groundwater hydrology is investigated with the installation of piezometers in many major salt-affected soils in the northeastern Thailand in order to investigating the relationship between groundwater and salinity hazards in the region (Dissataporn *et al.*, 1993).

As salt-affected soils are dynamic, more replication of sampling are required especially in large-scale mapping. Rapid, portable, non-destructive and surface applied method for assessing the soil electrical conductivity and locating the spatial distribution of salt within soil profiles as well as within a landscape are recommended. The recent commercial four-electrode and electromagnetic technique are accepted as the practical procedure for immediate assessing salt-affected soils (Rhoades, 1992).

The four-electrode resistivity technique measures the average soil electrical conductivity by sending the electrical current into a soil profile through current electrodes while potential electrodes read the voltage differences. The depth of reading depends on the spacing between current and potential electrodes. A regression model for converting the bulk soil electrical conductivity to the laboratory value was developed (Department of Land Development, 1989)

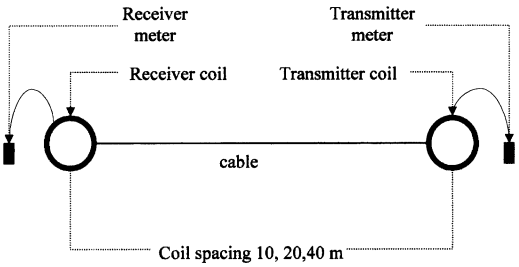
The electromagnetic terrain conductivity technique is a simple and rapid method for delineating the distribution of average soluble salt in a soil profile from the soil surface to the depth of 7.5, 15 and 30 m when the coil spacing of 10, 20 and 40 meters, respectively (McNeil, 1980). The technique is widely used for quantify the soil salinity (Cameron *et al.*, 1981 ; McFarlane, *et al.*, 1987 ; Williams and Hoey, 1987 ; Dixon, 1989 ; Cannon, *et al.*, 1994). The advantage of this instrument is rapidness but there are various factors which affect the terrain conductivity (McNeill *et al.*, 1992) Linear regressions between the soil electrical conductivity and the terrain conductivity at each depth of sounding were developed (Cook and Walk, 1992). The low conductivity on the upland corresponds to the recharge area while the high conductivity indicates discharge area (Bullock and Williams, 1987). Williams and Arunin (1990) identified the recharge and discharge area from the average ratio of the electromagnetic terrain conductivity of 30 m depth to 20 m depth, 30 m depth to 7.5 m depth and 15 m depth to 7.5 m depth of sounding at Nakorn Ratchasima in northeastern Thailand. The ratio greater or less than unity indicates recharge and discharge area, respectively.

The objective of this paper is to describe the use of the electromagnetic technique for salinity assessment and to determine the accuracy of this technique in identify the soil and water salinity of the salt-affected soils in northeastern Thailand.

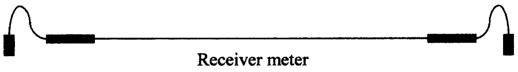
Principle of operation and instrumentation

The EITCM measures the average apparent electromagnetic terrain conductivity (Ec_a) of the soluble salt concentration in a soil profile in mS/m. The terrain conductivity of 1.0 mS/m is equal to 25 ppm of NaCl concentration. The instrument consists of the transmitter and receiver meters connected with the magnetic transmitter and receiver coils, respectively. The configurations of coils can be applied in horizontal and vertical dipole mode which provide the depth of sounding of 0.75 and 1.5 times of the distance between two magnetic coils, respectively. Surveying the soil conductivity can be done at the coil spacing of 10, 20 and 40 m (Fig. 1).

The transmitter coil with an alternating current generates time-varying magnetic fields at frequency of 6,400, 1,600 and 400 Hz to the soil profile, respectively. They induce small currents in the soil profile, and they produce secondary magnetic fields. The magnitude of the secondary magnetic field depends on the concentration of soluble salt, moisture content and clay content. The receiver coil determines the primary and secondary magnetic field, and calculates the ratio between primary and secondary magnetic fields, which yield the bulk apparent electrical conductivity of the soil profile. The depth of reading depends on the primary electromagnetic current frequency, on the distance between the transmitter and receiver coil and on the coil configuration. The coils in horizontal dipole mode with the coil separation of 10, 20 and 40 m and primary electromagnetic currents at frequency of 6,400, 1,600 and 400 Hz provide the depth of sounding of 7.5, 15 and 30 m from the soil surface, while that in vertical dipole mode configuration provides depth of sounding of 15, 30 and 60 m from the soil surface, respectively. Survey of terrain conductivity by the EITCM is commonly used in horizontal dipole mode as the reading in vertical dipole mode is sensitive to low conductivity materials and geologic structure, fractures while the reading in horizontal dipole mode is insensitive to those of materials. From this reason, the accurate conductivity can be obtained from the horizontal dipole mode. Further more, alignment of coils in vertical dipole mode is very difficult to adjust (McNeil, 1983).



EITCM in horizontal dipole mode



EITCM in vertical dipole mode

Fig. 1 Electromagnetic induction terrain conductivity meter, EITCM, in horizontal dipole mode and vertical dipole mode.

Operating procedure

Two persons are needed for operating the EITCM. The instrument needs to set up in order to cut down the magnetic field of earth and air before starting survey. This set up procedure is repeated during the survey wherever encounter low terrain conductivity area. The transmitter coil in horizontal dipole mode is placed vertically to the soil surface where subsurface features are interested. Electromagnetic currents are sent from the transmitter coil in the horizontal direction. The cable, 40 m long, is connected between the transmitter and receiver coil. The coil and frequency current switch are firstly set at 40 m distance. Receiver coil is moved forward and backward upon the coil separation meter in order to fix the coil separation at 40 m apart. Digital bulk apparent electromagnetic conductivity in ms/m from the soil surface to the depth of 30 m is recorded as well as landuse, landform and salt patches. The coil separation and frequency current are set to 20 and 10 m, respectively. The receiver coil is moved forward to transmitter coil to 20 and 10 m spacing, respectively. Repeatedly procedure is done in order to measure bulk salt concentration at the depth of 15 and 7.5 m. Vertical dipole mode can be done as horizontal dipole mode by laying down both coils on the soil surface. Electromagnetic currents are sent from the transmitter coil in vertical direction. As the EITCM is sensitive to any metallic material, the measurement should escape from fences and electricity cables.

Survey technique

The electromagnetic induction survey using the EITCM have been carried out investigated in salt-affected areas of northeastern Thailand since 1992. The horizontal dipole mode with the coil separation of 10, 20 and 40 m was used at the spacing of one-kilometer grid basis. Topographic maps at scale of 1 : 50,000 and aerial photos were used for locating the geographic position. Later on, Global Positioning System (GPS) was employed for rapid locating. Bulk apparent electromagnetic terrain conductivity, 48,683 records, at depths of 7.5, 15 and 30 m from soil surface with global coordinates were obtained and recorded in database. Further more, when close spacing need to be surveyed and the geographic position can not be accurately located by GPS. Sites are marked on aerial photos and later geographic positions are read by computer program (Fig. 2).

Fig. 2 Salinity assessment in northeastern Thailand.

Interpretation

The salinity data have not yet been converted into standard soil salinity because of unavailable instruments for collecting soil samples. The computer software Surfer for Windows was used for contouring the apparent electromagnetic conductivity of the soil profile at depths of 7.5, 15 and 30 m from the soil surface, respectively. Contours are produced by kriging method which is a useful geostatistical gridding method (Surfer for Windows, 1996). Salinity is classed by adverse symptoms of plant and soil due to salinity into 5 classes as non-salt-affected soils (0–80 mS/m), slightly salt-affected soils (80–120 mS/m), moderately salt-affected soils (120–160 mS/m), severely salt-affected soils (160–200 mS/m) and very severely salt-affected soil (＞200 mS/m). Isoconductivity in Surfer format was exported in to DXF interchange files. They were read into digital format of Arc info. Digital map of salt-affected soils covering the whole salt-affected soils of northeast Thailand is being developed.

Case study

Site characterization

The study area is in Nakhonratchasima province where salinity is major problem of the Korat basin. Soils are spread on the geologic Mahasarakram formation that is believed to the source of salt for the process of salinization (Phiancharoen, 1973). A topographic map is presented in Fig. 3 a with the 10 m contour and main drainage. A height above mean sea level of the area ranges from 180 to 240 meter. Most of the area is in low terrace and slightly undulating. Lam Chiang Krai and Lam Khang Phlu, which is tributary of Chi River, are the main drain of the area. The average rainfall and evapotranspiration is 1,108 and 1,873 mm per year, respectively. According to the soil salinity map of the northeastern Thailand at the scale of 1 : 100,000, salt-affected soil spreads in the lowest elevation and along the river. The degree of salinization is in scale of very severely, severely and moderately salt affected soil (Department of Land Development, 1991).

Methodology

Salt-affected soils of Nakhonratchasima province were surveyed by the EITCM in horizontal dipole mode with the coil spacing of 10, 20 and 40 meters. The average apparent terrain conductivity, 293 records, at the depth of 7.5, 15 and 30 m from soil surface were recorded including present landuse, landform and salt patches. Groundwater salinity from nested piezometers at the depth 15 m from the soil surface were collected. The statistic package, SPSS for Windows, was used for analyzing the characteristic of the terrain conductivity and the linear relationship between the terrain conductivity and the depth of reading. The salinity distribution at each depth of reading and groundwater salinity was contoured by computer program, Surfer for Windows. EXCEL drew the salinity distribution by depth and position of site of reading from mean sea level along cross section A-B.

Result of measurement

The terrain conductivity from the soil surface to the depth of 7.5, 15 and 30 m from the soil surface ranged from 19–300, 31–300 and 42–300 mS/m, respectively. The means values of terrain conductivity at the three depths of reading were 138, 152 and 172 mS/m, respectively. The standard deviation of the terrain conductivity at the depth of 7.5, 15 and 30 m varied from 65, 62 and 60 mS/m, respectively. The high correlations were found among the three depths of reading of 7.5–15, 7.5–30 and 15–30 with the correlation coefficient of 0.954, 0.811 and 0.880, respectively. It was observed from the frequency distribution of the terrain conductivity that there were 16 stations where the terrain conductivity at the three depth of reading were 300 mS/m, which is the maximum reading of this instrument. The regression analysis between the terrain conductivity of the three depths was developed in order to clarify the salt distribution within the soil profile. Linear regression equations between the terrain conductivity at the depth of 7.5, 15 and 30 m are as follow :

$$V(7.5\,\mathrm{m}) = -16.277 + 1.008\,V(15\,\mathrm{m}),\quad R^2 = 0.910$$

$$V(7.5\,\mathrm{m}) = -13.276 + 0.877\,V(30\,\mathrm{m}),\quad R^2 = 0.657$$

$$V(15\,\mathrm{m}) = -2.300 + 0.901\,V(30\,\mathrm{m}),\quad R^2 = 0.744$$

where $V(7.5\,\mathrm{m})$: Average conductivity of soil profile to 7.5 m depth
$V(15\,\mathrm{m})$: Average conductivity of soil profile to 15 m depth
$V(30\,\mathrm{m})$: Average conductivity of soil profile to 30 m depth

The coefficient of determination (R^2) of the three regression equations were 91, 65.7 and 74.4%, respectively. The linear regression models can be explained 91, 66 and 74% of the variation of the dependent terrain conductivity, respectively. From the three regression equations, it can be explained that when V (7.5 m) and V (15 m) is equal to 1, V (30 m) is greater than V(15 m) and V(7.5 m), while V(15 m) is as well greater than V(7.5 m). Thus, the average terrain conductivity of soil profile increases from soil surface to the maximum depth of reading. Further more, the terrain conductivity at the depth of 15 and 30 m from the soil surface can be estimated from the terrain conductivity at 7.5 m with these regression equations.

Salt distribution maps at the depth of 7.5, 15 and 30 m from the soil surface with map units and the topographic map of the study area were shown in Fig. 3. The magnitude of apparent terrain conductivities were classed into non, slightly, moderately, severely and very severely salt-affected soils in order to characterize the distribution of the salt concentration within a soil profile and within a landscape. Fig. 3 a and 3b indicated that there was an accumulation of salt in soil profile from the soil surface to the depth of 7.5 m. Very severely salt-affected soils spatially spread in the alluvium plain of the main drainage of the study area. It occurred mostly in the areas where the elevation is less than 200 m. Non salt-affected soils where the terrain conductivity is less than 80 mS/m were situated at the elevation greater than 210 m. Isoconductivity maps of the soil profiles at the depth of 15 and 30 m from soil surface showed that the areas of very severely salt-affected soils increased with the depth of sounding. Further more, the area of non salt-affected soils decreased with the depths of sounding, indicating the increase of the soluble salt content with the depth under non-salt affected soils at the depth more than 7.5 m from the soil surface (Fig. 3 c and 3 d). The result of cross-section AB showed that the degree of salinity in the high elevation areas was low and gradually increases further down slope. Low salinity could be detected in the undulating area. Salinity sharply increased with depth in alluvium plain while in the high elevation area there were little change in the terrain conductivity with depth (Fig. 3 f).

Groundwater salinity from the nested piezometer at the depth of 15 m from the soil surface was shown in Fig. 3 e. Groundwater salinity ranges from less than 1 to 45 dS/m. It was found that low salinity groundwater is located in the high elevation area while very high salinity is located in the flood plain.

Discussion

The EITCM was employed for the salinity assessment in northeastern Thailand. It has been proved that this technique can provide reliable data on the salinity distribution within a landscape and within a soil profile. The technique is easy for application, as no soil samples are taken. Further more, it is the surface treatment without inserting electrodes as Four-probe resistivity. The receiver coils can be adjusted from the coil separation meter comparing to four-probes resistivity meter, which need to adjust electrode spacing by tape measuring. Two persons are minimum requirement for operating electromagnetic terrain conductivity.

As the instrument can detect an average terrain conductivity of a soil profile from the soil surface to the depth of 7.5, 15 and 30 m, it not only enables to locate the salt concentration within the landscape but also within the soil profile which can not be observed by aerial photos or satellite imagery. Data collected from the study area can indicate that salt-affected soils occur in the flood plain of the three main drain of the study area. The source of salt can be situated at the depth of 15 and 30 m from the soil surface in the salt-affected soils.

Further more, the terrain conductivity of a soil profile, greater than 120 mS/m, can be found at the depth of 30 m from the soil surface in the high-elevated areas. The salt content situated at the depth more than 30 m from the soil surface may be higher than 120 mS/m if the instrument can operate at depth more than that of from soil surface. From this reason it can be shown that salt underlies Korat Basin even in the high-elevated area that were classified as non salt-affected soils (Piancharoen,

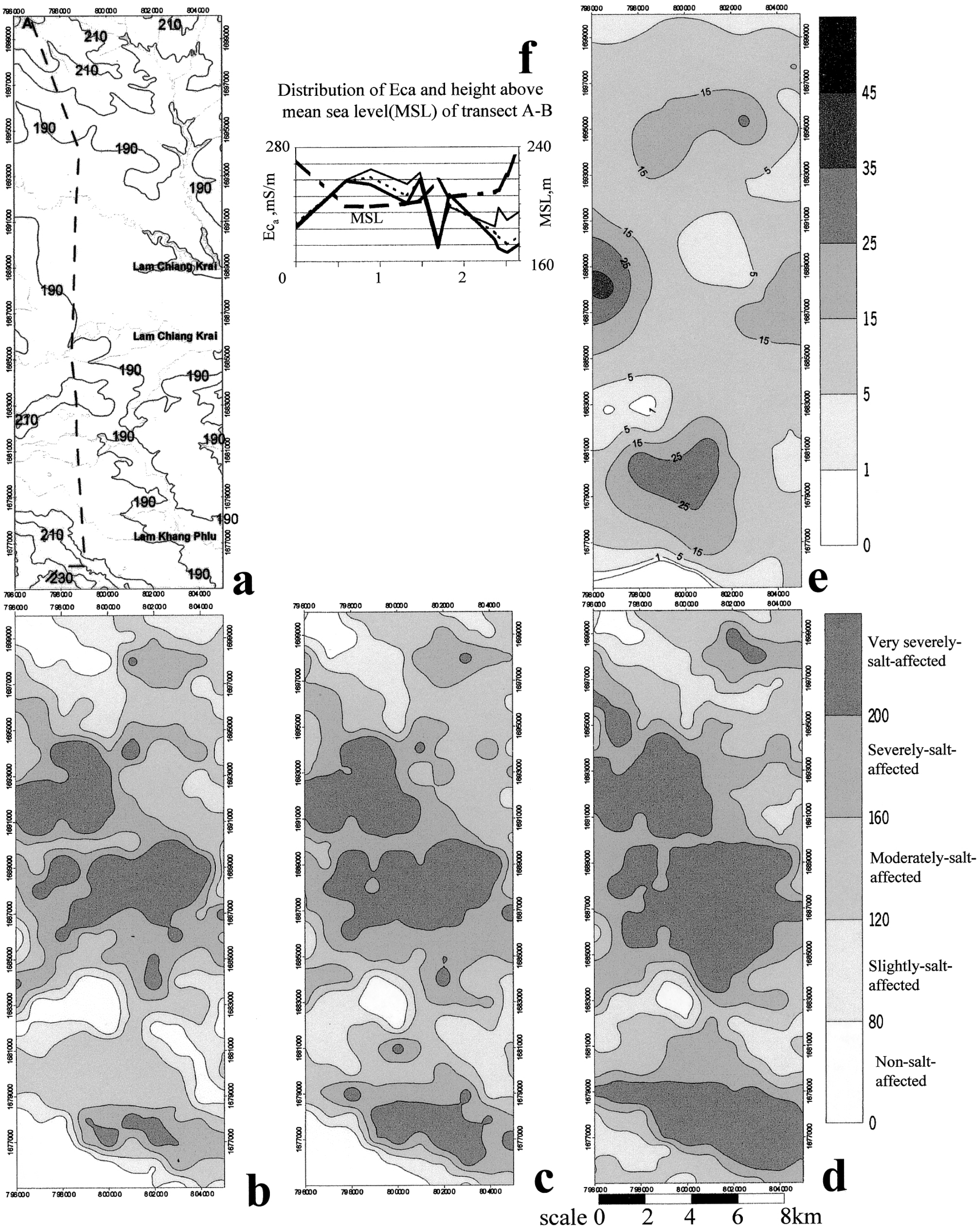


Fig. 3 Topographic map (**a**), isoconductivity maps (mS/m) at depth 7.5, 15 and 30 m (**b, c, d**) groundwater salinity (dS/m) at depth 15 m (**e**) and cross section of terrain conductivity and height from mean sea level (MSL) (**f**).

1973). Salt in the deeper profiles can not be observed because of the limitation of the instrument. In addition, salinization in this area can not occur because these areas are in the high elevation, and salt at the depth more than 30 m can not move up to the soil surface and leaching by rainfall is normally dominant in these areas. On the other hand, the result of the electromagnetic survey indicates that salt in the high-elevated areas is not situated at the depth where it can be a source of salt in the process of soil salinization, ie, saline seep (Sinanuwong and Takaya, 1974). Further more, the high-elevated areas in the salt-affected soils are the areas where they might supply water from the rainfall for the process of salinization. This local recharge should be aware of water management for salinity control (Dissataporn *et al.*, 1993).

The distribution of the terrain conductivity in the soil profile at each depth can be used for identifying the recharge and discharge area. As in the recharge area salt is leached down the soil profile by water and accumulated in the deeper profile. While in the discharge area salt moves up to soil the surface by the capillary rise from the shallow saline groundwater and accumulated in the upper soil profile (Williams and Arunin, 1996). But the terrain conductivity in the discharge areas increases with the depth of reading. This can clarify that the source of salt situates in the salt-affected soils and the magnitude of the accumulation of salt is much more than the accumulation of salt in the upper surface by the process of the capillary rise and the evaporation soil surface.

It is observed that sixteen sites in the very severely salt-affected soils class comprised of 300 mS/m for the whole depth of reading, which is the maximum reading of the instrument. Salinity in these sites may be greater than 300 mS/m if the digital model, which can measures more than 300 mS/m, is used (McNeil, 1980).

The distribution of the terrain conductivity at the depth of 15 m from the soil surface partly coincided with the groundwater salinity at the same depth (Fig. 3c and 3e). It can be seen from this comparison that the terrain conductivity might be used for identifying soluble salt in soil profiles. The variation of these two data may be due to the difference in the sample densities. Simple nonlinear regression equations of the terrain conductivity at the depth of 7.5, 15 and 30 m from the soil surface and the electrical conductivity of the groundwater at the same depth were developed (Yamclee *et al.*, 1996). It was found that the regression equation of the terrain conductivity could explain about 88, 77 and 81% of the variation of the groundwater salinity at the depth of 7.5, 15 and 30 m from the soil surface, respectively. From this study it can be seen that variations of the terrain conductivity may be caused by other factors about 12, 23 and 19%, respectively.

The low terrain conductivity in the high-elevated areas may be due to the low salt concentration and moisture content. As the groundwater level in these areas is always situated at the depth more than 5 m from the soil surface. Thus, the terrain conductivity of the soil profile measured in such places may be confounded by moisture content especially reading at the depth of 7.5 m from the soil surface. While in the salt-affected soils, the groundwater table is always at the depth of 2–3 m from soil surface. The difference in moisture contents can be ignored in the salt-affected soils. On the other hand, as salt-affected soils in northeast occur mostly in sandy soils which clay contents are not the major constitutes of these soil types. Thus, the variations of the terrain conductivity in the sandy soils are not due to clay content. The high terrain conductivity found in the flooded plain areas of the main drain may be interfered by the clay content in the soil profile (Williams and Hoey, 1987 ; McNill *et al.*, 1992).

These variations could be accepted for the salinity assessment in the regional scale. Anyhow, the anomaly of the terrain conductivity and electrical conductivity of soils should be further investigated, as the terrain conductivity is relying on not only soluble salt but also clay and moisture. It is necessary to develop the regression equation for converting the terrain conductivity to the electrical conductivity of the saturation paste especially in the clayey soil profile and in the high elevation areas where clay content and moisture content could interfere the terrain conductivity ; respectively. The calibration can be done for the 7.5 m reading as a hand auger can be drilled. Soil samples from the soil surface to the depth of 7.5 m must be collected and mixed together. Saturation extract of soil paste is used for measurement of the soil electrical conductivity. Regression of the average terrain conductivity and soil electrical conductivity can be developed. This finding will be useful for assessing the soil salinity in standard unit. As the salinity at the shallow soil profile is the main purpose for salinity assessment in agriculture production.

Since the terrain conductivity is used directly for classifying salt-affected soils and the responses of the terrain conductivity for each soil types and landscape are not the same. The terrain conductivity for each map unit should be classed for each catchment area. Surveyors can class the terrain conductivity for each map units from salt patches and native halophytes as well as symptom of plants.

In addition, the electromagnetic terrain conductivity meter measuring in the vertical dipole mode is sensitive to geologic structure, faults. Salinity survey should not only measure in horizontal dipole mode for the terrain conductivity but also in vertical dipole mode. As faults were claimed to be a channel of the deep saline groundwater which contacts with the Mahasarakram Formation. This saline groundwater leak through these channels and contaminate to the shallow groundwater aquifer (Imaizumi *et al.*, 1996). This information is useful for considering the salinity control.

Electromagnetic terrain conductivity with the short intercoil spacing and the single current frequency has been useful for the salinity assessment in the agricultural production area as it is portable, one man operate, rapid, root zone reading and can be related to laboratory analysis (Dissataporn *et al.*, 1993).

The information from the electromagnetic technique can be considered in planning the land-use strategy for the salinity control. It can be a basis data for reducing the cost of hydrological study which need to install expensive piezometers. Further more, Salt-affected soils map in GIS format can be used with other map layers, land use, elevation, hydrology, for predicting areas risk for salt-affected soils.

Conclusion

The EITCM was used for salinity assessing in northeastern Thailand. This technique is surface application, non-destructive, rapid and easy to operate. It immediately locates the salt concentration with in a landscape and within a soil profile. The results of mapping indicated that sources of salt in the process of the soil salinization is underlie the salt-affected soil. The deviation of the bulk conductivity within a landscape and within a soil profile may come from the difference in moisture content and clay content. Subsurface conditions can be investigated in more details by this technique. Anomaly of the terrain conductivity from the electrical conductivity of soil paste must be found out even for the shallow depth of reading.

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地盤電磁誘導法の塩性土壌への応用
—東北タイにおける地域的塩性土壌図の作製—

チャイヤナム　ディサタポーン*・成岡　市**・
プラモート　ヤムクリー*・ソムスリ　アルニン*
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** 岡山大学環境理工学部

要　　旨

地盤電磁誘導計（EITCM）の原理を概説するとともに，東北タイ塩性土壌地域において塩分査定に応用された実例を述べた。

本論では，地形および土壌内塩分濃度分布の概要を把握する目的で，最深30 m に対するEITCMの適応性について検討した。水文データおよび現在の土地利用形態に合わせて，EITCMにより得られた情報は，東北タイにおける塩性土壌管理の基礎資料として有益であることを論議した。

事例研究では，Nakhonratchasima州におけるいくつかの主要な塩性土壌地域でEITCMによる測定を行い，種々検討した。その結果，塩類土壌生成過程にある塩分の源泉を見いだすことができた。

本手法の応用により，標高の高い地域では，塩類土壌生成過程に対して水分供給あるいは地下水動態が重要な役割を果たしていることが明らかとなった。これについて，塩分含有量，土壌水分含有量および土壌型が基礎情報として加えられた。

測定精度については，今後さらに詳細な検討が行われなければならず，とくに土壌断面における高い粘土含有量および低い水分含有量を有する地域では，慎重な考慮を要することを述べた。

キーワード：地盤電磁誘導計，電導度，塩性土壌図，東北タイ

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