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Effect of Groundwater Level on Salinity Content and Environmental Land Classification

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Abstract

Saline affected soil is in the northeast of Thailand, especially in the Khon Kaen Province. The relation between the salinity accumulation in brackish groundwater and the groundwater level from ground surface represents the progress state of soil salinization.

The practice for suitable land use against the salinization can be established when the main conditions of salinization hazards are known. Based on this concept, the electric conductivity (EC) of groundwater and its level were measured with piezometers for three years in an experimental field at Khon Kaen Province. The field data showed that the groundwater level much affected by salinity was less than one and half meters from ground surface in the investigated area, and it was confirmed that the saline soil was mainly caused by the capillary rise of brackish water and by the accumulation of salt occurred at the soil surface.

Salt accumulation process was investigated by the change in groundwater level. The reducing effect of salinization caused by capillary water rise became remarkable when the groundwater level was lowered until ground surface soil was out of the dominant capillary water zone.

This indicates the reduction of groundwater level was very effective in reducing salinization. Allowing for field experimental results, a classification map for environmental land use in saline affected area was proposed.

Key words : salinization, capillary water, salt movement, land reclamation, land classification

1. Introduction

The prevention of soil salinization is one of the methods for environmental protection against deterioration of water and land resources. Many of the agricultural lands in the Khon Kaen Province, northeastern Thailand, were cultivated from woodland and forest. Some low-lying land gave rise to saline soils, which occurred after the clearing of forest. Sodic soils were also produced through capillary water rise induced by the high rate of evapotranspiration, sometimes through floods. A number of regions, arid and semi-arid, such as the northeast of Thailand as well as Mauritania in West Africa and others are still being afflicted with salinization problems and the deterioration of land productivity.

To decrease the rate of salinization, leaching of the accumulated salts by flooding or drip irrigation have been found to be effective (Goldberg and Uzrad, 1976). Farming systems such as multi cropping or agroforestry are also said to be effective. This idea is based on the fact that mixing fruit plants with cover crops take up soil moisture efficiently. The surface soil moisture content is taken up by shallow rooted plant such as grass, while the deeper subsoil moisture is tapped by deep roots, guaranteeing an effective moisture up-take.

Thus, a reduction in salt accumulation will be possible (Lovenstein *et al.*, 1989). This plant cultivation technique for soil salinity prevention is still empirical. Interruptions of rainfall and the capillary water rise to the soil surface using trees are one of the measures for preventing salinization hazards (Dissataporn *et al.*, 2001 a).

The fluctuation of groundwater level varied from season to season, and the annual change in the level was large in the area. Accordingly, it is not practical to set up a large scale (more than 100 ha for an example) land development project in the saline area. A small scale project (several ha) is rather suitable for each farmer because the degree of salinization changes by places so that multi cropping land use, and private land improvement will be beneficial. The hillside is usually used for orchard, eucalyptus and cassava cultivation, and the low land for paddy fields. For making an environmental land classification map for rehabilitation, field observations of the fluctuation of groundwater level and its salinity were conducted in this study.

2. Materials and Methods

The field experimental site, located 25 km southwest of Khon Kaen in the northeast of Thailand, has an altitude ranging from 177 to 184 m above mean sea level. An annual rainfall of 935 mm and soil salinization are strikingly damaging the area, especially in low land which gets water logged during the rainy season. However, the dry season brings about high evaporation rates amounting to 2,020 mm in a year. The surface soil texture in the area is classified as sandy loam (SL) to loamy sand (LS) which belongs to a kind of the lateritic soils (Wada, 1998).

The low land area was much affected by salinization, and ECe (electrical conductivity of saturate soil extract) of surface soil was generally over 20 dS/m. Values of more than 30 dS/m appeared during the dry season in low land where salt accumulation had badly damaged

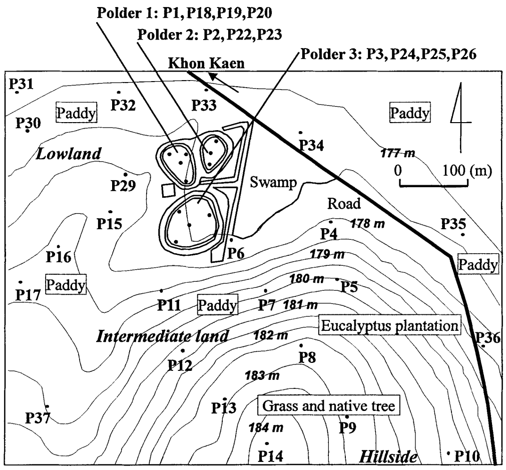


Fig. 1 Topography of investigated field with contour lines above mean sea level and location of piezometers (P).

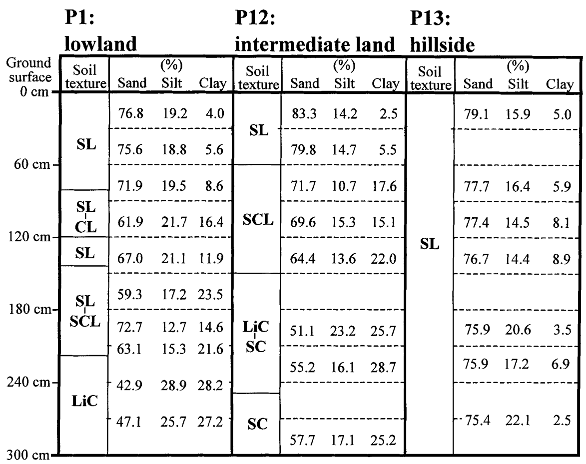


Fig. 2 Soil profiles in piezometer P1, P12 and P13.

the soil. In the hillside area, the ECe of the surface soil on average was generally less than 10 dS/m through the year.

The items of field experiment consisted of monitoring of groundwater level fluctuation in all seasons and of estimating the relationship between groundwater level and salinization. The groundwater level was defined here as the distance from ground surface to groundwater level. Thirty seven spots were selected in this study area included an area of 0.7 km×0.7 km in view of the topography (Fig. 1). Piezometers

Table 1　Annual standard deviation of groundwater level and electric conductivity of groundwater

Year	1996	1997	1998
Standard deviation of groundwater level from ground surface (m)	0.713	0.461	0.271
Standard deviation of electric conductivity of groundwater (dS/m)	4.940	3.605	2.842

Table 2　Changes in groundwater level between rainy and dry season (Khon Kaen 1996)

	Low land	Intermediate land	Hillside
Maximum difference (m)	2.60	2.25	2.46
Average difference (m)	0.46	0.87	3.17

(P1 to P37) were set up at each spot to monitor the groundwater level and its salinity (EC). Several piezometers did not work properly after setting owing to breaking down or floods so that actual measuring points were 25 to 27 in number, depending on the year. All the depth of piezometers installed was 7 m.

The area investigated was practically divided into three areas based on the contour lines. These are hillside (>180 m high from mean sea level), low land (<178 m) and intermediate land between 178 m and 180 m. The data from each piezometer were collected monthly for three years from 1996 to 1998. The salinity of the surface soil (ECe) was measured at several points. The typical soil profile P1 for the lowland, P12 for the intermediate land and P13 for the hillside were shown in Fig. 2. The profile of the hillside (P13) is stratified by SL, while that of the low land (P1) has finer particles layers like clay loam (CL) at the depth of 0.8 m which is rather impervious than LS. From these textures, the soil types of the area were classified as SL in the surface soil.

3. Results and Discussion

3.1 EC change of groundwater on annual basis

The groundwater level during 1997 and 1998 was lower compared with that in 1996, which increased the intensive evapotranspiration rate during the dry seasons. Standard deviations of the level showed that 1996 was the year of flood and high level of groundwater (Table 1). From the data, it can be seen that most fluctuations in groundwater level and EC values occurred in 1996.

During 1996, the differences between the maximum and minimum groundwater level of piezometers indicated less than 2.60 m in low land and 2.46 m in the hillside (Table 2). The average groundwater level changes of the piezometers between the rainy and dry seasons were 0.46 m in the low land and 3.17 m in the hillside.

The EC values of groundwater were taken as mean values of the fluctuating groundwater level for each three consecutive years (Fig. 3). The remarkable differences in the average groundwater level between the rainy and dry seasons were observed at the hillside. The low land and even hillside were often in flood after a heavy rainfall. The EC values of groundwater doubled from 1996 to 1997, especially in the area where the groundwater level was less than 2 m (Fig. 4). The increase in salinity of groundwater was more conspicuous in the low land, while the groundwater deeper than 2 m had no remarkable increase in salinity. There was almost no general change in 1998 compared to the previous year.

It was supposed that the soil surface was enough covered in the reach of capillary rise when the groundwater level was shallower than 1 m from ground surface. In this case, the soil surface was heavily damaged by the salt

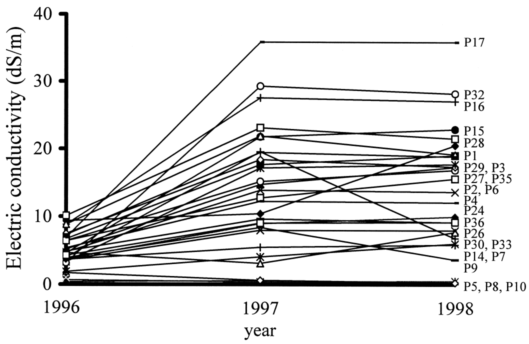


Fig. 3 Electric conductivity of groundwater taken from piezometers for three years observation (1996–1998).

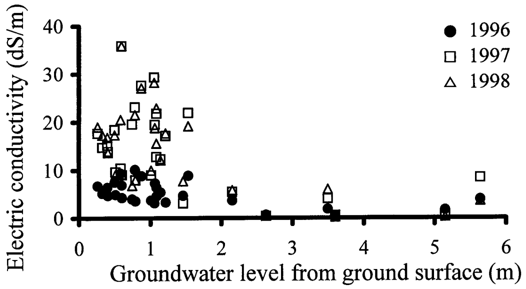


Fig. 4 Electric conductivity of groundwater against groundwater level from ground surface.

accumulation. In these circumstances, if the capillary rise was controlled or reduced, the salinization hazards could be minimized using plants, and a new soil improvement practice will be established (Dissataporn *et al.*, 2001 b).

3.2 Measurement of soil salinity and groundwater level

It is assumed that the soil salinization process is a function of groundwater level, water salinity of groundwater and evapotranspiration. The data of site P1 is shown as an example in Fig. 5 and Fig. 6. The salinity of surface soil was remarkably affected by going up of groundwater level. In Figs. 5, 6 for an example of P1, when floods covered the surface, EC values of surface soil increased sharply. There were many floods in the low land, a discharge area of groundwater where the salinity was easily condensed, while the hillside is a re-

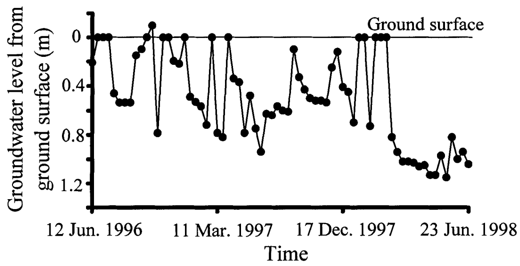


Fig. 5 Example of fluctuation of groundwater level from ground surface in period during 1996 to 1998 in P1 piezometer.

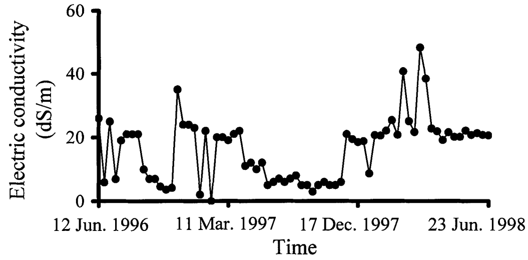


Fig. 6 Example of fluctuation of electric conductivity of groundwater in period during 1996 to 1998 in P1 piezometer.

charge area of groundwater by percolation through the soil.

The salinity of surface soil was increasing when the groundwater was shallow. As an example shown in Fig. 7, the ECe values of surface soil (0–20 cm in soil depth) were between 20 dS/m and 28 dS/m. When the groundwater level was lower than 1 m from the surface during the dry season in 1997, ECe of soil in P1 was lower than 20 dS/m. The soil, during the rainy season in 1996 and dry season in 1996, had higher salinization than that during the dry season in 1997, because groundwater levels during the rainy season in 1996 and dry season in 1996 were 0.06 m deep and 0.63 m deep from the surface, respectively. This indicates that the groundwater deeper than 1 m did not give much impact on salinization of the surface (Fig. 8).

Using the estimate equation of capillary rise $H=75/d$, where capillary height H mm and average particle diameter d mm, and another

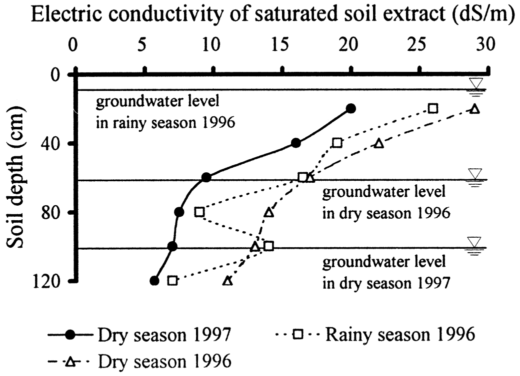


Fig. 7 Changes in electric conductivity of saturated soil extract with soil depth in P1 piezomter.

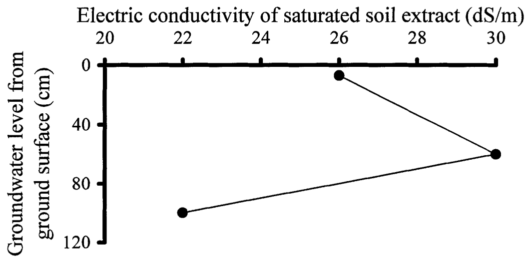


Fig. 8 Relation between groundwater level and electric conductivity of soil in P1 piezometer.

experimental equations (Scott, 1963, Tabuchi, 1971), the capillary rise was calculated in between 90 cm and 110 cm for the soil profiles given in Fig. 2. As the capillary height calculated for P1 fell within 98 cm to 100 cm, a critical value for capillary rise may be at about 1 m deep from ground surface (Yacouba, 2001).

Groundwater makes it possible that capillary water from shallow groundwater level is easily connected to the surface soil. When the severe evaporation of the water at soil surface urges the movement of capillary water, the salt accumulation of water soluble salt contained in capillary water occurs in the low land.

Based on the data obtained in Iran (Matsumoto, 1995), the concentration of salinized soil was extremely high at a groundwater level of about 70 cm from ground surface, but if the groundwater level was as deep as 2 m, the salinization was outstandingly restricted in the case of salt affected area.

According to the report by Watanabe *et al.* (1998), the upward movement of water consists of two types, one is liquid water movement by capillary, the other is by vapor which did not convey the salinity. From these experimental investigations, it could be guessed that the less saline affected soil depends mainly on the type of vapor movement, and much saline affected soil on that of the liquid water movement.

Therefore the reducing effect of salinization by capillary water will be remarkable when the groundwater level is lowered until the surface soil is out of the dominant capillary water zone.

From above discussion, it can be proposed that much affected area of salt is classified as vulnerable area A where the top capillary rise (H) situates above ground surface, and less affected area as safer area B where the top of capillary rise situates below ground surface, respectively.

3.3 Salinity based soil classification for land use

It can be possibly taken for granted that salinization proceeds in the case of the experimental field when the capillary water range is situated between 0 and 1.5 m, rain water can easily leaches down the accumulated salts to condense the groundwater salinity. The percolating front of rainwater will induce the capillary front to go up when they are connected. Then groundwater comes up again to the surface during the seasons. On the other hand there is no rapid increase in the soil salinity in the range deeper than 2 m where capillary water rise does not arrive quickly at the ground surface, though the salinization may proceed gradually for a long time if no rain.

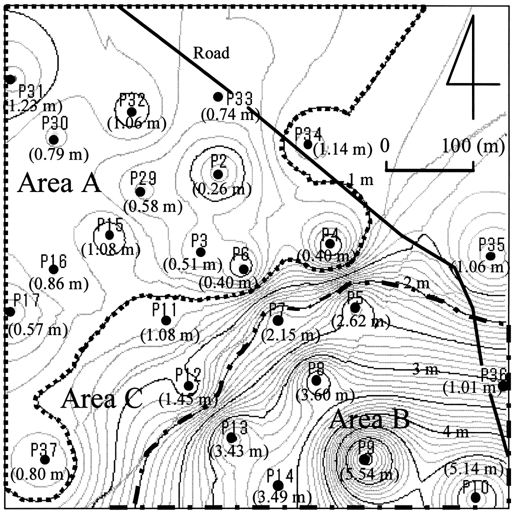
Reducing the capillary water movement is decisively important for the prevention of soil salinization. The up and down movement in all seasons will condense the groundwater salinity in the field. This type of flow will also get the surface salinization to increase.

On the basis of Fig. 4, it became clear that the critical level between the area A (much affected capillary zone) and the area B (less affected capillary zone) in the field site may be situated between 1.5 m and 2 m. The level more than 2 m shows that the water quality of groundwater will be useful, if the quality limit of EC for irrigation is 3 dS/m (Ayer and Westcot, 1976) because over which the relative land productivity decreases remarkably though it depends on a variety of crops. When the soil salinization increases up to 10 dS/m in ECe, the yield may be drastically damaged (Carter, 1981). The quality of groundwater EC observed in the field was about 5 dS/m, so that it will be useful for irrigation if it is diluted by fresh water.

Accordingly, it may be useful for minimizing the salt accumulation to provide a map showing as follows. The area A is vulnerable to be contaminated by brackish water (less than 1.5 m level from ground surface), the area B is not easily contaminated by the water (deeper than 2 m from ground surface) if well managed, and the area C is in between both areas. Based on these standards, the areas with salinization problem can be classified as shown in the map (Fig. 9).

The map may offer a useful data for land development as well as land conservation and rehabilitation planning in the region with salt problems. For the area A, reducing groundwater level will be effective to reduce the salinity. The irrigation water for leaching will be obtainable from the groundwater in the area B.

The agroforestry cultivation system to reduce the evapotranspiration and to reduce groundwater level will be expected applying high water use and fast growing trees as Eucaliptus to the recharge area of groundwater, in particular reforestation may be effective in the area B, because the area A and B are linked with groundwater. If a quick and inexpensive method to identify the salinity in the ground is applied, the map will be delineated easily (Dissataporn *et al.*, 1996).



● piezometer number
( ) annual average groundwater level

Area A : easily affected by salinity (groundwater level＜1 m)
Area B : not easily affected by salinity (groundwater level＞2 m)
Area C : intermediate between area A and area B (1 m＜groundwater level＜2 m)

Fig. 9 Land classification map of soil affected by salinity using annual average groundwater level from ground surface (counter lines fo groundwater level).

4. Conclusion

Capillary rise of groundwater was one of the main causes of salinization. Therefore the most important practice for salinization prevention is to interrupt capillary water rise, and to reduce the groundwater level. In the case of the site investigated, salinization proceeded quickly in the area where the annual average of groundwater level was shallower than 1.5 m from ground surface.

When the surface is out of the much affected zone by capillary rise, the application possibility of plant root system and agroforestry to absorb the salinity will be worth considering. A practical way of improving the soil in the area A is to lower the groundwater level by drainage to the depth of more than 1.5 m from ground surface. The leaching with flood irrigation using the groundwater from the area B and C to area A will be useful. The application of an agroforestry system in the area B and the area C may be useful as a practice of the soil improvement by reducing water supply to the area A.

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地下水位が塩分含量に及ぼす影響と環境的土地分類に関する研究

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要　　旨

東北タイのコンケン地域では土壌の塩類化が著しい。これは地下水からの塩類（NaCl）供給が原因の一つである。土壌塩類化の進行した地域において，最も自然環境に適した土壌修復と土地利用を進めるための土地分類の手法を提案した。

地下水位と塩分濃度を 3 年間にわたりフィールドで観測を行った結果，調査対象地域の場合，自然状態で毛管水の地表への影響を少なくするには，年平均の地下水位を 2 m 以深の状態に保つ必要があることを確認できた。これを基準として地下水位が塩分含量に及ぼす影響程度に応じて環境的土地分類を行い，農地としての土壌修復と土地利用の方向性について述べた。

キーワード：塩類化，毛管水，塩分移動，土地改良，土地分類

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