Integrated analysis on soils and ecosystem processes in southern and eastern Cameroon for establishing sustainable agriculture

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Abstract

Agro-ecological conditions were evaluated from three different viewpoints, i.e., soil fertility status, risk of nutrient leaching loss, and risk of soil erosion, and overall recommendations are given for agricultural practices in the targeted regions. The soil fertility status was evaluated using five parameters, i.e., the level of organic matter, C/N ratio, pH and base status, supply of N and K, and supply of Ca and Mg. The risk of nutrient loss was assessed based on solution study and soil erosion risk was by the *in situ* water permeability and topography. At Gribe, combination of banana, cacao and agro-forestry is recommended, to avoid leaching loss of nutrients and to utilize soils with relatively high fertility for long period in future. At Bityili, soil erosion might be a primary risk for sustainable agriculture due to the predominance of sloped land. Combination of banana, cacao and agro-forestry is recommended. Cassava and other annual field crops may be available on relatively gentle slope or flat land. In the forest zone of Andom, the agro-ecological conditions are similar to Gribe. Combination of banana, cacao and agro-forestry is recommended as sustainable land use. In the savanna zone of Andom, soil fertility might not be so high among the soils studied. Cassava planting may be one of the feasible options to effectively utilize such soils. Furthermore, at Andom, soil fertility status was often remarkably high in the soils under young fallow forest compared with those in the other land use stages, presumably due to an active supply of forest litter to soil as well as the pump-up effect of deep-soil nutrients by forest vegetation. An inclusion of forest fallow, instead of savanna vegetation, into the land use systems may greatly contribute to improve the soil fertility and to maintain it for a long period of time.

Key words: risk of nutrient leaching loss, risk of soil erosion, soil fertility status, sustainable agriculture
Component of Activity: 3-4

Introduction:

This article intends to summarize the respective activities of soil ecological studies of the FOSAS project, in order to give basic recommendations for enabling sustainable agricultural development while maintaining the precious forest resources in the targeted regions of southern and eastern Cameroon.

Ferralsols/Oxisols are widely believed to be low-fertility soils, which are poor in mineral nutrients due to the intensive mineral weathering under tropical climates (FAO 2001). Kaolin minerals and Fe/Al oxides/hydroxides are dominated as major clay mineral components and the supply of mineral essential nutrients such as P, K, Mg, and Ca are limited. These characteristics are counted as one of major constraints for agricultural practices there.

Ferralsols are widely distributed on stable plains associated with the 'Precambrian shield' in eastern South America or equatorial Africa. It is contrasting that soils in humid Asia are mostly Acrisols and Alisols and exhibit relatively incipient mineralogical characteristics due to dominant steep slopes, crust movement and volcanic activity on 'young alpine fold belts (FAO 2001).' It is essential to understand basic ecosystem processes on respective soil conditions to establish an appropriate strategies for sustainable agricultural management. In this article, therefore, extensive and intensive soil surveys, basic soil analyses, field measurement of ecosystem processes and nutrient dynamics, and field monitoring of the water budget (including rain water, soil water and surface runoff) are involved to achieve the objectives presented earlier..

Methodology:

Details of methodologies used in these studies are given in respective reports (Nishigaki et al. 2015; Shibata et al. 2015; Sugihara et al. 2015; Watanabe et al. 2015). General physicochemical properties of the soils distributed in the regions were firstly assessed, and then ecosystem processes both in forest and agricultural fields in Andom village were analyzed in terms of *in situ* nutrient dynamics. The process of water dynamics and surface runoff generation were analyzed by field water monitoring at the small-scale soils erosion plots installed in Andom and Bityili villages..

Results and Discussions:

Chemical properties of soils in Cameroonian plateau: comparison with soils in Southeastern Asia

It is widely accepted that major parts of southern and eastern Cameroon are covered by Oxisols or Ferralsols (The European Commission's Joint Research Centre 2014). One of the central concepts of Oxisols/Ferralsols is the lack of weatherable minerals both in sand and clay fractions and kaolin minerals and Fe and/or Al oxides dominate in clay fraction of the soils.

According to our extensive soil survey, which covered in total 150 soil profiles from the Provinces of East, South, South-West, North, North-West, West, Littoral and Adamaoua, the majority of soils is characterized with a typical kaolin-dominated clay mineralogical composition (Fig. 1), as typically observed for Ferralsols/Oxisols in different regions of Africa and Latin America. However, more detailed chemical analyses revealed that the soils exhibited rather unique characteristics in terms of the level of cation exchange capacity (CEC) in that: the effective cation exchange capacity

(ECEC) determined at low pH ranges was usually low as satisfying Ferralsols' requirement (i.e. ECEC < 12 $cmol_c$ kg $clay^{-1}$), the CEC value determined at pH 7 was often much higher than the cutting value for Ferralsols, 16 $cmol_c$ kg $clay^{-1}$, indicating a development of variable negative charge originating from Fe oxides/hydroxides (Fig. 2). In addition, total reserve of bases (TRB) was also often exceeding 25 $cmol_c$ kg $soil^{-1}$ and, therefore, soils in this region were not considered to be extremely infertile. As a result, a fairly high proportion of the soils distributed in the region failed to meet the taxonomic requirement of Ferralsols, and the taxonomic Ferralsols (Oxisols) were more frequently found in drier regions on the plateau.

Figure 3 gives scattergrams among chemical properties of the B-horizon soils of the present study with comparable data of soils from Kalimantan, Indonesia, and northern Thailand. According to the extensive study for Asian soils where Ultisols dominated (Funakawa et al. 2008), Alisols were the majority under rainforest climate, whereas Acrisols are common under monsoon climate with distinct dry season. They were separated by the relative abundance of expandable 2:1 minerals and were characterized well by the values of pH and CEC/clay of the B horizon soils; i.e., the B horizon soils from northern Thailand were typically characterized by higher pH (above 5) and low CEC values (usually < 24 $cmol_c$ kg $clay^{-1}$), whereas those from East Kalimantan, Indonesia, were by lower pH (below 5) and high CEC values (mostly > 24 $cmol_c$ kg $clay^{-1}$). In contrast with the Asian soils, the kaolin-dominated nature of the Cameroonian soils directly affected their CEC values (usually < 16 $cmol_c$ kg $clay^{-1}$) and potential for retaining exchangeable Al^{3+}, which was the most harmful acidic substance in soil; that is, in spite of low pH values comparable with the Indonesian soils, possible amount of neutralizing materials (such as lime) for the Cameroonian soils may be much lower than that for Indonesian soils with higher Al-derived acidity. From the viewpoint of acidity amelioration, the Cameroonian soils are considered to be rather easy to be handled. Additionally a possibly good physical properties derived from their mineralogical characteristics (kaolin-dominant) enables us to develop modern agriculture after acid neutralizing treatment for these soils.

Chemical properties of the soils distributed in Andom, Gribe and Bityili villages

Figure 4a represents a scattergram plotting total reserve of organic C and N in the surface 30-cm layers of soils, indicating that the amounts of organic C and N were similarly low as below 50 Mg ha^{-1} at surface 30-cm layers of soil in all the matured forest of the three villages. Similarly, the pH level and total stock of the exchangeable bases (Na, K, Ca and Mg) in the surface 30-cm layers of soil were not very much different among these forest soils, characterized typically by low pH and low base status (Fig. 4b).

At Andom village, we conducted more detailed sampling by separating soils from different land use stages, i.e., matured forest, young secondary forest, savanna, and cropland. As a result, following points were revealed:

1) In young fallow forest (8-30 years), organic matter level was higher than in the other stages, while C/N ratio in the very surface horizon of young forest already reached at the same level of matured forest (Fig. 4a).
2) The C/N ratio was higher in the surface soils from savanna (Fig. 4b).
3) Succession of vegetation might have affected soil acidity; i.e., during the early succession to establish young secondary forest, basic cations tended to be accumulated and soil pH increased in the soil profiles, presumably due to the pump-up effect of deep soil nutrients by young forest. The increased base status in the young secondary forest was, however, gradually mitigated during further growth to matured forest presumably through intensive accumulation of basic cations into stems of big trees.

We can conclude that, at Andom village, soil fertility status, i.e., the amount of soil organic matter stock and its quality (C/N ratio), the level of exchangeable bases, and soil acidity, is often remarkably high in the soils under young fallow forest compared with that in the other land use stages. In contrast, such basic cations were progressively taken up the vegetation and, therefore, soils were acidified in the matured forest. In the course of the later stage of forest growth, the supply of litter-fall might also be decreased relative to growth of tree biomass, resulting in decrease of soil organic matter level in matured forest.

Nutrient dynamics under the natural forest and savanna vegetations in the studied sites in Cameroon and their alteration after conversion to agricultural cropland

Soil solution study revealed that at Andom-forest nitrate flux was already substantial and was dramatically increasing after forest reclamation for agricultural use (Fig. 5). High nitrate flux in forest ecosystem is rather unique characteristics and could be attributable to the dominance of leguminous trees such as *Albizia zygia* in the Andom-forest. This figure was not observed for the savanna site with surface soil having relatively high C/N ratio (17). In Mvam-forest, the presence of organic acids as a dominant anion should be noted. Such a trend is somewhat similar with the Indonesian forest with strongly acidic surface soils (Fig. 6).

The increasing contribution of nitrate ion among anions is a common feature in the ion fluxes in all the agricultural lands studied (Figs. 5 and 6). Note that the nitrate flux was higher in the cropland after forest than in that after savanna in Andom, presumably reflecting C/N ratios at the two plots. The high nitrate flux accompanied high cation flux as well, which could be promoted through mineral weathering under strongly acidic conditions. The ion flux pattern at Gribe exhibited a similar figure with that of Andom-forest and cropland after forest, though the chemical analysis for Gribe plots was not completed yet.

It should be noted that the high fluxes of N and cations are the favorable condition for crop growth, but also are risk factors that could promote the leaching loss and fertility degradation of the soils in the long run. In Fig. 7, potential nutrient loss through leaching and product removal during

4-years cultivation (maize and cassava) was assessed for the croplands after forest and savanna reclamation at Andom, respectively. According to the estimation, the exchangeable pool of K was not high enough to compensate the K removal during the 4 years cultivation. Also, larger amounts of Ca and Mg could be leached out from the system unless anion flux (mostly of nitrate) was not closed, and the exchangeable amounts of these cations are just equivalent to several times of the leaching loss estimated, indicating that the exchangeable pools of Ca and Mg would be depleted within several years' cultivation and soil fertility be declined shortly. Mineral weathering is, therefore, an essential process for keeping plant growth even in Ferralsols.

In addition, it should be noted that cassava planting may result in huge loss of mineral nutrients through stimulating N flux and an intensive uptake by cassava plants. In the long run, some trials for nutritients replenishment would be indispensable for maintaining cassava production. Introduction of agro-forestry and/or land use systems involving tree plantation may be one of solutions to compensate leaching loss of nutritional elements from the ecosystems.

Physical characteristics of the soils studied based on the field monitoring on the fate of rain water

Figure 8 represents the temporal patterns of water movement during the selected rainfall events, in which rainfall amounts, soil moisture contents at 0-15, 15-30 and 30-60 cm layers of soils and the amount of surface runoff were monitored by datalogger systems in the closed erosion-measuring plots installed at the sloped lands at Andom and Bityili. In both plots, generation of surface runoff was limited even at the strong rainfall events and water percolation toward the deep layers of soils was very rapid. Minor difference at the two plots are: at the Andom plot, a rapid invasion of water into the surface layers was clear, followed by sequential percolation into underlying horizons after saturation of the upper layers, while, at the Bityili plots, rain water penetrated immediately into the deep layers of soils before saturating the soils at the overlying horizons, possibly due to the predominance of bypass flow.

Based on the results of this field experiment, it is possible to conclude that the soil erosion risk may not be high at least in terms of water infiltration into deep layers of soils at both the plots. Factors relating to topography and/or land cover are, therefore, more important for decreasing soil erosion risk. In this sense, we have to take care of land selection especially in Bityili village, because the territory of the village is covered predominantly with relatively steep sloped lands.

Overall evaluation of agro-ecological conditions and recommendation for land management in the targeted regions

Table 1 summarized soil chemical properties, characteristics of ecosystem nutrients dynamics and physical conditions of the cropland at the three villages, together with the comparable data from tropical Asia by the authors. Then the relative soil fertility status was evaluated using five parameters relating to both soil chemical and mineralogical properties and nutrient dynamics data, i.e., the level of organic matter in the surface 30-cm layers of soils, C/N ratio of the surface soils, pH and base status of the surface 30-cm layers of soils, supply of N and K, and supply of Ca and Mg. Also, the risk of nutrient loss was assessed based on solution study and soil erosion risk was by the *in situ* water permeability and topography.

Then overall evaluation of agro-ecological conditions for agricultural practices was given based on the relative soil fertility status, risk of nutrient leaching loss, and soil erosion.

1) At Gribe, combination of banana, cacao and agro-forestry is recommended, to avoid leaching loss of nutrients and to utilize soils with relatively-high fertility for long period in future.
2) At Bityili, soil erosion might be a primary risk for sustainable agriculture due to the predominance of sloped land. Combination of banana, cacao and agro-forestry is recommended. Cassava and other annual field crops may be available on relatively gentle slope or flat land.
3) In the forest zone of Andom, the agro-ecological conditions are similar to Gribe. Combination of banana, cacao and agro-forestry is recommended as sustainable land use.
4) In the savanna zone of Andom, soil fertility might not be so high among the soils studied. Cassava planting may be one of the feasible options to effectively utilize such soils.

Recommendation for agricultural practices in Andom villages

At Andom village, soil fertility status, i.e., the amount of soil organic matter stock and its quality (C/N ratio), the level of exchangeable bases, and soil acidity, was often remarkably high in the soils under young fallow forest compared with that in the other land use stages, presumably due to an active supply of forest litter to soil as well as the pump-up effect of deep-soil nutrients by forest vegetation. On the other hand, continuous cassava planting may accelerate nutrient loss through stimulating N flux and an intensive uptake of mineral nutrients by cassava plant. Therefore, introduction of forest-fallow, instead of savanna vegetation, into the land use systems may greatly contribute to improve the soil fertility and to maintain it for a long period of time.

General discussion and conclusion

Agricultural practices inevitably remove certain amounts of essential nutrients, such as N, P, K, Mg, Ca, etc., as agricultural products from the agro-ecosystem. We have to compensate the nutrient loss, in order to maintain agricultural production.

There are essentially two ways for such compensation of nutrient loss. One is input from outside, for example, by adding chemical fertilizers and/or manures and the other approach is to utilize natural ecosystem processes.

Among the second approach, in order to recover soil N, we can utilize and enhance the biological nitrogen fixation, since the essential source of N is the atmosphere. On the other hand, most of mineral nutrients are derived from soils and lithosphere. The essential process to incorporate mineral nutrients to biological cycle is the liberation of nutritional ions from mineral crystals through mineral weathering. Plant root system, especially of trees, is excellent in this ability; it can promote mineral weathering by adding acid loads, it can extend its activity to deeper layers of soils where more amounts of mineral nutrients may be present, and it can return such nutrients to the soil surface through litter-fall.

In this context, agro-forestry and/or mix cropping of trees and annual crops could be one of approaches to utilize the ability of tree root systems for nutrient replenishment. On the other hand, crop rotation system with forest-fallow, such as shifting cultivation, is another approach for utilizing such functions of forest in a temporal sequence. Our recommendation shown previously basically follows this idea. For sustaining long-term agricultural production, it is necessary to realize nutrient replenishment either by the on-site recovery using tree functions or by utilizing outside resources such as manures.

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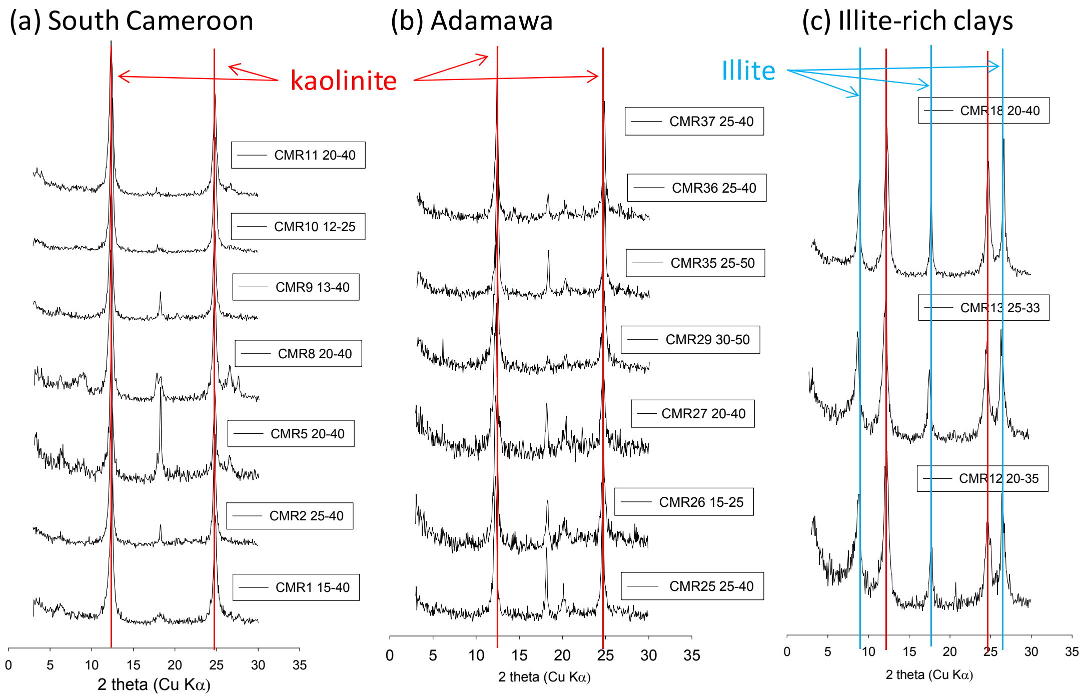


Fig. 1. Clay mineralogical composition of representative soils by X-ray diffraction analysis

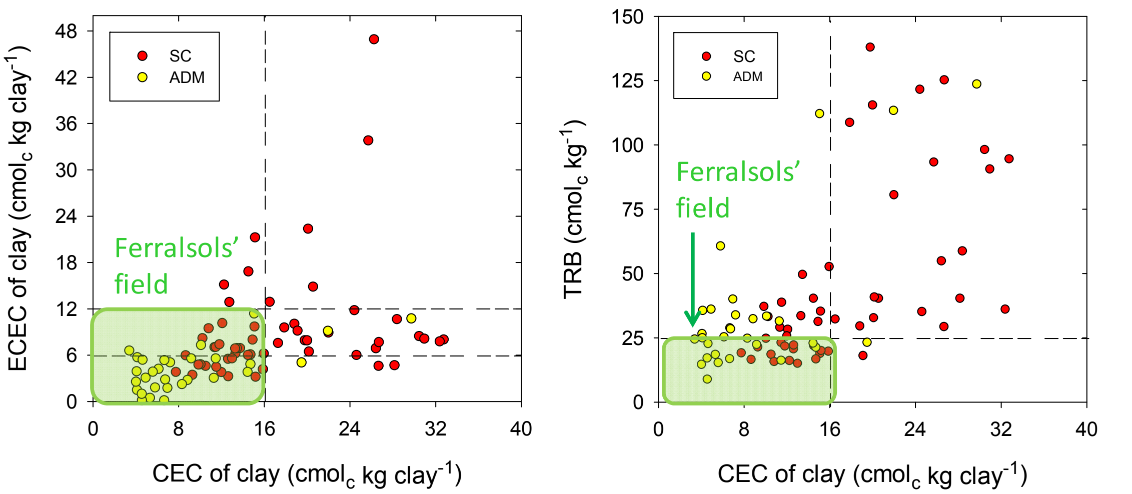


Fig. 2. Relationship between cation exchangeable capacity (CEC), effective CEC (ECEC) and total reserve of bases (TRB)

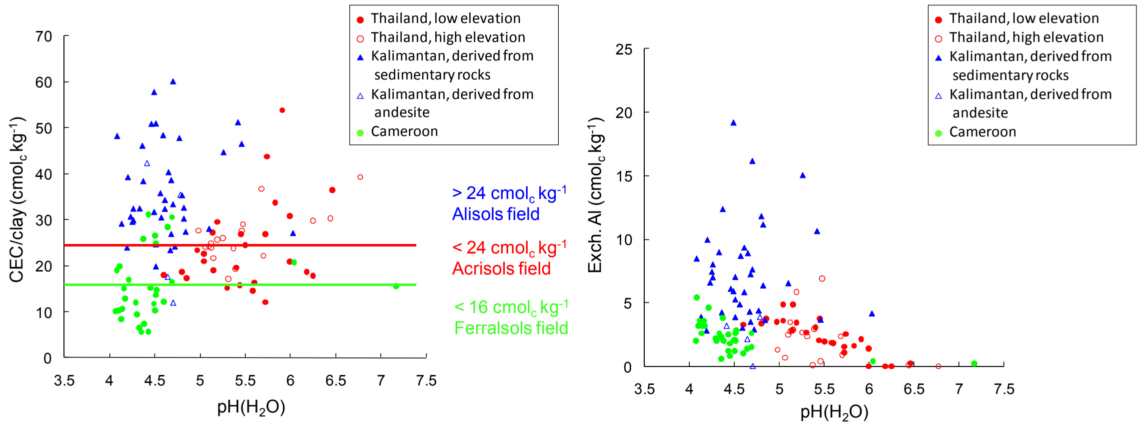
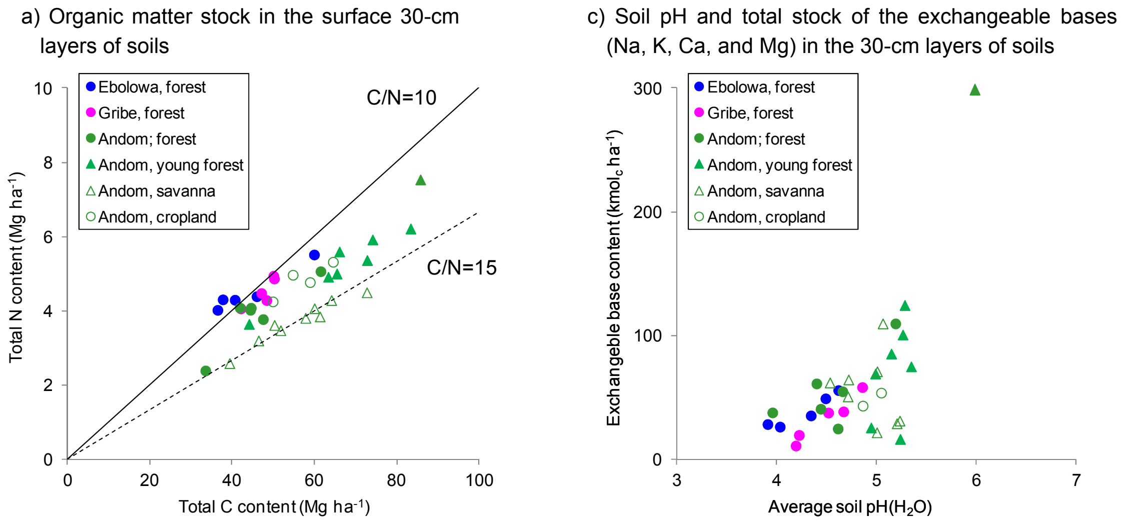


Fig. 3. Chemical properties of B horizon soils in Cameroon: comparison with soils from Southeast Asia



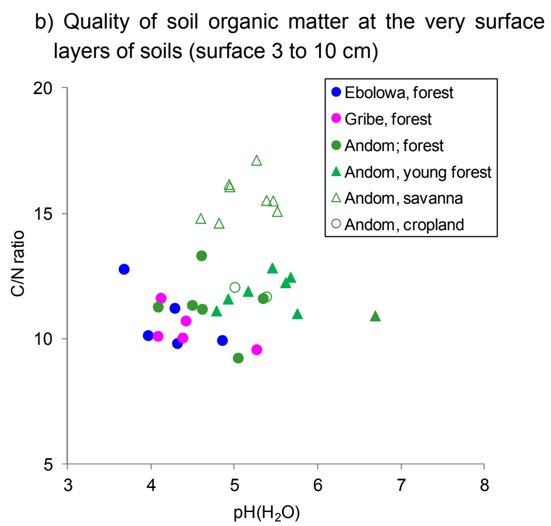


Fig. 4. Chemical properties of surface soils distributed in the three villages

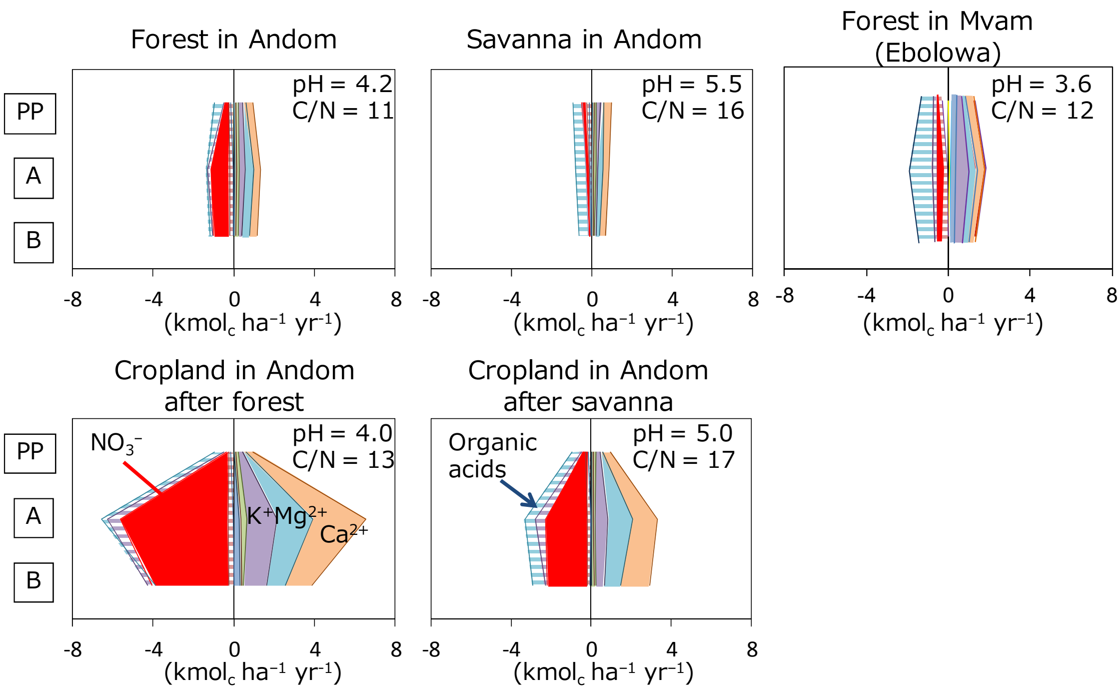


Fig. 5. Alteration of ion fluxes after forest reclamation: comparison among different plots in Cameroon

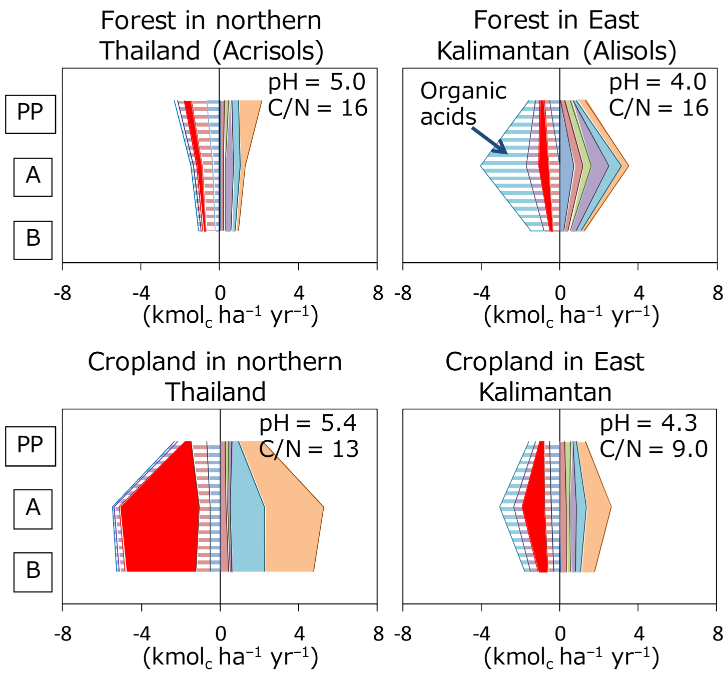


Fig. 6. Alteration of ion fluxes after forest reclamation: comparison with Southeast Asia (original data is cited from Fujii et al.)

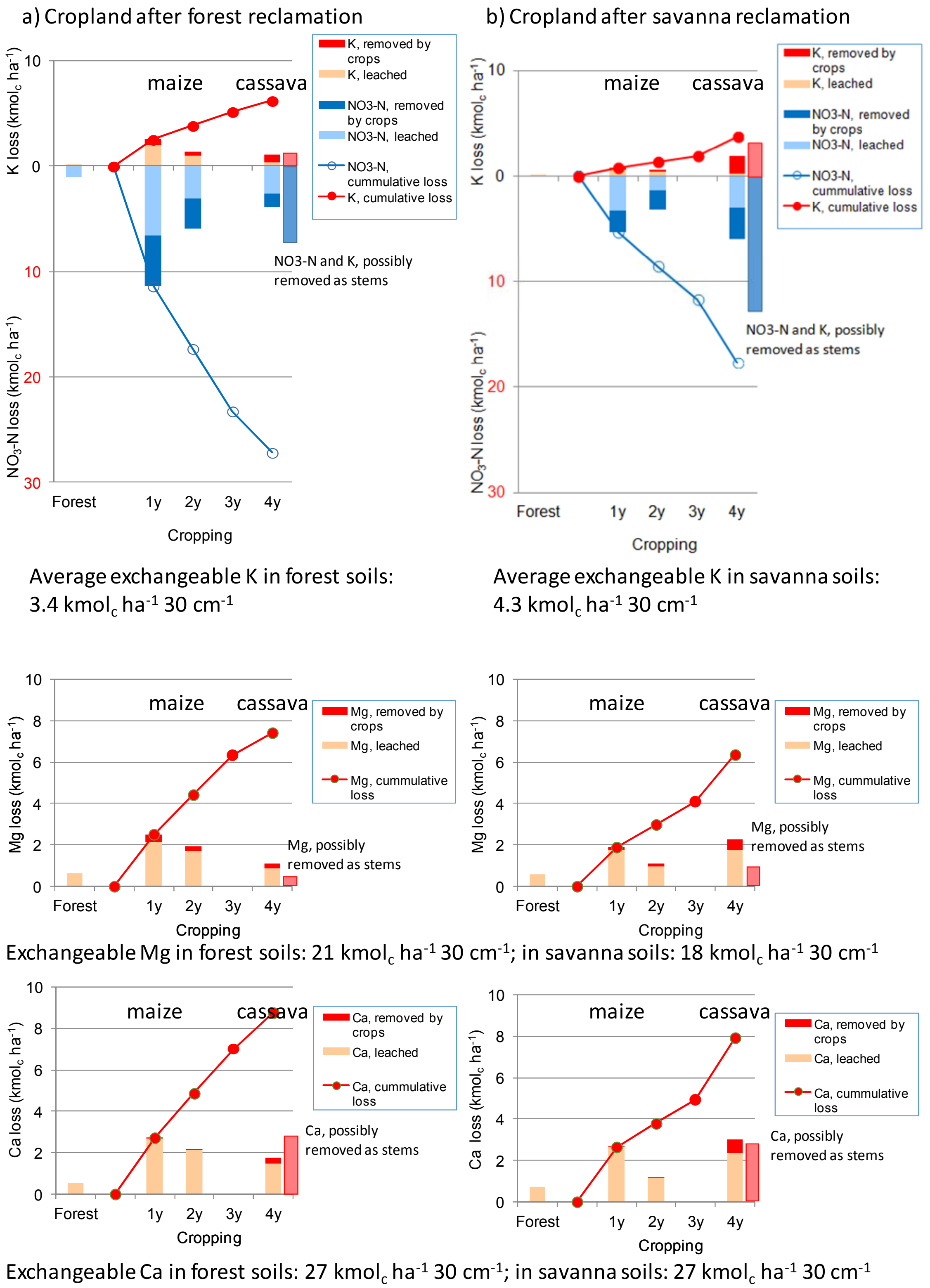


Fig. 7. Estimation of removal of NO_3^-, K, Mg, and Ca from the soils

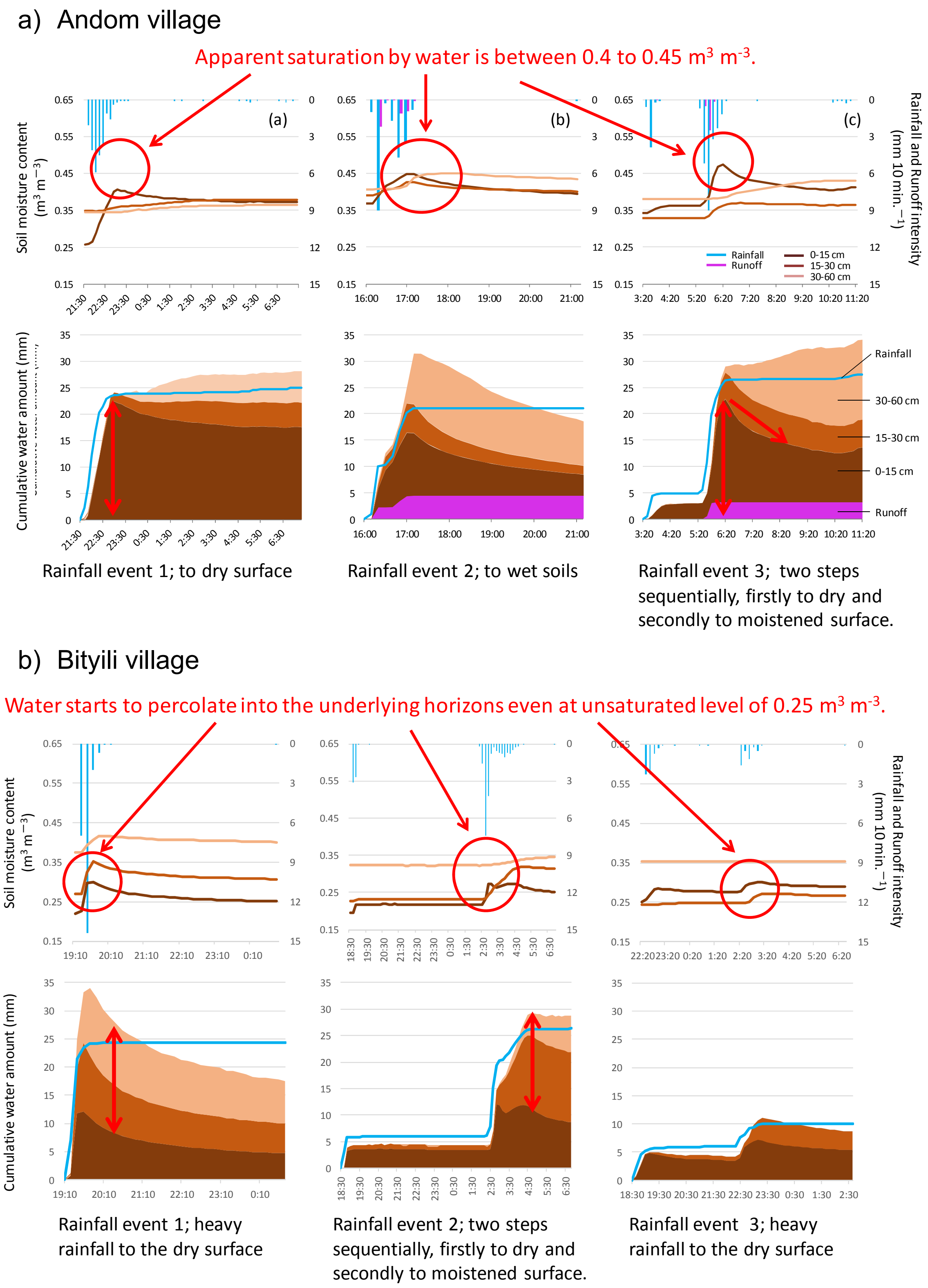


Fig. 8. Water dynamics during rainfall events at sloped cropland in Andom and Bityili

Table 1. Summary of agro-ecological conditions in the study areas

		Chemical and mineralogical properties of soils			Nutrient supply and risk of leaching loss in cropland basrd on the solution study	
		Level of organic matter (30 cm layers of soils) (*a*)	CN ratio (A hor) (*b*)	pH and base status (30 cm layers of soils) (*c*)	Supply and leaxhing risk of N and K (*d*)	Supply and leaxhing risk of Ca and Mg (*e*)
Gribe		low (OC < 50 Mg ha^{-1})	low (9-12)	low (pH 4-5)	high	moderately high
Bityili		low (< 50)	low (10-12)	low (3.5-5)	possibly low	possibly low
Andom	forest	low (< 50)	low (10-12)	low (4-5)	high	moderately high
	savanna	moderately high (40-80)	high (12-17)	intermediate (4.5-5.5)	moderately low	moderately low
East Kalimantan		low (< 50)	moderately low (10-15)	low (4-5)	low	low
Northern Thailand		high (> 80)	high (12-18)	high (5-7)	moderately high	high

		Parameter for erosion risk evaluation		Evaluation from respective conditions		
		Water permeability (*f*)	Topography (*g*)	Relative soil fertility status based on (*a*) to (*e*)	Risk of leaching loss based on (*d*) and (*e*)	Erosion risk based on (*f*) and (*g*)
Gribe		possibly high	gentle	moderately high (3/5)	high	low
Bityili		high	steep	low (1/5)	low	moderately high
Andom	forest	possibly high	gentle	moderately high (3/5)	high	low
	savanna	high	gentle	moderately low (2/5)	moderately low	low
East Kalimantan		possibly very low	steep	low (1/5)	low	high
Northern Thailand		possibly low	steep	high (4/5)	high	high