Soil Resilience Study in Semi-Arid Sub-Saharan Africa

Hitoshi Shinjo
Graduate School of Agriculture, Kyoto University

Significance of Resilience

In semi-arid sub-Saharan Africa, droughts resulting in crop failure are common and have induced serious food insecurity that is closely interacted with poverty. Since the majority of poor make their living from smallholder farming under rainfed conditions, the land degradation closely linked with poverty and food insecurity prevails in rural areas. Rockström (2003) attributed the causes of land degradation to interacting pressures from population growth, poor land management practices and weak land policies acting on a vulnerable resource base. Land degradation reduces the capacity of the agricultural ecosystems to absorb environmental shocks, such as floods and droughts, that are projected to increase due to global climate change (IPCC 2001). As a result, we may have orthodox views that land degradation affects the considerable area of the Earth's land and the situation is getting worse as pointed out by the influential document '*Protecting Our Planet: Securing Our Future*' (UNEP/NASA/World Bank 1998).

However, several researchers argued the reality of those views. Scoones (1998), for example, carefully examined some of such doom-laden views and found that these views derived from two main sources: first, detailed scientific studies carried out at the microlevel whose findings are extrapolated to address wider issues; second, macrolevel economic analyses of food and agricultural policy which make inferences about longer-term trends from aggregate data at country, regional or even continental levels. Although non of the original studies cited in these views were, of course, incorrect, we should be aware of their data quality, the spatial scale at which the original studies were conducted, and the non-linear dynamics in time scale. Particularly, the last issue has been recognized as the key missing one in current investigations of agricultural resource management. Even if a trend over a short period in the recent past is observed, it cannot be assumed that such a linear pattern will continue into the future. Rockström (2003) pointed out that nature with which we are coping is not a balanced system filled with nice biogeochemical cycles, circulating in a predictable pattern, but instead consist of complex and adaptive systems, where extreme events, such as floods and droughts, form a natural part of the reality. Stocking (2003) also maintained that the linear view as doomsday scenarios of increasing population and declining soil resource quality fail to capture the diversity of soils. This perception reflects increase of our findings on the behavior of systems especially since Holling (1973) originated the idea of "resilience" in the field of ecology.

Among diverse definitions of resilience, two major ones are *engineering resilience* and *ecological resilience*. *Engineering resilience* is the speed by which the system returns to the equilibrium after certain disturbance. As Bengtsson (2002) claimed, however, in ecosystem studies, the concept of ecological resilience seems more relevant since ecosystems are complex entities that have not only one but many stability domains. *Ecological resilience* can be defined as the capacity of a system to undergo disturbance and maintain its functions and controls and can be measured by the magnitude of disturbance the system can tolerate and still persist before it moves into a different region of state space and a different set of controls. Although resilience has often been discussed in the context of sustainability, it should be noted that a sustainable system possesses the resilience to disturbance, but not vice versa. Sustainability is commonly accepted as the desirable goal, while resilience can be desirable or undesirable. System states decreasing social welfare, such as racism or dictatorships, can be highly resilient. Since the semi-arid sub-Saharan Africa is fully exposed to the changing, unpredictable settings, such as drought and institutional instability, the resilience concept would help to analyze the interrelationship between agricultural land use, food security and land degradation.

Since the resilience can be defined theoretically as above, its operational and measurable definitions consistent with the theoretical ones are required for the analysis of systems in the real world. In this sense, we should specify what system state is being considered (resilience *of* what) and what disturbances are of interest (resilience *to* what) (Carpenter et al. 2001). Firstly, this paper reviews how the resilience concept has been used in the arena of terrestrial ecosystems with special reference to "resilience of what to what". Secondly, it will discuss the context in which soil resilience should be evaluated in the semi-arid sub-Saharan Africa.

Experiences in Resilience Studies in Terrestrial Ecosystems

Most of the resilience studies in terrestrial ecosystems were categorized into two major groups according to the disturbances (resilience to what); manmade or natural. Examples for the manmade disturbances are logging (Asner et al. 2004), mechanical compaction by machinery (Munkholm and Schjønning 2004) and man (Lemauviel and Rozé 2003), contamination of metals (Griffiths et al. 2005) and organic chemicals (Benitez et al. 2004), grazing (Holm et al. 2005) and military training (Quist et al. 2003), while those for natural disturbance are wild fire (Certini 2005), flood (Jackson and Colmer 2005) and drought (Lloret et al. 2004). As for the system observed upon disturbances (resilience of what), they monitored the temporal changes in productivity of plant communities, function of soil microbial communities or soil nutrient status. In addition, the other attribute of the soil resilience studies can be type of the human interventions examined as impact on the change in resilience. One typical example is the comparison of organic and conventional farming systems in terms of the soil resilience to the certain disturbances (for example, Van Diepeningen et al. 2006; Griffiths et al. 2001). Thus, the soil resilience studies can be grouped according to the three attributes; what does affect resilience of what to what?

In spite of so diverse systems examined in terms of resilience from the scale of DNA (e.g., Fitter et al. 2005) to landscape (e.g., Holm et al. 2005), most of the authors have tried to describe the effect of disturbance on the functions of systems through diversity of their target, based on the hypotheses that the diversity of a system controls its resilience that might decline with improper human interventions. Van Diepeningen et al. (2006) reported that organic management resulted in higher numbers of bacteria of different trophic groups, larger species richness in bacteria and nematode communities and more resilience to a drying-wetting disturbance than conventional management. Griffiths et al. (2001) also found that the grassland soils and the organically managed soils with more protozoan populations were more resilient[1] to copper addition and heat stress than the polluted soils. As these studies reveal, the diversity appears to ensure the resilience of the system.

On the other hand, relationships between diversity and productivity or functionality are not apparently straightforward. Rosenzweig and Abramsky (1993) cited a number of the measurements showing the common trend that the diversity reached to the maximum at the middle level of productivity within a region (Fig. 1). Although its theoretical background has not been yet fully understood, Shinjo et al. (2005) discussed the application of this trend to evaluate desertification processes after extending the original hypothesis by Schlesinger et al. (1990) (Fig. 2). Thus, if both of the resilience and the productivity are controlled by diversity,

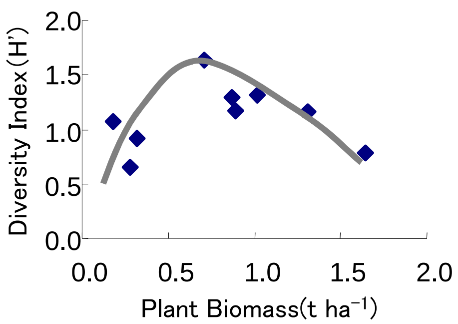

Fig. 1 Relationship between diversity index and plant biomass in northern Burkina Faso (Shinjo et al. 2005). At 9 sites, plant species were identified at intervals of 50 cm in the 50 m transect and aboveground plant biomass in 1 m^2 was measured at 3 points in the transect. Shannon-Weaver's diversity index, H', was calculated at each site by

$$H' = -\Sigma P_i \times \log_e P_i$$

where P_i is the frequency of plant species i in the 50 m transect. Plant biomass showed the maximum value at the middle of plant species diversity

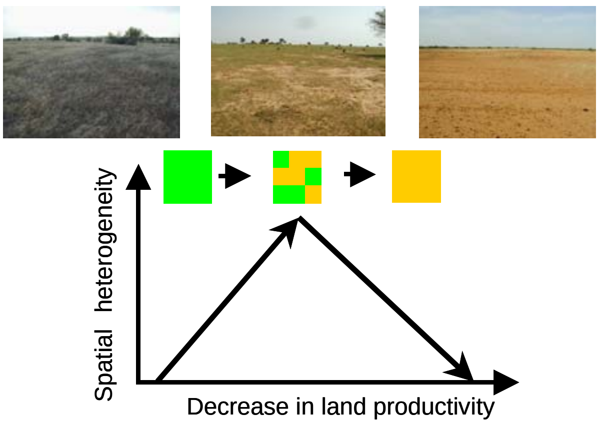

Fig. 2 Hypothetical diagram of desertification process (Shinjo et al. 2005). Spatial heterogeneity of soil and vegetation will reach a maximum at the middle of desertification processes, while soil and vegetation would in general have a homogeneous character at its beginning and end. Photos show landscapes found in northern Burkina Faso at the same sites in Fig. 1.

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[1] In the original article (Griffiths et al. 2001), "resistant" was used instead of "resilient". They referred "resilient" to another feature of systems stability. This inconsistency in the definition of "resilience" among articles strongly suggests us to use "resilience" with explicit definition not to confuse readers.

tradeoffs between resilience and productivity might take place. The most resilient system would be at the middle level of productivity. This possibility should be examined carefully and thoroughly especially for the food security and the improvement of livelihood in the semi-arid sub-Saharan Africa. Food security system resilient to droughts or shocks might be achieved with investment of surplus in good years for stabilizing the system not for shifting to a second stable state.

Needs for Soil Resilience Study in Semi-Arid Sub-Saharan Africa

Recognizing the significance of the diversity in natural resources and also social capital for smallholder farmers in sub-Saharan Africa to mitigate disturbances, some authors called for its analysis to provide more realistic intervention for them (Scoones 1996; Stocking 2003; Rockström 2003). There is missing area for this analysis. Firstly, few studies have defined resilience as operational and measurable indices. For example, Rockström (2003) proposed water harvesting and conservation farming as options of resilience building for drought mitigation, but did not specify how to evaluate their effectiveness yet. Secondly, dynamic nature of spatial variability in complex systems has rarely been elucidated at field or landscape level although diversity in time and space might contribute to the resilience of the system (Fig. 2). Scoones (1998) exemplified how farmers in Ethiopia managed space at field and plant level in order to maximize the efficiency of use of fertility amendments. For this purpose, experiments that can distinguish effects of human intervention on soil resilience from those of disturbance would be promising since disturbance itself also affects soil resilience. Thirdly, relevance of soil resilience in the context of social systems is not examined yet. Smallholders do not only rely on soil resilience for mitigating disturbance. Social resilience also plays a significant role. Reciprocal help among different ethnic groups

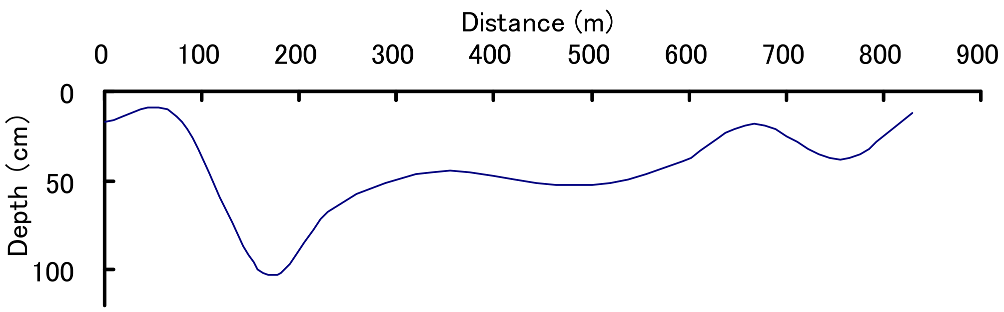

Fig. 3 Spatial pattern of the depth of petroplinthic horizon along a transect in a village of central Burkina Faso (Tanaka unpublished data). A petroplinthic horizon is an indurated layer, in which iron is an important cement (FAO, ISIRC and ISSS, 1998). Since this horizon is extremely hard, its depth corresponds to the effective soil depth in terms of plant productivity. This depth could be more critical in drought years than in normal years since the soil thickness down to this horizon determines the amount of water that can be held in the soil. Thus, the depth of petroplinthic horizon can be one of the indicators for soil resilience to the drought in this study site. This spatial pattern was mainly determined geomorphologically, but could be modified by human-induced erosion.

and family members living in the different regions is an good example. Social resilience is also not static, might be eroded due to both of land degradation and socio-political change. Decline of soil resilience would trigger a loss of social resilience and vice versa. Dynamics in soil resilience should be evaluated in the context of social resilience.

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