Impact of enclosure management on soil properties and microbial biomass in a restored semi-arid rangeland, Kenya

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Abstract: Rangeland degradation is a serious problem throughout sub-Saharan Africa and its restoration is a challenge for the management of arid and semi-arid areas. In Lake Baringo Basin of Kenya, communities and individual farmers are restoring indigenous vegetation inside enclosures in an effort to combat severe land degradation and address their livelihood problems. This study evaluated the impact of enclosure management on soil properties and microbial biomass, being key indicators of soil ecosystem health. Six reseeded communal enclosures using soil embankments as water-harvesting structures and strictly regulated access were selected, varying in age from 13 to 23 years. In six private enclosures, ranging from 3 to 17 years in age, individual farmers emulated the communal enclosure strategy and restored areas for their exclusive use. Significant decreases in bulk density, and increases in the soil organic carbon, total nitrogen and microbial biomass contents and stocks were found in the enclosures as compared with the degraded open rangeland. In the private enclosures, the impact of rehabilitation on the soil quality was variable, and soil quality was in general lower than that obtained under communal management. The significant increase of absolute stocks of carbon, nitrogen and microbial biomass compared to the degraded open rangeland indicates the potential for the restoration of soil quality through range rehabilitation. Over-sowing with indigenous legume fodder species could improve total nitrogen content in the soil and nutritional value of the pastures as well.

Keywords: rangeland degradation; enclosures; microbial biomass; rehabilitation; reseeding; soil quality; Kenya


In severely degraded semi-arid rangeland, withdrawal of livestock grazing is often not sufficient to initiate the autogenic recovery of vegetations (Kinyua et al., 2009; Opiyo et al., 2011). As degradation continues, the condition of the rangeland ecosystem declines and then becomes relatively stable and resilient beyond a certain threshold (Milton et al., 1994). Rehabilitation hence needs to focus on the improvement of the microclimate and seedbed, reduction of water and wind erosion, installation of water harvesting structures and reseeding (Kinyua et al., 2009; Opiyo et al., 2011). Successful restoration of vegetation cover improves soil water balance and soil fertility, reduces soil erosion and restores the soil biodiversity and ecosystem services (De Baets et al., 2006; Descheemaeker et al., 2006; Tongway and Ludwig, 2011). This illustrates the linkages
and feedback loops occurring between biotic and abiotic components of the rangeland ecosystem, capable of reversing land degradation (Perrow and Davy, 2002a, b; King and Hobbs, 2006).

The capacity of the physical environment to sustain reproducing populations, eliminate potential threats, and exert resilience to natural disturbances is related to important soil functions that have to be evaluated when measuring the impact of rehabilitation (SER, 2004). In practice, soil processes such as nutrient cycling and biological interactions are studied to measure the recovery of the soil and to evaluate the long-term functioning and resilience of the restored ecosystem (Ruiz-Jaen and Aide, 2005). Good measures of the rehabilitation success can be obtained when the evolution of these ecosystem attributes with time is compared to the evolution recorded in reference sites (SER, 2004; Ruiz-Jaen and Aide, 2005). However, most soil functions recover much more slowly than the biotic attributes such as vegetation structure and diversity, and consequently, they are only rarely measured (Ruiz-Jaen and Aide, 2005). Recent studies on soil-vegetation feedbacks in rangeland health focused on the relationship between enclosure age and its effectiveness in improving the soil physical, chemical and biological properties that are key indicators of soil quality (Mekuria and Aynekulu, 2011; Mekuria, 2013). Although the aforementioned studies focused on the natural re-vegetation of enclosed rangelands, other scientists have studied the impact of different rehabilitation techniques on the recovery of vegetation (Kinyua et al., 2009; Opiyo et al., 2011) and soil quality (Wu et al., 2010).

The Njemps Flats in the Lake Baringo Basin in Kenya is a semi-arid rangeland inhabited communally by the Il Chamus agro-pastoral community, whose main livelihood source is livestock keeping (Meyerhoff, 1991). Severe environmental degradation and habitat loss in the Lake Baringo Basin have been reported in literature since the 1930s (Little, 1996). Major causes of land degradation in the Njemps Flats include burgeoning human and livestock population pressure, land use changes, overgrazing and droughts. The Rehabilitation of Arid Environments (RAE) Trust was initiated in 1982 to rehabilitate the severely degraded rangeland around Lake Baringo and the surrounding hills, helping address the socio-economic problems caused by land degradation (de Groot et al., 1992). RAE established large-scale communal enclosures using a participatory approach to serve as demonstrations for range rehabilitation. Establishment of communal enclosures entailed fencing and preparation of the seedbed by ripping along the contours using a tractor fitted with chisel tines, producing parallel micro-catchments. Water harvesting structures were installed by alternately closing these furrow-like micro-catchments, followed by broadcast-seeding with a mixture of indigenous grass species. Main grass species used were *Cenchrus ciliaris*, *Eragrostis superba* and *Entrepogon macrostachyus*. Scattered indigenous drought-resistant trees, such as *Acacia tortilis*, were also planted. The utilisation through occasional grazing and other income generating activities (IGAs) was strictly regulated and controlled. The main IGAs included fattening steers for sale, grass seed harvesting, dry season grazing, bee-keeping, grass-cutting (for thatch or hay) and wood-cutting (for building or fencing posts and fuel wood). Such benefits and the rehabilitation success attained in the communal enclosures increasingly inspired many local inhabitants to establish private enclosures, giving exclusive access and user rights. The result was a mosaic of enclosures, differing with respect to the management type and years since establishment.

In view of the increasing adoption of rangeland enclosure and the pressure exerted on the remaining communal grazing areas in the Lake Baringo Basin, it is important to understand its effectiveness in restoring the functions of degraded rangeland ecosystems. Focusing on the soil physical, chemical and biological properties of communal and private enclosures and the open rangeland, this study aimed to assess the impacts of different enclosure management strategies in restoring the abiotic ecosystem functions following rehabilitation.

## 1 Materials and methods

### 1.1 Study area and site selection

The Njemps Flats (0°15′–1°45′N, 35°45′–36°30′E)