Agriculture, Ecosystems and Environment 207 (2015) 109–118

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

# Impact of farmland exclosure on the productivity and sustainability of a mixed crop-livestock system in the Central Rift Valley of Ethiopia

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ARTICLE INFO

*Article history:*
Received 12 August 2014
Received in revised form 30 March 2015
Accepted 2 April 2015
Available online xxx

*Keywords:*
Zero-grazing
Biomass trade-off
Smallholder
Land rehabilitation
Sustainable intensification
Collective action

ABSTRACT

Livestock provides numerous benefits to smallholders in sub-Saharan Africa, but also represents a potential agent of environmental degradation. Exclosures have been implemented in grazing areas for the past decades in Ethiopia and have been effective in regenerating natural vegetation, controlling soil erosion and increasing soil fertility. More recently, the principles of exclosure have been applied to farmland in pilot areas of Ethiopia. This paper analyzes the impact of eight years of farmland exclosure in the Central Rift Valley of Ethiopia. The performance of 'exclosed farms' (EF) – in which livestock was excluded from the farmland throughout the year – was compared to the performance of neighboring 'open grazing farms' (OF) – in which fields were open for aftermath grazing in winter. EF and OF had significantly different feed and fuel use strategies. Compared to OF, EF relied less on cereal residues, farmland grass, and livestock dung, and more on biomass produced in the communal grazing area (trees and grass) and tree biomass produced on-farm. Because of these different patterns of feed and fuel use, more biomass – in the form of crop residue, manure and compost – was available as soil amendment in EF. This translated into significantly more fertile soils and significantly higher tef yields in EF as compared to OF ($1980 \pm 644$ kg ha$^{-1}$ in EF *vs.* $1173 \pm 434$ kg ha$^{-1}$ in OF). These results demonstrate that farmland exclosure is a practical pathway toward sustainable intensification. However, attention should be drawn to three points: (1) the approach impacted positively on crop productivity, but had a negligible impact on livestock productivity, (2) EF livestock still depended partially on grazing (outside of the exclosure) for their acquisition of feed, pointing at the fact that zero-grazing *sensu stricto* may not be realistic in semi-arid areas of Ethiopia, and (3) land rehabilitation through controlled grazing may only be feasible in particular geographic locations (*e.g.*, physical barriers preventing outside livestock to access the area, and presence of alternative grazing areas in the vicinity).



## 1. Introduction

In most of sub-Saharan Africa, livestock plays a number of key functions that are crucial to rural livelihoods. These include, to various degrees, the provision of nutritious animal products, the generation of income through the sale of part of these products, the cycling of nutrients through manure, the provision of traction, the multiplication of inflation-proof saving assets, insurance in times of hardship, and the display of status (Fafchamps et al., 1998; Wilson, 2003; Moll, 2005; Rufino et al., 2007; McDermott et al., 2010). However, in many parts of the region where livestock depends heavily on crop residue for feed and where farm size is shrinking, the cost of maintaining livestock is becoming prohibitive (Tegebu et al., 2011). In addition, where its density is high, livestock may be responsible for environmental degradation through heavy grazing, which leads to soil compaction, soil erosion and riverbank erosion (Kauffman and Krueger, 1984; Trimble and Mendel, 1995; Evans, 1998). Heavy grazing may also lead to shifts in vegetation, which are sometimes irreversible, such as woody plant encroachment (Sharp and Whittaker, 2003). In other cases, grazing may lead to loss of tree cover as cattle keepers collect woody material for firewood on a daily basis while herding (Babulo et al., 2008).

Exclosure is a land rehabilitation approach implemented on highly degraded communal grazing areas, by excluding livestock and restricting people's access (Tucker and Murphy, 1997). Excluding livestock reduces the grazing pressure and physical soil disturbance while restricting people's access avoids uncontrolled cutting of trees and grass for fuel and fodder. Over the past three decades, exclosures have been widely implemented in the wet and

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http://dx.doi.org/10.1016/j.agee.2015.04.003
0167-8809/

dry agro-ecological regions of Ethiopia and their impact on the restoration of the native vegetation, the improvement of water infiltration, the conservation of soil through sediment trapping, the improvement of soil fertility, and the conservation of biodiversity is well documented (Argaw et al., 1999; Asefa et al., 2003; Mengistu et al., 2005; Descheemaeker et al., 2006a,b,c; Nyssen et al., 2010; Mekuria et al., 2011; Mekuria and Veldkamp, 2012). Exclosures are cost-effective, as in most cases the rehabilitation is achieved through natural regeneration and additional measures such as conservation structures and tree plantings are only used in few cases to enhance the natural processes (Descheemaeker et al., 2006a). Exclosures may generate direct benefits to communities in the form of increased productivity of fuel and fodder, exploited on a cut-and-carry basis (Mengistu et al., 2005). In addition, new springs may be generated and rivers may flow for a longer period of time as a result of improved rainwater infiltration in exclosures (Descheemaeker et al., 2006b; Nyssen et al., 2010).

However, in areas where exclosures have been adopted, zero-grazing is applied in the communal grazing area but not in the farmland where aftermath grazing (in winter) occurs in most of Ethiopia (Nyssen et al., 2010). Therefore, restriction on biomass use in grazing areas without restrictions on biomass use in farmland may lead to increased grazing pressure on farmland, and result in soil degradation and loss of productivity. The concept of farmland exclosure is an innovative approach tested by the Ethiopian Ministry of Agriculture. It applies the principles of zero-grazing to farmland, with the aim of halting farmland degradation, conserving soil and water, producing more fodder, and improving crop and livestock productivity (Nedessa et al., 2005; Lenaerts, 2013). Zero-grazing compels households to adopt year-round stall-feeding, which may generate additional benefits. In the Kenyan highlands, stall-feeding has contributed significantly to the intensification of dairy production by allowing increased stocking rates (Bebe et al., 2002). Permanent confinement throughout the year not only allows the collection of large quantities of manure, but also of high-quality manure, as collection can be done immediately after excretion, prior to major losses of C and N (Lekasi et al., 1998; Rufino et al., 2007). In Ethiopia, however, year-round stall-feeding is rarely observed in zero-grazing schemes (see *e.g.*,Lenaerts, 2013).

Although, the impact of zero-grazing in communal grazing areas is well documented, studies of its impact in farmland are limited. Thus, this study was conducted in the semi-arid Central Rift Valley region of Ethiopia to examine the impact of farmland exclosure on biomass utilization, soil fertility and its management, crop and livestock productivity, and labor use.

## 2. Materials and methods

### 2.1. Study area

The study was conducted in Edo Tedecha and Waagilo villages, in the Hadegulele catchment of the Central Rift Valley of Ethiopia, located between 39°19′ and 39°22′ East and 8°29′ and 8°32′ North (Fig. 1). The Hadegulele catchment lies between 1500 and 1700 m above sea level. Its climate is semi-arid, characterized by low and erratic rainfall ranging between 500 and 800 mm per year and by high evapo-transpiration rates. The mean minimum temperature ranges from 7.8 to 14.4 °C and the mean maximum temperature ranges from 27.2 to 28.6 °C. The study area is characterized by two clearly defined seasons: a main rainy season from June to October (summer), and a long dry season from November to May (winter). Tef (*Eragrostis tef* (Zucc.) Trotter), maize (*Zea mays* L.), common bean (*Phaseolus vulgaris* L.), and wheat (*Triticum* sp. L.) are the main crops grown. Most farmers keep livestock in the form of cattle, sheep, goats, and donkeys.

At the time of the study, part of the farmland in Edo Tedecha village had been exclosed for eight consecutive years (see exclosure on Fig. 1). The entire farmland of Waagilo village, which is adjacent to Edo Tedecha village, was open for aftermath grazing in winter, following traditional practices. Both villages were characterized by identical sandy soils (Eutric Leptosols), identical climate and identical elevation (see Fig. 1). In 2014, Waagilo was comprised of 122 households (corresponding to 576 inhabitants) and Edo Tedecha was comprised of 184 households (corresponding to 862 inhabitants). The farmland exclosure in Edo Tedecha was occupied by 52 households. Farms in the farmland exclosure of Edo Tedecha village are referred to as 'exclosed farms' (EF) in the rest of the paper, and farms in Waagilo village as 'open farms' (OF).

### 2.2. Data source and sampling

In 2012, a sample of 20 households was randomly selected in the farmland exclosure of Edo Tedecha village (*i.e.*, sampling of 38% of the households in the farmland exclosure). Similarly, 20 households were randomly selected in Waagilo village (open farmland). The head of each household was interviewed using a standardized questionnaire addressing crop production, crop management, livestock management, management of crop residue and other biomass used for feed, fuel, and soil amendment, and labor dedicated to livestock management. The farmland area was measured for each farming household using a hand-held global positioning system (GPS). The presence of trees was also recorded.

A subsample of 24 farms – 12 in the exclosed farmland of Edo Tedecha village and 12 in Waagilo village (open farmland) – was selected and composite soil samples were collected in these farms at a depth of 20 cm. The soil samples were analysed for chemical and physical properties at the National Soil Laboratory in Addis Ababa. Samples were first air-dried for 48 h at 60 °C and then sieved. Organic matter content was measured through oxidation of organic carbon with potassium dichromate in a sulfuric acid medium. Available phosphorus was measured by sodium bicarbonate extraction. Available potassium was extracted using the sodium acetate method and was measured by flame photometer. The sum of exchangeable cations was measured through conductometry. Soil texture was determined using the hydrometer method.

To gain insight into the spatial organization and the history of both villages and to better understand livestock management and the impact of farmland exclosure, two focus group discussions (FGD) were organized: one in Edo Tedecha village and one in Waagilo village. FGD were followed by transect walks through both villages to observe the various land units and better understand the dynamics affecting both villages.

### 2.3. Calculations and data analysis

Yields were calculated by dividing the quantity of grain harvested (as mentioned by farmers during the household interview) by the area of the corresponding field (as measured using a GPS) and multiplying it by 0.9 (the estimated dry matter content of the grain harvested). To compare livestock density in the two villages, the livestock numbers reported in the survey were converted into Tropical Livestock Units (TLU), using a value of 250 kg live weight for 1 TLU (Le Houérou and Hoste, 1977). Following the method of Jahnke (1982), sheep and goats were assumed to be equivalent to 0.1 TLU, donkeys 0.5 TLU, and all types of cattle to 0.7 TLU.

Data was tested for normal distribution using Kolmogorov–Smirnov tests. Means of quantitative data following a normal