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Management of harvested C in smallholder mixed farming in Ethiopia

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ABSTRACT

Increasing the share of the harvested C ending up in food and returned to soil could contribute to climate change mitigation and food security. The aim of this study was to quantify empirically the proportion of the harvested C ending up in food and soil and the C losses occurring when managing harvested C in smallholder mixed farming systems in Ethiopia. Four case farms were explored; one resource-limited and one better-off farm, in two socio-ecologically contrasting regions important for food production. Material flow analysis (MFA) was used to determine the flows of harvested C. The losses of harvested C, from the livestock, compost and household energy use were quantified based on C balances. The C flows were estimated as means for two growing seasons, 2008/2009 and 2009/2010, with low and average precipitation, respectively. Analysis was founded on semi-structured interviews and sampling, supplemented with information from databases and the literature. From the total harvested C, 9–16% was allocated to food and 4–12% to agricultural soil. Since the residues are utilized apart from human excreta with a negligible significance, increasing the proportion of harvested C used for food and returned to soil is in these farming systems only possible by reducing the gaseous C losses. The largest losses of the harvested C occur through biomass burning (15–60%), animal metabolism (16–44%) and composting (5–23%). The large C loss through the replaceable residue burning seems to offer the most accessible remedy to smallholder management of harvested C. Consequently, the proportion of harvested C used for fuel appears as the main determinant for the proportion of harvested C ending up in soil and food. Energy substitutes for manure and straw, improved manure management and more stable food and fodder supply to reduce the requisite number of animals are all keys to close C cycles in the farming systems. Quantification of the organic C flows using MFA is useful in revealing the allocation of harvested C and losses occurring in its management in farming systems when measurement of gaseous emissions and leaching are not feasible.

1. Introduction

Climate change poses a threat to food security in sub-Saharan Africa (SSA), where economies are highly dependent on agriculture (IPCC, 2007). Thornton et al. (2011) estimated a 24–71% decrease in crop yields by 2090, and in places a shift from crop production to livestock husbandry, although these figures imply a high degree of uncertainty. Simultaneously, high population growth and soil degradation exert pressures to increase agricultural productivity. Carbon (C) sequestration in agricultural soils has the greatest potential to mitigate climate change in SSA agriculture (Smith et al., 2008), and to increase agricultural productivity (Lal, 2004). In farming systems, food security and C sequestration can be enhanced by allocating a high share of harvested C to food and agricultural soil. Such development can be contributed to by reducing C losses before harvested C ends up in food or soil.

In agriculture, carbon dioxide (CO_2) is assimilated during photosynthesis in crops and rangelands. Part of this C is released back into the atmosphere during plant and soil respiration or fire, part of it being stored in soil organic matter (SOM) and in harvested biomass and animal products, and part being liable to erosion and leaching as dissolved organic and inorganic carbon and methane. Biomass C is harvested as crops and through grazing of livestock and collecting fuel wood. Harvested C can also be imported into the farm as fodder, food, fuel, construction material and organic soil amendments. The quantity of harvested C lays the ground for availability of food and soil amendment, but there are also other competitive uses for these resources.

Agriculture in Ethiopia is characterized by low-input and low-output production (Devereux, 2000). The pressure to satisfy the need of the growing population for food and fuel has decreased holding size, intensified agriculture, and reduced forest cover

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(Bationo et al., 2007; Pohjonen and Pukkala, 1990) to a current 4% of the land area (Berhanu, 2005). The decrease in forest resources has led to the use of dried cow dung for fuel, while crop residues are mainly used as fodder for livestock (Corbeels et al., 2000). Therefore, return of residue C to the soil is reduced, which in turn reduces soil productivity.

Allocation of a higher share of harvested C in food would directly improve food security. Further, returning a higher share of harvested C not used as food to soil would contribute to increasing soil C storage (Girmay et al., 2008) and improve soil nutrient supply and water holding capacity, and consequently soil productivity and stability of food supply (Lal et al., 2011).

About 72% of greenhouse gas (GHG) emissions in Ethiopia originate from agriculture (WRI CAIT, 2013). Most of the emissions comprise methane (CH_4), enteric fermentation being the largest source, totalling 28,077,000 tonnes of (CO_2) equivalent (Tadeke, 2001). More than twice as large emissions occur in biomass burning in households totalling over 66,000,000 tonnes of CO_2 (Tadeke, 2001). Emissions from bioenergy are not, however, added to inventories of national emissions reported to UNFCCC as they are considered "carbon–neutral", corresponding to the amount of C bound from the atmosphere in photosynthesis (Metz, 2007). On farms, however, fuel use and soil amendment compete for the scarce resource of residue C.

Material flow analysis (MFA) (Brunner and Rechberger, 2004) allows direct tracing of C material flows and indirectly also the gaseous losses from these flows through C balance counting, and thus quantification of the proportion of harvested C used for food and soil. Such analysis provides valuable information that further research can exploit to assess the impacts of changes in C management practices on household welfare and potential to sequester C. Such a C budget approach has strengths and weaknesses analogous to those of nutrient budget approaches (Oenema et al., 2003; Öborn et al., 2003), an important strength being accessibility of the primary data to the researcher. To date, there are few empirical data on the use of harvested C for food and soil amendment, or about the potential to improve the resource-use efficiency in farming systems. To our knowledge, organic C flows and C losses in East African farming systems have not been studied before. Empirical quantitative case studies of the flows of harvested C and losses occurring in its management in Ethiopian farming systems provide in-depth understanding of the use of this valuable, scarce resource and of the significance and causes of the various losses.

The aim of the study was to increase understanding about the potential to enhance the use of harvested C for food and soil amendment on mixed smallholder farms in East Africa. The examination focused on the losses of harvested C reducing the share ending up in food and soil. The following research questions were posed: What is the proportion of harvested C allocated to food and soil in smallholder mixed farming systems in the Ethiopian highlands? What are the major losses of harvested C reducing the proportion allocated to food and soil? What are the determinants for the proportion of harvested C used for food and soil and of the C losses? The usefulness of MFA to indicate C the proportion of the C use and C losses in farming systems was also discussed. Smallholder mixed case farms with Good Agricultural Practices (GAP) (FAO, 2003) in the Ethiopian highlands, with limited and greater resources were studied in two regions contrasting in agroecological and socioeconomic conditions.

2. Materials and methods

An instrumental case study approach was used, where the cases were explored to understand causal relations and mechanisms of the phenomenon (Creswell, 2007; Stake, 1995). Documents and data from the national and local archives and agricultural offices were used in addition to interviews, sampling and published literature (Yin, 2003). Two representative but contrasting case regions and two farms in each region were selected for this collective study (Stake, 1995) to facilitate generalization (Yin, 2003).

2.1. Case characteristics

The topography of Ethiopia varies since the East African Great Rift Valley divides the high plateau diagonally. The Ethiopian economy relies on agriculture, which accounts for 43% of total GDP (CountrySTAT, 2012) and employs 85% of the population (CIA, 2012). Around 60% of Ethiopian farms cultivate less than 0.9 ha and 40% less than 0.5 ha (Taffesse et al., 2011). The present study was carried out in Kobo, on the border of the cool semi-arid and warm semi-arid agroecological zones, and Sire, on the border of cool semi-arid and cool sub-humid agroecological zones (Harvest Choice/IFPRI, 2009), on the slopes of the Great Rift Valley (Fig. 1). The sites represent relatively food-insecure and food-secure regions of Ethiopia, respectively (See Appendix A). Kobo is characterized by severe soil degradation and low soil fertility, small land holding size, high water stress and low crop yields compared with Sire (World Bank, 2004) (Appendix A). Low income, due to lack of off-farm employment opportunities, has worsened poverty and hindered access to food. At the turn of the 21st century the number of people receiving food aid ranged between 27% and 50% of the total population (Ali, 2002). Sire represents an area of greater potential for food production as it has higher precipitation and more land available. Both districts represent important food production areas in Ethiopia (Taffesse et al., 2011). Due to local variation in precipitation and lack of weather station data for rainfall intensity we relied on farmer descriptions (Regassa et al., 2010) of the annual weather relative to the long-term average (Appendix A). According to farmers, 2008/2009 was low and 2009/2010 average in precipitation, on all of the case farms.

Highland temperate mixed farming prevails in both case regions. It is the most common farming system type in Ethiopia and is conducted on approximately a third of the land area, a share similar to that allocated to pastoralism. In East Africa this farming system covers 5% of the land area (Dixon et al., 2001; FAOSTAT, 2011). Livestock represents financial security, draft power, transportation, fuel and cultural values. Animals graze freely on communal rangeland and on field plots after harvesting. Poor livestock nutrition due to lack of forage limits productivity and increases emissions per product unit. In Kobo, subsistence production dominates and is constrained by erratic rainfall and lack of inputs. In contrast to Sire, sorghum (*Sorghum bicolor* L.) is widely cultivated in Kobo for its drought tolerance. In Sire, crop rotations are more diverse than in Kobo, and include cash crops such as pulses and vegetables. Agroforestry is practised around the homesteads on many farms. The agroecological and socioeconomic characteristics of the case regions were described in detail by Kahiluoto et al. (2012).

As available resources substantially influence the use of inputs in cropping (Mwaniki, 2005), in each of the two regions we selected one case farm with limited resources and another with greater resources, compared with the average for the district (Table 1). Farmers with limited resources participated in the Productive Safety Net Programme, a social protection scheme under the national Food Security Program, addressing chronically food-insecure people (Negatu, 2008). Better-off farms with greater resources had more field area and livestock and more advanced agroecological management practices than on average for the region. All four case farms applied GAPs (Table 1). Farms representative of size, number of livestock, degree of food aid, and applied management were selected from within each of the