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Feeding, crop residue and manure management for integrated soil fertility management – A case study from Kenya

A. Castellanos-Navarrete [a,*], P. Tittonell [b], M.C. Rufino [c,1], K.E. Giller [a]

[a] Plant Production Systems, Wageningen University, P.O. Box 430, 6700AK Wageningen, The Netherlands
[b] Farming Systems Ecology, Wageningen University, P.O. Box 563, 6700AN Wageningen, The Netherlands
[c] Livestock Systems and the Environment, International Livestock Research Institute (ILRI), Kenya

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ABSTRACT

Western Kenya is one of Africa's most densely populated rural areas, characterised by intensive smallholder crop–livestock systems on degraded lands managed with small inputs of mineral fertiliser and animal manure. Competing uses for crop residues and other organic resources often results in poor nutrient cycling efficiencies at farm scale. Modifying livestock feeding, retaining more crop residues in the field, and improving manure management can help conserving considerable amount of nutrients on-farm. To examine to what extent such strategies would be feasible, we analysed whole-farm nutrient cycling efficiencies (NCE) of a range of farms differing in resource-endowment and production orientation, identifying the most efficient farmer strategies considering labour and financial constraints. Nutrient concentration in excreted cattle manure was relatively small (i.e., N < 1.7%; P < 0.6%). Current manure management practices led to low NCE's (average 27%) due to nutrient losses from excretion through storage and application. Farmers have few incentives to improve manure management given the small amounts of excreta and nutrients to be recycled. Yet, manure, both composted and fresh, represented the greatest N (16 kg ha^{-1} season^{-1}) and C returns to the soil (312 kg C ha^{-1} season^{-1}). Retention of crop residues was the cheapest source of nutrient inputs for the next crop, especially when compared with manure, but farmers prioritised its use for cattle feeding. Our findings highlight the critical lack of nutrients and organic residues on smallholder farms in the densely-populated highlands of East Africa, as well as low NCE when it comes to manure. In these conditions, efficient nutrient cycling for manure and improved cattle feeding are essential to increase use efficiencies of any possible external nutrient added in these farms.

1. Introduction

Western Kenya is one of the most densely populated rural areas in the East African highlands. Farmers face poor soil fertility on very small crop–livestock farms (i.e. average 0.5 ha in Vihiga; Kiptot et al., 2007) leading to poor yields of the staple crop, maize (i.e. 1.2 t ha^{-1}; Tittonell, 2008). Agricultural intensification is constrained by poor availability of nitrogen (N) and phosphorus (P) from the soil caused by continuous cropping with little, if any, mineral nutrient inputs (Shepherd et al., 1997; Tittonell et al., 2005b). Integrated soil fertility management (ISFM), which combines inorganic and organic inputs with the use of improved germplasm, is advocated to address these problems (Vanlauwe et al., 2010). Increasing nutrient cycling efficiencies (NCE), or the ratio of recycled nutrient output to input, is a key component of ISFM. The main organic inputs in these farms are livestock manure and crop residues, but the intensive cut-and-carry livestock feeding commonly practiced in the region means that little crop residue is returned to the soil. Given the small rates of inorganic fertiliser used (i.e. <20 kg ha^{-1}; Tittonell et al., 2005c), and the competing uses for crop residues, manure management has gained a prominent role in ISFM strategies (Bationo, 2004). Yet there is little information on how NCE is modified by cattle feeding and manure management, and what constraints smallholder farmers face to achieve efficient nutrient recycling between cattle and soils.

* Corresponding author. Current address: Knowledge, Technology and Innovation Group (KTI), Wageningen University, Hollandseweg 1, 6706KN Wageningen, The Netherlands. Tel.: +31 317 482776; fax: +31 317 485616.
E-mail address: antoniocene@gmail.com (A. Castellanos-Navarrete).
[1] Current address: Centre for International Forestry Research (CIFOR), Forest and Environment programme, Eastern and Southern Africa Regional Office, c/o World Agroforestry Centre United Nations Avenue Gigiri, P.O. Box 30677-00100, Nairobi, Kenya.

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Cattle constitute an efficient way of adding value to crop residues through increasing the nutrient content in manure per unit of mass (Rufino et al., 2006). Also, farmers can reduce the amount of nutrients lost from manure by adding crop residues as bedding or organic waste to stored manure. Thus, from a nutrient cycling perspective, whether crop residues should be better kept in the field or fed to livestock depends largely on the efficiency of nutrient cycling through the animal sub-system. There is evidence that farmer practices often lead to poor NCE through livestock. For instance, overall nitrogen cycling efficiencies in smallholder African farms have been estimated to be 44% under optimum conditions but less than 1% in the worst-case combinations of cattle feeding, manure handling and crop response (Rufino et al., 2006). Knowledge on how farmers' manure collection and storage practices modify quality and mass losses compared with crop residue retention is thus crucial to identify possible NCE improvement pathways, as well as to inform current efforts for increased residue mulching and zero tillage (also known as conservation agriculture) in resource-constrained smallholder farms (Giller et al., 2009; Valbuena et al., 2012).

While research has explored the importance of organic resource quality (Lekasi et al., 2003; Palm et al., 2001), there is less knowledge on how labour investments, economic efficiency, and farmer preferences shape nutrient management. For this purpose, resource endowments have to be considered along with farm production orientations (Tittonell et al., 2005b). Livestock production goals (e.g. sale of animal products, financial insurance) are known to strongly modify cattle management strategies and therefore both manure management (Rufino et al., 2006) and competitive uses for crop residues (Schiere and De Wit, 1993). In this study we hypothesised that biomass allocation, and the NCE achieved, can be better explained by considering both farm-level resource endowments as well as the economic and productive role played by cattle on smallholder farms. To test this hypothesis, we: (i) quantified the NCE of crop residue and manure management on a range of farms differing in their financial and labour resources and production orientations; and, (ii) examined strategies to increase nutrient inputs into soils considering labour and financial investments. Our research was designed to strengthen current efforts to identify windows of opportunity to improve NCE in smallholder agriculture in Africa.

2. Materials and methods

2.1. Site characterisation

The study was carried out in Emuhaya division (0°4′N; 34°38′E) in western Vihiga district. This is a high agricultural potential area (Jaetzold and Schmidt, 1982) given average temperature and rainfall (i.e., 20.4 °C and 1850 mm with bimodal distribution allowing maize double-cropping) and a relatively flat landscape (2–15%) at 1640 m.a.s.l. However, continuous cropping with little inorganic inputs in these intensively weathered low-saturated red soils (i.e., Nitosols and Ferralsols) have led to strong nutrient deficiencies (Tittonell et al., 2005b).

Emuhaya, land to the Luhya ethnic group, has on average 930 inhabitants km^{-2} (Tittonell et al., 2005b) as a result of population growth and historical patterns of land distribution (Crowley and Carter, 2000). Production systems are rainfed, maize-based crop–livestock systems with small plots of cash crops (i.e., tea, Napier grass, sugar cane and woodlots). Despite intensification, over 60% of farms are food insecure and off-farm employment is key for 80% of the households (Tittonell et al., 2005b). Wealthy farmers, with better education and social capital, are able to access skilled or semi-skilled employment and invest in their farms (e.g. through purchasing land or livestock upgrading or hiring labour). By contrast, poorer household migrants resort to unskilled positions providing smaller, if any, remittances. This forces migrants' families to sell their labour to cover for absent males for minimum returns and leads to labour shortages on their own farms (Crowley and Carter, 2000; Tittonell et al., 2005b).

2.2. Crop–livestock systems

Crop–livestock farms predominate in western Kenya (71% for Vihiga; Waithaka et al., 2002), with the poorest households lacking cattle. Most farmers own Zebu (*Bos indicus*) cattle with wealthier farms having cross- and even pure-breeds (i.e., Jersey, Ayrshire and Friesian). Given the absence of common lands, all farmers in Emuhaya rely on cut-and-carry fodder systems, with some grazing on fallow land, roadsides or other small public areas. Small land sizes limit cattle herds to 1–2 heads on average. Under these conditions, 87% of the farms in Vihiga report recurrent cattle feed shortages (Waithaka et al., 2002). Given the small farm sizes, cattle are fed fodder in the home compound (when tethered on-farm) or in feeding troughs (zero-grazing units). Zero-grazing units in the region are commonly semi-open constructions with partial metal roofs and with soil, wood or concrete floors. Cattle also feed by grazing on compound grass, normally kikuyu grass (*Pennisetum clandestinum*). To avoid theft, cattle are stalled at night in the homestead or in enclosed zero-grazing units if available.

Regarding manure management, faeces are collected when cattle graze in the home compound or are stall-fed. Manure is normally added to heaps or pits located in the home garden, to which other organic materials are also added. After storage, manure is applied in the fields and incorporated using a *jembe* (hand hoe), or added into planting holes. Manure is usually applied to home gardens and close or mid-distance maize fields resulting in gradients of decreasing soil fertility with distance from the homestead (Crowley and Carter, 2000; Tittonell, 2008).

2.3. Case study selection

Resource endowment, production orientation and main production constraints were the criteria used for selecting case study farms. Once criteria were established based on published studies (Waithaka et al., 2002) and grey literature (e.g. TSBF databases) and possible sub-locations chosen, 25 farms away from both the road network and village centres were characterised to select a group of representative farms. Household resource endowments and livestock production systems were characterised through semi-structured interviews carried out in both home compounds and cropping fields. These criteria helped us to identify key strategies for cattle management. As our study was designed to characterise contrasting cattle management in depth, requiring intensive data collection at each individual farm, a sub-sample of 10 case study farms was selected based on cattle management and farmers' willingness to participate.

2.4. Cattle management: a range of strategies

Cattle management strategies were analysed in relation to household wealth, livestock production orientation and the farm development cycle (Fortes, 1949; cited by Crowley, 1997). Classifications based solely on resource endowments have been found to be a poor proxy for resource allocation patterns (Tittonell et al., 2005b). By considering production orientations, we identified three major strategies, also reported by Schiere and De Wit (1993). First, labour- and capital-constrained households had as their main production goal to maintain herd sizes for distress sales or social obligations (e.g. dowry, funerals, etc.), and adjusted