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Resource use efficiency and farm productivity gaps of smallholder dairy farming in North-west Michoacán, Mexico

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ABSTRACT

Smallholder dairy farms that intensify production risk resource degradation and increased dependence on external feeds and fertilizers due to lack of knowledge and appropriate technology, which undermines farm productivity and profitability. Here we analyze underlying causes at farm level of such process through an integrated analysis at the farm scale by assessing current resource use efficiency for grazing-based dairy farming systems representative of NW Michoacán, Mexico. Whole-farm yield gaps were quantified by comparing current farms to virtual reference farms that have the same farm surface area but improved farm management. Productivity of reference farms was calculated by assuming best crop production practices (as observed within the set of case study farms) and improved herd management. Three family-based (FB) and three semi-specialized (SS) dairy systems spanning three levels of intensification in terms of density of livestock units (LU): extensive (E, <0.8 LU ha^{-1}), medium-intensive (M, between 0.8 and 1.2 LU ha^{-1}), and intensive (I, >1.2 LU ha^{-1}) were monitored during one year (rainy and dry seasons) to assess productivity and resource use efficiencies. Milk production was generally low and variable (2.2–4.3 Mg milk cow^{-1} $lactation^{-1}$, and 0.6–5.8 Mg ha^{-1}) due to high incidence of mastitis, a large fraction of non-productive animals in the herd and inefficient reproduction management. During the dry season, grazing areas provided insufficient metabolizable energy, and milk production was sustained through increased use of concentrates (from 310 g kg^{-1} DMI in rainy season to 454 g kg^{-1} DMI^{-1} in dry season of the herd) and conserved forage. All farms had positive nitrogen, phosphorus and potassium balances, averaging 75 ± 16, 15 ± 6, and 19 ± 6 kg ha^{-1}, respectively. Nutrients in animal excreta were mostly not recycled on the farms but lost to the environment, and nutrient surpluses increased with livestock density. The reference farms exhibited an attainable milk yield of 2.7 Mg ha^{-1} on the basis of full feed self-supply, and 4.2 Mg ha^{-1} when the crude protein limitation in the ration was lifted. Compared to the reference farm actual milk yields were on average 78.4% lower on FB farms and 57.9% lower on SS farms. The underlying causes of the farm yield gap differed between farms and were due to sub-optimal areas of forage maize, low forage and forage maize productivity and deficient herd management. We conclude that the farm yield gap analysis was effective in identifying the major shortcomings in management of the dairy farming systems and enabled formulation of change avenues for farm reconfiguration focusing on combined improvements in crop, feed and herd management and recycling of nutrients through manure management.

1. Introduction

Although smallholder farms produce a large share of the world's food supply and their production systems could potentially be diverse and sustainable, market and policy developments force them to intensify their production in order to compete with larger specialized farms (Kiers et al., 2008; Herrero et al., 2010). This often leads to an 'intensification-trap': in order to increase productivity small farmers intensify their production systems by increasing livestock density and inputs, but inadequate

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management results in larger nutrient surpluses or losses, farm resource degradation and strong dependence on external feeds and fertilizers.

The intensification trajectories of dairy farms in the northwest of Michoacán (Mexico) are a point in case. In this region where dairy production is an important economic activity, nutrient surpluses from livestock systems resulting in nutrient runoff and leaching are considered to be a major cause of negative environmental impacts on the 'Lerma – Chapala' basin. In Lake Chapala, the largest fresh water lake of Mexico, high concentrations of N and P compounds (2.23 and 0.57 mg l^{-1}, respectively) hamper the use of water resources for human consumption and irrigation (Silva et al., 2002; Ramírez et al., 2007). In the lowest part of the basin, continuous use of saline groundwater has increased the salinity and sodicity of the soil, limiting crop production and impacting soil management (Silva-García et al., 2006).

In addition to these environmental impacts, profitability of local production systems is cause for concern, mainly related to the high feed costs and the low milk productivity in the systems (Espinoza-Ortega et al., 2005; Cortez-Arriola et al., sumitted for publication). Most livestock feeding systems in Mexico depend on the use of concentrates, conserved forage, and grazing land. In Mexico forage production during late spring and summer (the rainy season in most of the country) contributes between 60% and 79% to the total annual forage production (Améndola et al., 2005; Martínez et al., 2008; Sosa et al., 2008). Farmers address potential periodic forage shortages via the use of largely imported conserved forage (silage, hay and stover) or concentrates (Améndola et al., 2005; Cortez-Arriola et al., sumitted for publication). However, these options increase the dependence on external feed resources: 70% of the ration and represents up to 90% of the feeding costs. As a consequence farm profitability is reduced (Espinoza-Ortega et al., 2005; Cortez-Arriola et al., sumitted for publication). On the other hand, animal productivity is a key variable to enhance the milk production in Mexico and the profitability of farming. In the period from 2004 to 2010 the average production was only 1.65 Mg milk cow^{-1} $lactation^{-1}$ (SAGARPA, 2011). In contrast, in The Netherlands and Italy where feeding is mainly based on own forage production with low contribution from external inputs in feeding costs (ca. 18% of the total costs) production levels were 7.6 and 6.7 Mg milk cow^{-1} $lactation^{-1}$ (European Comission, 2011).

Efforts to develop more sustainable intensification trajectories may benefit from interventions based on yield gap analysis at the farming system level. To diagnose differences in performance among farms that operate under similar climatic conditions and natural resource availability, farm yield gap analysis is relevant to identify the most limiting and reducing factors that determine the yields and to find adjusted practices that could contribute to closing the gaps. Usually, yield gap analyses are conducted to determine differences between attainable and actual crop yields in cropping systems (Bhatia et al., 2006; Nin-Pratt et al., 2010; Van Ittersum et al., 2013). To narrow the gap, field crop production practices such as use of fertilizers, establishment of irrigation systems, and genetic improvements may then be proposed. In more complex agro-ecosystems such as mixed crop-livestock systems, a large farm yield gap can originate from shortcomings related to farm design, resource allocation and tactical planning. The resulting imbalances between feed supply and herd size combined with lack of effective herd management practices thus may hamper optimal use of forage resources and prevent farmers from attaining the production potential of livestock.

Here, we present a method to diagnose farming systems by constructing a virtual farm based on best existing local practices and use this as a reference to assess the farm yield gap and the contribution of constraints in the various sub-systems. We quantitatively analyze six dairy farms that represent the variation of dairy farming in the region of Marcos Castellanos, Michoacán, Mexico (Cortez-Arriola et al., sumitted for publication). Furthermore, we assess how farm management affects annual metabolic energy (ME), crude protein (CP), and N, P, and K balances. The objectives of this paper are: (a) to quantify the gap between attainable and current farm milk yields taking a whole farm perspective, (b) to diagnose the major factors that limit productivity of dairy farming systems in NW Michoacán; and (c) to analyze how management affects farm gate nutrient balances and use efficiency of nutrients.

2. Material and methods

2.1. Case study region

The municipality of Marcos Castellanos is located in the Northwest of Michoacán, Mexico, (19° northern latitude and 103° west longitude) at altitudes between 1500 and 2400 m above sea level. According to the classification of Mexican hydrological regions it is located in the upper part of the 'Lerma – Chapala' basin, in the sub-basin 'Chapala', and in the micro-basin 'San José de Gracia'. The area of the municipality is 23,285 ha, representing 0.39% of the State; 86% of the area is grazing land (mainly native rangeland) and 12% is cropland, mostly used for forage maize production (Secretaría de Gobierno, 2010). The climate is classified as temperate with one main rainy season between June and October. Overall precipitation and temperature averages are 798 mm and 18.9 °C, respectively. Chromic and pellic Vertisols are the dominant soil type, in associations with Luvisols, Inceptisols, Phaeozems, and Andosols (SEMARNAT, 2003). The physiography is constituted by slightly sloping hills ending in ravines, and small almost flat areas. Thorny forest is the dominant type of vegetation, followed in importance by broadleaf forest (SAGDER, 2000).

2.2. Selection of farms representative of regional farming systems

During 2007 a survey was carried out in the region, which was used to develop a farm typology presented elsewhere (Cortez-Arriola et al., sumitted for publication). From the total of 630 farms listed in the census of the regional association of dairy farmers, 14.6% were randomly selected and interviewed. Multivariate analysis of the survey data resulted in six main farm types, distinguished by the use of family versus hired labor and the intensity of production, in particular cattle densities. Based on these farm types and the national Mexican dairy farm classification (FIRA, 1997; SAGARPA, 2000; Amendola, 2002), six farms were selected for more detailed study. These farms are being referred to as family-based (FBx) or semi-specialized (SSx), where x describes the intensification level based on livestock density as E (extensive, <0.8 LU ha^{-1}), M (medium-intensive, between 0.8 and 1.2 LU ha^{-1}) or I (intensive, >1.2 LU ha^{-1}) (Table 1).

2.3. Farm characterization

In order to characterize each individual farm, close monitoring of system management and agro-ecological parameters took place between July 2009 and June 2010. At the crop subsystem level, information was collected on forage production, quality, utilization, inputs, and production costs. At the animal subsystem level, data were obtained pertaining to herd structure, milk production and composition, animal body weight and condition score, quality and intake of feedstuffs, and sanitary and reproductive management.

To determine soil physical and chemical properties and soil losses in grazing and cropping lands, soil sampling and runoff measurements were carried out during the rainy season on two selected farms. Following the Benchmark sampling design (Pennock