Impacts of the agro-ecological techniques on soil nutrient- and C-balance in rainfed cropping systems in the highlands of Madagascar

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INTRODUCTION

In the Vakinankaratra region of Madagascar, the development of rainfed upland crops is a consequence of land pressure. Moreover livestock, especially dairy cattle, is developed in this region. Consequently, upland fields are also used to produce forages for dairy cattle feeding. Farmers cultivate their fields with less and less fallow period and try to compensate the nutrients' export through biomass and grain by organic manure and rarely mineral fertilizer. However, soil fertility tends to decrease. With an expensive price of agricultural inputs (mineral fertilizers, concentrates feeds), the most important for farmers is to reduce their dependency. All the actors of development and research agricultural organizations advice farmers to use resources available on farms, to promote recycling and to limit losses (FAO, 2102). However, only few researches are interested on improving the manure fertilizer value and nutrient conservation (Salgado *et al*., 2002). The aim of our study is to evaluate the effect of the conservation agricultural (CA) practices combined with manure improvement on reducing nutrient losses to maintain soil fertility in the long-term and consequently to improve animal and vegetable productions. The objectives of this paper are: (1) to compare the biomass production from different agro-ecological innovations with different fertilizer treatments; (2) to estimate N and C supply to soil according to the management of biomass export; (3) to evaluate biomass management on animal performance.

MATERIALS AND METHODS

This study was carried out in the highlands of Madagascar. The area has a tropical altitude climate, characterized by a hot rainy season from November to April and a cold dry season from May to October. The hillside soils are ferralsols (Razafimbelo *et al.*, 2010). We compared CA cropping systems and conventional tillage systems. Both techniques were conducted on two sites: (1) research station and (2) farmer's fields. Only results from research station are reported here.

Three cropping systems were compared: (1) a rotation between upland rice (cultivar *Chomrong Dhan)* followed by maize (local cultivar Tombontsoa) intercropped with

Crotalaria grahamiana with no-tillage and residue retention (CA) (R-MC), (2) a rotation between rice followed by maize intercropped with common bean (*Phaseolus vulgaris*) under conventional tillage (CT) and no residue retention (R-MB), and (3) a rotation between rice followed by oat (*Avena sativa*) intercropped with vetch (*Vicia villosa*) with no-tillage (R-OV). Each year the two components of the rotation (*i.e.* crops of year 1 and crops of year 2) were cultivated, meaning that three biannual rotations give six plots for each level of fertilization and each replicate. Four fertilizations' levels were used: (1) no fertilizer (F0), (2) fertilization with manure produced by conventional management techniques (FuC) at 5 t ha^{-1}, (3) fertilization with improved cattle manure (FuA) at 5 t ha^{-1}, and (4) conventional cattle manure at 5 t ha^{-1} plus mineral fertilizer (NPK 11-22-16; 100 kg ha^{-1}). Only results from two fertilization's levels (F0 and FuA) are reported here.

Above- and below-ground biomasses were measured on each unit plot at flowering and maturity stages. Below-ground biomass was collected from 0 to 180 cm according to plant species, with the soil core method. Above-ground biomass was determined on a 5m x 5m plot in the middle of fields. C and N content and forage nutritive value were inferred from literature (FIFAMANOR *et al.*, 2011; Feedipedia, 2014; Naudin *et al.*, 2012).

For this paper we have simulated three different management options for plant residue to mimic the use of plant biomass as forage: 0, 50 and 100% of crop residue removal. Table 1 presents the method used to calculate forage nutritive value and C and N remained in the soil according to the biomass export rates.

Table 1: Method to calculate the forage nutritive value and the amounts of C and N remained in the soil according to the biomass export rates

	R-MC			**R-MB**			**R-OV**		
Biomass export	**0%**	**50%**	**100%**	**0%**	**50%**	**100%**	**0%**	**50%**	**100%**
Productions	1 = Rice and maize grain 2 = Rice and maize straw 3 = Residue of *Crotalaria grahamiana* 4 = Below ground			1 = Rice and maize + bean grain 2 = Rice and maize straw + residue of bean 3 = Below ground			1 = Rice grain 2 = Rice and oat straw + oat and vetch green forage 3 = Below ground		
Production of grain	100% of 1	100% of 1	100% of 1	100% of 1	100% of 1	100% of 1	100% of 1	100% of 1	100% of 1
Forage nutritive value	No export	50% of 2	100% of 2	No export	50% of 2	100% of 2	No export	50% of 2	100% of 2
C and N remained in the soil	100% of 2 + 3 + 4	50% of 2 + 100% of 3 + 4	100% of 3 + 4	100% of 2 + 3	50% of 2 + 100% of 3	100% of 3	100% of 2 + 3	50% of 2 + 100% of 3	100% of 3

Anova analysis of data was performed with XL-STAT.

RESULTS AND DISCUSSION

The quantity of forage production and the C and N supply to soil depends on the management biomass exports, whereas grain production is the same for all the biomass export rates. Rice yields and cover crop grains with FuA increased respectively 5% and 53% on R-MC, 19% and 26% on R-MB, and rice yields increased 2% on R-OV compared to productions with F0 (Figure 1). The significant difference between crop yields can be explained by the quantity and quality of fertilizer inputs. Improved management of manure decreases N losses during manure storage and consequently increases nutrients contents in manure (2.6% N, 1.2% P and 4.1% K) with a positive impact on agricultural production (Ruffino *et al.,* 2005; Alvarez *et al*., 2013; Salgado *et al*., 2012).

Firstly, with 0% export residues, R-MC stored from 4.88 t ha^{-1} (F0) to 6.46 t ha^{-1} (FuA) of C and 0.22 t ha^{-1} (F0) to 0.28 t ha^{-1} (FuA) of N (Figure 1). The quantities of C and N stored were lower on R-MB and R-OV systems compared to R-MC. Between R-MC and R-MB, we observed a decrease of 38% (F0) and 24% (FuA) for C stored and a decrease of 71% (F0) and 56% (FuA) for N stored. Between R-MC and R-OV, the decreases of C and N were respectively 37% with F0, 50% with FuA and 49% with F0, 66% with FuA. The high quantity of C and N supply to soil on R-MC can be explained by the capacity of *Crotalaria grahamiana* to produce large amount of biomass (Smestad *et al.*, 2002). In addition, the amounts of C and N supply to soil were always lower with F0 compared to FuA.

Secondly, with total export biomass (100%), the R-MB system produced the highest forage nutritive value (from 3 178 UFL DM ha^{-1} with F0 to 4 286 UFL DM ha^{-1} with FuA, and from 338 10^3 t protein DM ha^{-1} with F0 to 459 10^3 t protein DM ha^{-1} with FuA). R-OV system produced less UFL (15% and 20% for F0 and FuA, respectively) and less protein (6% and 12% for F0 and FuA, respectively). The differences were much higher with R-MC system (approximately 49% and 43% less UFL and protein, respectively between each fertilizer). The forage production with R-MC system was lower because *Crotalaria grahamiana* was used only to produce biomass for the next crop.

Thirdly, partial export biomass (50%) can produce grain, forage and the remain N and C are stored in the soil. R-MB provided a better return of grain (rice or maize and bean) and forage nutritive value for each fertilizer treatment compared to R-MC or R-OV systems. Contrarily, it generated lower quantity of C and N supply to soil regardless of the fertilizers than R-MC. Compared to R-OV system, with F0, R-MB stored in the soil less 15% and 43% of C and N, respectively, whereas with FuA, the C and N supply to soil increased 41% and 26%, respectively. The statistic analyze showed no difference on forage nutritive values with 50 and 100% biomass export under FuA treatment. In addition, no significant difference was observed between the amount of C and N remained in the soil with 0% biomass export and 50% export with FuA. In fact, partial residues remained in field are enough to cover the soil and given the same effect in C and N inputs with total biomass remained in fields.

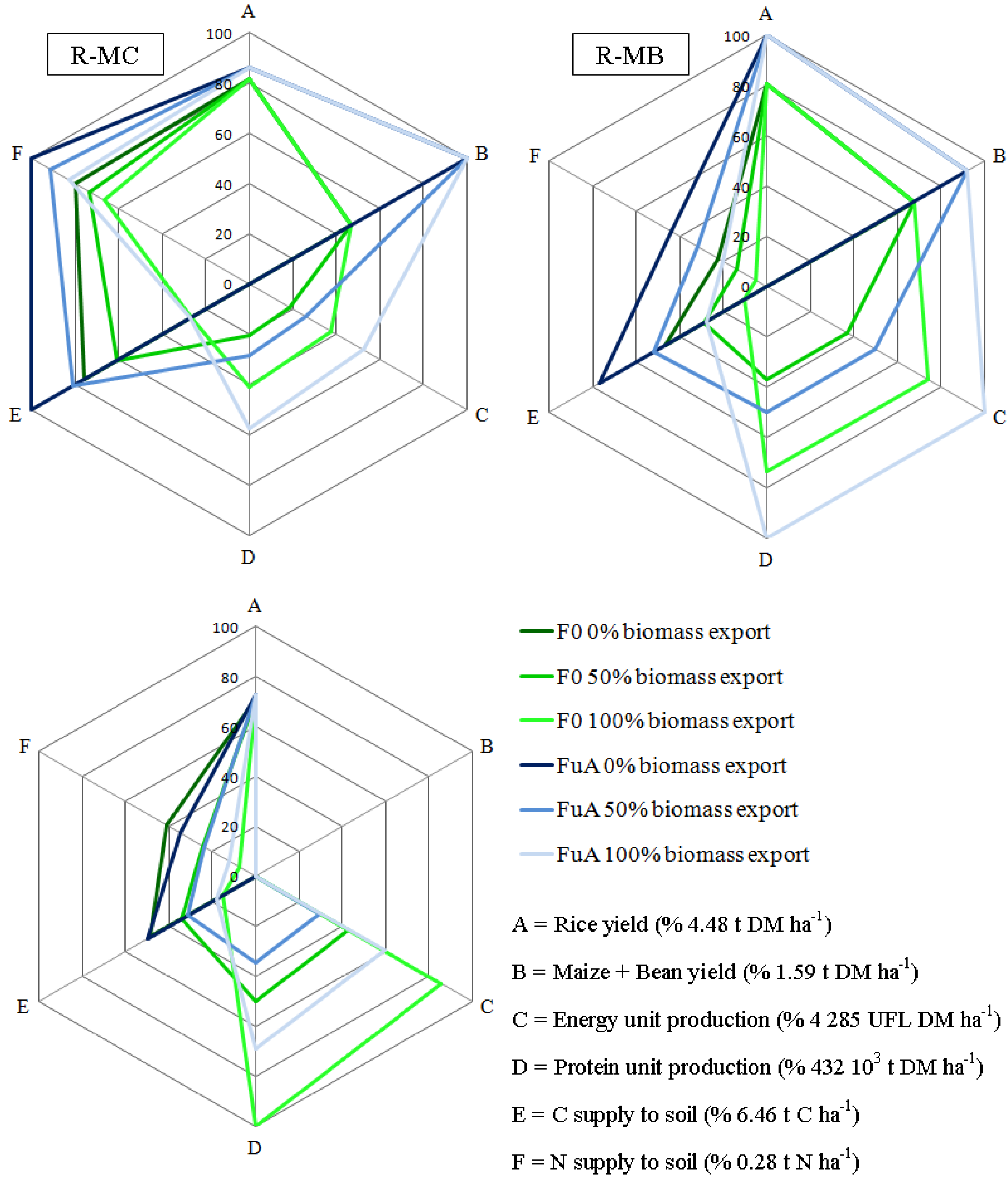

Figure 1: Vegetable, animal production and C and N supply by each system

CONCLUSION

R-MC, R-MB and R-OV systems produce grain for food for humans, forage for livestock and C and N for soil storage. The R-MC system allows a highest quantity of C and N supply to the soil but the lowest amount of forage nutritive value (UFL and protein). By contrast, compared to R-MC, R-MB and R-OV presented higher amounts of forage production but the quantities of C and N supply to soil were lower. The choice of the system, the type of plants and biomass management depend on the goals of each farmer. When the farmer are also a cattle owner, exporting 50% of residues is more interesting than 100%, because it allows to combine forage production and also C and N supply to soil. In addition, improving manure management can increase grain and biomass production yields. Combined with CA, improving manure management allows a better N balance. As shown in other studies in Madagascar CA and livestock are mutually beneficial (Andriarimalala *et al*., 2013; Naudin *et al*., 2004).

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