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CREATING SYNERGIES BETWEEN CONSERVATION AGRICULTURE AND CATTLE PRODUCTION IN CROP–LIVESTOCK FARMS: A STUDY CASE IN THE LAKE ALAOTRA REGION OF MADAGASCAR

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SUMMARY

Conservation agriculture (CA) has been promoted as a strategy to cope with deterioration in soil fertility, but its adoption on smallholder farms in tropical areas remains limited. In Madagascar, livestock production is facing shortages in forage especially during the dry season. The value of cover crops used in CA as livestock feed could be an incentive to make this form of agriculture more acceptable in rural areas. To do so, farmers must find a trade-off between the use of biomass from cover crops for animal production and its maintenance on the soil to meet CA's criteria. In this study, we evaluated the impact of biomass flows (cover crops and manure) between cropping and cattle production in crop–livestock farms in the Lake Alaotra region. Surveys among crop–livestock farmers were used to calculate feed concentrate and mineral fertilizer equivalents. Our results show that on average 42, 22 and 10% of biomass production (dry matter basis) of *Brachiaria* spp., *Stylosanthes guianensis* and *Vicia villosa*, respectively, are used for livestock feeding. The economic benefit in feed concentrate equivalent is between €73 and €723/year per farm. The use of manure contributes, just as CA, to improve soil fertility without using external fertilizing resources. The economic benefit in mineral fertilizer equivalent is between €116 and €2365/year per farm. The integration of CA and livestock production shows, beyond the agronomic advantages, an obvious economic benefit, which is essential to secure the Malagasy agricultural systems. Moreover, this economic benefit is another argument for the dissemination of CA practices in rural areas.

INTRODUCTION

Conservation agriculture (CA) corresponds to a set of cropping practices based on a strong combination of ecological processes. It is defined by the simultaneous implementation of three principles: minimum tillage, permanent soil cover with a cover plant and/or crop residues, and crop association or rotation (Hobbs, 2007). CA is now an alternative to conventional agriculture characterized by soil tillage and monocropping. From an agronomic perspective, the beneficial effects of CA are proven

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in diverse world ecosystems: limiting soil evaporation and water loss by runoff (Scopel *et al.*, 2004; Smets *et al.*, 2008), enrichment of soil organic matter (Neto *et al.*, 2010), weed control by mulch cover (Teasdale and Mohler, 2000). These effects accumulate over time and usually result in increased crop yields. Despite their agronomic benefits, the adoption of CA in smallholder farms in the tropics is often limited (Carsky *et al.*, 2003; Erenstein, 2003; Giller *et al.*, 2009). The implementation of CA requires farmers to have a period of adaptation and learning, the access to minimum inputs (herbicides, fertilizers) and incentives. The adoption of CA and particularly the maintenance of crop residues on the soil during the dry season involves a change in some animal production practices such as the abandonment of common grazing on the parcels involved and the replacement of crop residues or coverage biomass forage by other feed resources for livestock.

In Madagascar, significant effort has been made to promote CA in smallholder farming. In the Lake Alaotra region, the gradual increase in area using CA in the last 10 years (410 ha of CA practices *stricto sensu* with 600 farmers in 2010; Penot *et al.*, 2011) shows that adopters have passed the experimentation stage. In this region, livestock production faces a chronic forage shortage in the dry season with a limited access (low availability and high prices) to other feed resources such as feed concentrates and agro-industrial by-products. Within this context, cover crops can be used for CA soil cover and livestock feed. Therefore, crop–livestock farmers face trade-offs between using cover crops either to enhance soil properties improving production of staple crops or to feed livestock coping with feed deficits and improving animal production (Naudin *et al.*, 2011).

At the same time, livestock production generates manure, which is the main source of soil amendment for smallholder farmers who have limited capital to buy inorganic fertilizers. For the majority of Malagasy farms, manure is the only fertilizer available at low cost. Due to mineral fertilizers high price, crop–livestock farmers opted by improving manure production, quantitatively and qualitatively (Salgado *et al.*, 2011a).

Until now, few studies have focussed on how to better adapt CA in smallholder mixed systems, specifically on making use of cover crops to improve both crop (soil properties and green manure) and livestock production (feed availability). CA impact measurements focused in particular on changes in soil organic matter content and technical and economic performance of cropping practices within CA, compared to those of conventional practices (Penot *et al.*, 2010). The focus on soil and crop production largely disregards the potential economic benefits of integrating CA and livestock production in smallholder farmers. In this context, the evaluation of all biomass flows from CA and livestock production integration might highlight a greater economic interest for the multiple use of biomass from plant and animal origins. This would favour the acceptance of CA and the adoption of this cropping practice by crop–livestock farmers. As it has been recently pointed out by others authors (Fisher *et al.*, 2012; Naudin, 2012), we assume that CA and livestock can be mutually beneficial, in certain biophysical and economic conditions that is the case of Lake Alaotra region.

The objective of this study is to assess the economic benefit of combining CA and livestock production by using part of the cover crops as livestock feed and recycling organic manures in mixed crop–livestock farm in the Lake Alaotra region.

MATERIALS AND METHODS

The study area

The study was conducted in the Lake Alaotra region (17°10′S – 48°10′E and 18°00′S – 48°40′E) of Madagascar. The mid-altitude tropical climate is characterized by an average temperature of 22 °C and an average annual rainfall of about 1000 mm. Three distinct agronomic landscape units are encountered according to toposequence, soil fertility and texture and water regime: (i) upstream *tanety* or hills where some parts can be cultivated, (ii) downstream *baiboho* or colluvial soils and (iii) plain-irrigated rice fields. Residential areas and food crops like cassava and groundnuts are generally located on *tanety*. The downstream (*baiboho* and rice fields) are used for food crops such as maize, rice in the rainy season and dry season vegetable crops. The *tanety* soils are Cambisols (20% clay, 38% silt and 42% sand). The rice fields are Ferralsols (39% clay, 29% silt and 32% sand) as well as *baiboho* (15% clay, 17% silt and 68% sand) (Naudin *et al.*, 2011; Razafimbelo *et al.*, 2010).

At Lake Alaotra, after poultry, cattle represent the most numerous livestock species, with a stock of approximately 160 000 head. Four types of cattle production are encountered: (i) zebus in extensive production and used to build up capital, (ii) draught zebus, (iii) fattening zebus from the extensive herd and (iv) cross-bred zebus or dairy cows from improved breeds used for milk production. Cattle production is dominated by small herds with an average of six heads per farm. Zebu cattle are raised on natural grazing lands (*tanety*) without receiving feed supplements. Generally, animals are on pasture day and night, but recently, because of an increase in cattle insecurity, they have been confined at night.

Farmer selection and survey

A sample of 14 crop–livestock farmers associating CA and livestock production was selected from a total of 50 farmers previously surveyed. The sampling criteria were: (i) seniority in CA, (ii) field area with CA, (iii) number of cattle per farm and (iv) geographical area (east and west side of Lake Alaotra). A survey, carried out in 2010/2011, was used to assess cover crops and animal manure recovery practices. The amounts of biomass from cover crops harvested to feed cattle were estimated based on the number of bags collected. Production of animal manure was estimated based on the number of carts declared, and using conversion units adapted to each farm (depending on the density and proportion of straw within the manure).

Cover crops and manure biomass

Three main species of cover crops were selected because CA practices in Lake Alaotra generally adopted *Vicia villosa*, *Stylosanthes guianensis* and *Brachiaria* spp. (*B. brizantha* and *B. ruziziensis*). *V. villosa* is a dry season leguminous plant that uses water

Table 1. Average forage yield and nutritive value of cover crops (Husson *et al.*, 2008; Naudin *et al.*, 2011).

	Brachiaria spp.*	*S. guianensis*	*V. villosa*
DM (%)	25	30	20
NEL (kcal/kg DM)	1020	1190	1445
DCP (g/kg DM)	95	150	150
Yield (t DM/ha/year)	14.0 (in three cuts)	7.5 (in two cuts)	7.5 (in two cuts)

**B. brizantha* and *B. ruziziensis* combined.
DM: Dry matter; NEL: Net energy for lactation: DCP: Digestible crude protein.

reserves from deep soils. It is installed on *baiboho* or rice fields and is usually followed by a rice crop in the rainy season. *S. guianensis* and *Brachiaria* spp. are rarely associated with food crops. Farmers recognize three main interests in these two cover crops: (i) fight against erosion, (ii) improve fertility of *tanety*'s soil and (iii) produce forage. Recent studies confirmed the high potential of these cover crops to produce aerial biomass (Husson *et al.*, 2008; Naudin *et al.*, 2011; Table 1).

Manure samples were collected to determine their dry matter (DM) and nitrogen (N) content. The samples were weighed, dried at a temperature of 45 °C for approximately 48 h and then finely ground (1 mm screen). Nitrogen content was determined using near-infrared spectroscopy (NIRS) analysis. The phosphorus (P) and potassium (K) contents were taken from previous studies in the similar area of Madagascar (Salgado *et al.*, 2011a).

Data analysis

Intensity of removal of cover crops (IR): This indicator is the ratio between the total quantity of removed DM for feeding cattle and the average DM productivity of the cover crop:

$$IR = \frac{(DMR \times RD)}{(DMP \times A)},$$

where IR = Intensity of removal of cover crops (%), DMR = DM removed (DM/day), RD = removal duration (days/year), DMP = average DM productivity of cover crop (DM/ha/year) and A = area (ha).

Coverage of the maintenance requirements for cattle (DC and AC): This indicator is the ratio between nutrient inputs [Net energy for lactation (NEL) and digestible crude protein (DCP)] from cover crops removed and cattle maintenance requirements (Salgado *et al.*, 2011b, Table 2):

$$DC = \frac{(DMI \times ncCC)}{(Cnmr)},$$

where DC = daily coverage in NEL or DCP during the feeding period with cover crops (%), DMI = DM intake (kg DM/day), $ncCC$ = NEL or DCP content of cover crops

Table 2. Energy and protein maintenance requirements of cattle (Salgado *et al.*, 2011b).

	LW (kg)	Production level	TLU* equivalent	NEL (kcal/day)	DCP (g/day)
Zebu young	90	Growth	0.4	1700	60
Zebu adult male	350	4 h work/day	1.4	6120	210
Zebu adult female	180	Gestation	0.7	3910	120
Dairy cow adult	400	10 l of milk/day	1.6	5440	245

*One TLU corresponds to an adult zebu with a live weight of 250 kg, with an intake capacity of 2.5 kg DM/100 kg of live weight (4760 kcal NEL and 160 g DCP as average maintenance requirements per day).
LW: Live weight; TLU: Tropical livestock unit; NEL: Net energy for lactation; DCP: Digestible crude protein.

Table 3. Fertilizer element (N, P and K) requirements of crops (Husson *et al.*, 2009).

	N (kg/ha)	P (kg/ha)*	K (kg/ha)†	Yield (t/ha)
Cereals				
Rice (paddy) 30%	48.0	10.5	7.5	3.0
Rice (straw) 70%	87.5	10.5	175.0	7.0
Corn (grain) 40%	40.0	7.0	7.0	2.0
Corn (straw) 60%	42.0	4.5	67.5	3.0
Oilseed plants				
Groundnuts (seeds)	67.5	6.0	9.0	1.5
Soya (seeds)	75.0	8.0	17.5	1.0
Grain Legumes				
Bean (seeds)	30.0	3.6	17.2	0.8
Bambara groundnut (seeds)	67.5	6.0	9.0	1.5
Tubercles				
Potato	67.5	26.3	67.5	15.0

*In 1 kg of P, there are 2.29 units of P_2O_5.
†In 1 kg of K, there are 1.20 units of K_2O.
N: Nitrogen; P: Phosphorus; K: Potassium.

(/kg DM), *TLU* = tropical livestock units, *Cnmr* = cattle NEL or DCP maintenance requirements (/day) and

$$AC = \sum \frac{(DC \times RD)}{365}$$

where *AC* = annual coverage in NEL or DCP of cover crops (%) and *RD* = removal duration (days).

Coverage of the fertilizer requirements for crops (CF): This indicator is the ratio between inputs of fertilizer elements (N, P and K) from manure and farm crop fertilizer requirements (Husson *et al.*, 2009, Table 3):

$$CF = \frac{(MP \times fcM)}{(A \times frC)},$$

where *CF* = coverage in N or P or K of crop requirements by application of organic fertilizer elements (%), *MP* = manure produced (kg DM), *fcM* = N or P or K content

Table 4. Composition of raw materials used for calculating the feed concentrate equivalent.

Concentrated feed (90% DM)	NEL (kcal/kg DM)	DCP (g/kg DM)	Unit cost (€/kg)
Cassava tuber	2210	11	0.2
Groundnut cake	1938	300	0.6

DM: Dry matter; NEL: Net energy for lactation; DCP: Digestible crude protein.

of manure (/kg DM), A = crop area (ha) and frC = N or P or K requirement of crops (units/ha).

Crop requirement in N, P and K fertilizer elements was estimated by the contents of aerial crop production (grain and straw) for these elements (Table 3).

Economic analysis

Currently, neither the biomass of cover crops nor the forage produced on the farms is commercialized. To assign an economic value to these resources, a calculating method "feed concentrate equivalent" was used. To do so, a complete substitution of energy (NEL) and DCP contained in cover crops was calculated using the locally available ingredients (cassava tubercle and groundnut cake) to formulate a feed concentrate equivalent (Table 4). The monetary value of this substitution feed is calculated from its composition and ingredient prices in the local market. For manure, although it is sometimes sold in the region, we observed a strong variability of nitrogen content and prices between farms. A method of calculating "mineral fertilizer equivalent" was used to assess the economic value of the manure produced. This value was calculated by considering the fertilizer element content (N, P and K) of manure by giving a monetary value to these elements by considering the price of mineral fertilizers and their N, P and K contents. We must underline that the economic benefits calculated correspond to the savings made by crop–livestock farmers by replacing imported inputs to feed cattle or fertilize crops by resources produced on the farm (cover crops and manure).

RESULTS

Structural characteristics of the surveyed farms

The studied farms were characterized by their production factors: (i) cultivated area, (ii) area in CA, (iii) crop rotation, (iv) number of cattle and (v) permanent workforce (Table 5). The fields in CA represent on average 37 ± 19% of the farm total agricultural area. The average number of cattle per farm is 7.9 ± 4.7 tropical livestock units (TLU). The crop–livestock farmers surveyed have adopted CA from 4 to 8 years. The permanent workforce (employees and family) is on average 2.6 ± 0.8 man work units (MWU) for all farms.

Table 5. Characteristics of farms according to their production factors: area, number of cattle, permanent workforce.

	Farm													
	S1	S2	S3	S4	S5	S6	S7	NE1	NE2	NE3	NE4	NW1	NW2	NW3
Location	East side								West side					
CA Area/TAA (%)	45	31	21	18	30	35	24	49	78	46	60	14	57	13
Food crop area (ha)														
Rice (irrigated + rain fed)	1.3	2.3	2.0	3.5	3.6	4.0	5.0	2.8	1.0	0.8	6.0	4.0	3.3	4.0
Corn	–	1.0	0.5	–	0.2	–	–	–	1.0	0.6	–	0.1	–	0.4
Groundnut	–	–	0.3	0.3	–	–	–	–	0.5	0.2	–	–	0.1	0.6
Bambara groundnut	–	–	0.3	–	–	–	–	–	0.4	–	–	–	0.6	0.5
Soya	–	–	–	–	–	–	–	–	0.4	–	–	–	0.1	0.5
Bean	–	–	–	–	–	0.1	–	–	–	–	0.6	–	–	0.4
Potato	0.2	0.5	–	–	–	–	–	–	0.6	0.7	2.5	–	–	3.0
Forage CA area (ha)														
Brachiaria spp.	–	0.1	0.2	0.3	–	2.2	1.0	0.1	0.7	0.1	0.1	0.3	0.3	0.5
S. guianensis	–	–	–	0.3	0.5	1.8	–	1.6	0.9	0.5	–	0.1	–	0.3
V. villosa	0.8	0.1	–	0.2	0.9	–	0.7	–	–	–	–	–	–	–
Number TLU	2.8	3.2*	2.8	2.8	9.2	16.7	16.8	5.6	10.3	9.1	11.6	5.6	6.8	7.2
Adoption CA (years)	6	5	4	5	7	4	7	7	7	4	8	5	5	5
Permanent workforce (MWU)	2.3	1.8	2.6	2.8	3.3	3.6	2.8	1.8	2.3	1.8	1.8	3.3	2.3	4.3

*S2 is a dairy farm with two dairy cows from an improved breed.
S: South; NE: Northeast; NW: Northwest; CA: Conservation agriculture; TAA: Total agricultural area; TLU: Tropical livestock unit; MWU: Man work unit; by convention we adopt 1 MWU = a man over 15 years, 0.8 MWU = a woman over 15 years and 0.5 MWU = a child under 15 years.

Practices and impact of the removal of cover crops

The intensity of removal (IR) of cover crops, coverage of herd maintenance requirements and the economic benefit in feed concentrate equivalent data are presented in Table 6. All crop–livestock farmers distribute fresh biomass from one to several cover crops to feed cattle. The cover crops are used from December/January to May/June during the rainy season (period of high plant growth) except for *V. villosa*, which is mainly used in the dry season from June to November. *Brachiaria* spp. is used to feed cattle more than *S. guianensis* and *V. villosa*, and only one-third of farmers use *V. villosa* for animal feeding during the dry season. The average IR of cover crops varies from 10 to 42% for all farms. It is relatively low for leguminous plants (22 ± 21% and 10 ± 6% for *S. guianensis* and *V. villosa*, respectively) compared to *Brachiaria* spp. (42 ± 28%). There are differences in IR of cover crops between farmers with an important range between minimum and maximum IR values. There are no correlation between IR values and farm structural characteristics including surface area of cover crop, number of cattle per farm, duration of adoption of CA and permanent workforce in farm (data not shown).

The coverage of herd maintenance annual requirements varies from 3 to 52% for energy (NEL) and 10 to 116% for protein (DCP). On average, 32 ± 13% of

Table 6. Removal intensity, livestock and economic impacts of cover crop removal.

	Average	Standard deviation	Minimum	Maximum
Brachiaria spp. ($n = 12/14$)				
RD (day/year)	133	52	30	210
DMR (kg DM/day/year)	13	8	5	30
IR (%)	42	28	12	96
DMI (kg DM/TLU/day)	1.5	0.7	0.4	3.2
DC NEL (%)	32	13	8	59
DC DCP (%)	92	43	23	195
S. guianensis ($n = 8/14$)				
RD (day/year)	143	35	90	180
DMR (kg DM/day/year)	5	3	2	9
IR (%)	22	21	3	56
DMI (kg DM/TLU/day)	0.5	0.2	0.3	0.9
DC NEL (%)	14	5	7	22
DC DCP (%)	51	20	24	83
V. villosa ($n = 5/14$)				
RD (day/year)	96	44	30	150
DMR (kg DM/day/year)	7	5	1	12
IR (%)	10	6	6	21
DMI (kg DM/TLU/day)	1.1	1.1	0.3	3.0
DC NEL (%)	31	27	10	78
DC DCP (%)	83	59	30	181
Annual coverage (%)				
NEL	16	12	3	52
DCP	48	27	10	116
Economic gain (€/year)				
Brachiaria spp.	291	174	73	598
S. guianensis	194	115	88	424
V. villosa	169	166	26	455
Total	420	197	73	723

n: number of farmers using cover crop to feed animal; RD: Removal duration; DMR: Dry matter removed; DM: Dry matter; IR: Intensity of removal; DMI: Dry matter ingested; TLU: Tropical livestock unit; DC: Daily coverage of cattle maintenance requirements; NEL: Net energy for lactation; DCP: Digestible crude protein.

cattle maintenance energy requirements are covered by *Brachiaria* spp., 14 ± 5% by *S. guianensis* and 31 ± 27% by *V. villosa*. For protein requirements, on average 92 ± 43% are covered by *Brachiaria* spp., 51 ± 20% by *S. guianensis* and 83 ± 59% by *V. villosa*. The total economic benefit in feed concentrate equivalent varies from €73 to €723/year per farm. Specifically for each cover crop, the economic benefit in feed concentrate equivalent is on average €291 ± €174, €194 ± €115 and €169 ± €166/year for *Brachiaria* spp., *S. guianensis* and *V. villosa*, respectively.

Management practices and agronomic and economic impacts of manure use

The manure management practices were analysed at the collection and storage stages. Generally, litter mixed with animal excreta and collected in the cowshed is either used directly in the field or stored in pile or pit for several months. Litter and

Table 7. Manure production modalities and their agronomic and economic impact.

Manure production modality	Man1	Man2	Man3
Number of farms	2	7	5
Facilities of manure management			
Cowshed with roof	Yes	Yes	No
Existence of manure pit	Yes	Yes	No
Manure pit with roof	Yes	No	–
Production			
t DM/farm/year	8.8 (1.8)	2.8 (1.0)	1.7 (0.5)
t DM/TLU/year	0.98 (0.07)	0.71 (0.69)	0.45 (0.33)
Content (% DM)			
N	2.2	1.4	0.8
P_2O_5	4.4	3.1	1.8
K_2O	9.0	7.2	4.0
Coverage fertilizer requirements (%)			
N	20 (3)	11 (4)	3 (1)
P	206 (30)	149 (41)	38 (6)
K	70 (2)	50 (22)	10 (2)
Economic gain (€/year)	2070 (418)	510 (184)	168 (47)

Note. Data represent the average of the corresponding farms and the standard deviation (in brackets).
Man: Manure production modality; DM: Dry matter; N: Nitrogen; P: Phosphorus; K: Potassium.

manure are spread alone or mixed with other materials such as household waste and crop residues.

Three modalities of manure production were identified according to the type of infrastructure (Table 7). The crop–livestock farmers of type Man1 invest in infrastructure improvements, such as the cowshed roof and the manure pit to better valorize the litter in manure.

The amount of manure produced on each farm is highly variable and depends primarily on herd size and the management practices (addition of litter, scraping frequency, storage place, etc.). In our sample, the farms representing the Man1 modality produce significant amounts of manure (on average 8.8 t DM/farm/year; 0.98 t DM/TLU/year). The amount of manure produced by the Man1 modality is about 40% higher than the Man2 modality and is twice the one produced with the Man3 modality (0.45 t DM/TLU/year). The total N content of manure is 2.2, 1.4 and 0.8% DM for Man1, Man2 and Man3, respectively.

Most farmers give priority to the application of manure on food crops, nutrient demanding (rice for self consumption and sale, vegetable gardening for sale) and on other crops present in the *tanety*. The coverage of farm requirements in fertilizer elements depends not only on the cultivated area and crop requirements but also on the quantity and quality of manure inputs. In our sample, the coverage rate of crop requirements in fertilizer elements by the farm's manure is highly variable (Table 7); it is more important for the Man1 production modality, characterized by high contents in fertilizer elements (N, P and K) of manure. Even in the best cases, manure production is still insufficient to cover the crop's total requirements on N and K, and crop–livestock farmers would need to buy organic and/or mineral fertilizers to cover this deficit. With regard to P, more than half of the farms are self-sufficient if crop–livestock farmers properly recover the whole manure produced.

The economic benefit calculated on the basis of mineral fertilizer equivalent varies from €116 to €2365/year according to the farm. The economic benefit is relatively high for the Man1 production modality with an average of €2070 ± €418/year.

DISCUSSION

At least three conditions should be fulfilled to ensure the adoption of CA by farmers: (i) a real benefit in term of crop production (better yield) and production stability (less variability and/or better sustainability), (ii) a real significant increase in farm net margin per year (>10%) or at least at plot level (>20%) and (iii) the acceptability of the new technique regarding risk aversion and other sociological constraints. The present study focused mainly on the economic impact of CA adoption and synergies with livestock.

Trade-off for the use of cover crop biomass

At farm level, the trade-offs for the use of cover crop biomass are between giving cover crops biomass to the cattle and increasing animal production (milk, meat) and keeping the biomass on field to be use as a mulch and therefore increasing crop productivity and sustainability (decreasing weed pressure, improving water balance, increasing N and C input). Even if cover plants are dedicated to be used first to cover the soil and improve fertility, until now, promoters of CA have not enough put forward the possibility of removing a portion of the forage biomass for livestock feeding. Nevertheless, farmers have understood the interest in using cover crops for feeding their livestock, mainly on the basis of empirical knowledge, without questioning the principle of soil cover.

Naudin *et al.* (2011) point out that the relationship between the amount of biomass potentially exportable and its impact on the soil cover rates can help crop–livestock farmers to make decisions in the management of the biomass produced on their fields. Govaerts *et al.* (2005) emphasize the need to establish, for each agro-climatic context, the threshold quantity of residues needed to run a cropping practice in CA, maintaining soil productivity whilst using part of the biomass as a forage resource. However, trade-offs for biomass uses between livestock and soil cover require implementing management tools on farms (biomass measurement, indicators such as the height of the cover plants). The crop–livestock farmers of Lake Alaotra are still at an experimental and discovery stage regarding the forage potential of cover crops and the quantities that they can collect without compromising the CA function. Currently, the weight of livestock on the farm and the direct benefit generated by the feeding value of cover crops mainly determine the attention that crop–livestock farmers give to these crops.

Intensity of removal and use of cover crops

The availability of biomass from cover crops and the importance in the livestock feed requirements have no direct impact on the IR of cover crops. The experience acquired by crop–livestock farmers in CA crop management does not necessarily lead to a greater IR of cover crops for animal feed. Besides, the availability of a workforce is sufficient to carry out the cutting work.

The IR and cover crop removal practices vary according to the plant species under consideration, the time of year and the type of farm surveyed. The importance given to soil cover (mulch) seems to have an influence on the level of biomass removed for feeding livestock. In fact, a minimal amount of crop residues is necessary to ensure agronomic roles, such as weeds control. Naudin *et al.* (2011) showed that it took about 4.0 t DM/ha of *V. villosa* for a 95% coverage of the field area. Therefore, the removal of *V. villosa* biomass should be moderated (less than 3 t DM/ha) if the farmer wants to keep the mulch effect of this cover crop. By removing approximately 21% of the average production of *V. villosa*, it will remain at approximately 6.0 t DM/ha, a quantity sufficient to cover the field. For *S. guianensis*, the amount of mulch covers a maximum of 75% of the field area in five of eight cases (IR $<$ 11%). However, in some cases, IR is very high (56%; 4.2 t DM/ha) and no longer allows the coverage of 30% of the field (Naudin *et al.*, 2011). In the case of *Brachiaria* spp., a moderate biomass removal is rare but the average yield observed for this cover crop is of 14 t DM/ha (Husson *et al.*, 2008). Thus, with IR below 50%, there is still enough *Brachiaria* spp. biomass on the soil for an acceptable coverage of the field.

The interest shown for livestock also seems to influence the duration and the IR of cover crops. To ensure that animals are in good general condition before the major work in the rice fields, some crop–livestock farmers prolong the period of cutting *S. guianensis* and/or *Brachiaria* spp. until the beginning of the dry season and thus collect a larger amount of biomass. In the particular case of dairy farms, crop–livestock farmers seek to collect large amounts of fresh biomass during a period long enough to support the production and sale of milk and thus increase the monetary income in the absence of any form of conservation forage, hay or silage. The feeding of draught castrated cattle or small numbers of fattening zebu cattle may be ensured by a moderate removal of plant cover on farms that have adopted CA practices, without the need to dedicate a part of the farm's crop rotation to forage crops in the strict sense. In all cases, the IR of cover crop remains limited, particularly for leguminous plants, compared to the average production of biomass of these resources (Husson *et al.*, 2008, Naudin *et al.*, 2011).

Livestock and economic impact of cover crop removal

The feed use of cover crop forage covers annually, on average, 16 and 48% of energy and protein maintenance requirements, respectively. The required coverage rate depends on the plant species, farm and period of use. If we refer only to the period of cover crop used to feed cattle, the nitrogen requirements for animal maintenance are covered by more than 80% in the case of *Brachiaria* spp. and *V. villosa* (Table 6), which confirms that the cover plants used in CA in the studied area are an important source of nitrogen.

The annual economic benefit in feed concentrate equivalent is in average €420 per farm or 1.6 times higher than the annual average agricultural wage in the region. Despite a certain difficulty in understanding these economic benefits, crop–livestock farmers admit that cover crops are nutritionally essential for their herds: cover plants are rich in nutrients and allow an improvement and diversification of the livestock's feed whilst reducing the purchase of fodder and feed concentrates. Cover plants also help to reduce the overgrazing of *tanety* and limit soil degradation by erosion during the rainy season and the predominance of poor quality grass (such as *Aristida*) in the livestock's feed. The increase in forage supply within the farm also helps to reduce the attendance of distant rangelands, thus allowing to save working time that can be reinvested in other activities and reduce the risk of straying and theft of animals.

Analysis of the practices of manure production

Practices to improve manure production are still poorly adopted and concern only two monitored farms. Although animal manure is the main resource for fertilizing crops, farmers invest little time and financial resources to improve production quantitatively and qualitatively. The use of traditional animal manure without additional litter and poor fertilizer quality remains predominant.

Recent work in the area of the Madagascar highlands has shown that the use of a slab on the cowshed floor, the addition of rice straw as bedding, manure storage in a pit, the addition of swine or poultry slurry and the reduction of storage time are among the major practices that improve the preservation of manure's nitrogen value (Salgado *et al.*, 2011a). However, these practices to improve manure fertilizer quality were absent in Lake Alaotra's farms. These practices require investment in capital and labour, which are generally limited on small smallholder farms (Rufino *et al.*, 2006). For farmers, these investments need to be justified by the benefits in terms of agricultural production growth or yield stability.

Economic impacts of manure recovery

The current high cost (particularly since 2008) of mineral fertilizers and the lack of investment capital do not encourage crop–livestock farmers to purchase these inputs. Faced with these constraints, the affordable way is to develop management practices to improve manure production and its recovery in order to restore or maintain soil fertility in the long term, food security and remunerative production (Makinde *et al.*, 2007). The annual economic benefit in mineral fertilizer equivalent is in average €610 per farm or 2.3 times higher than the annual average agricultural wage in Madagascar. Cover crops and manure recovery contribute also to carbon sequestration and greenhouse gases mitigation (by reducing mineral fertilizer use). Smallholder crop–livestock systems could then contribute significantly to environmental sustainability, if public policies were implemented to encourage a large proportion of farmers to adopt better practices.

CA practices and livestock production integration

The integration of CA practices and livestock production improves biomass, energy and nutrient recycling with the farm. A part of the biomass (and nitrogen) taken from crop–livestock systems is exported for animal feeding and subsequently recycled through the faeces and urine for crop fertilization. However, this biomass transfer from cover crops through animals increases the risk of loss of nitrogen from the farm. According to Rufino *et al.* (2006), maintaining crop residues and cover crops on the soil (mulch) is more efficient in terms of nitrogen conservation than the indirect return through the consumption of forage biomass by animals and manure spreading in the fields. However, livestock provide numerous advantages to crop–livestock farmers through output such as animal power, meat or milk. Thus, the valorization of manure contributes, as well as CA practices, to soil fertility recovery. This integration not only supports the growth of agricultural productivity and the income of crop–livestock farmers but also makes the farm more autonomous with respect to external inputs.

CONCLUSION

Given their forage potential, cover crops used in CA practices are starting to be used as livestock feed in the Lake Alaotra region, in Madagascar. The nutritional inputs of cover crops meet a significant part of the maintenance requirements of cattle and the economic benefits generated are substantial. Cover crops can have an important place in production systems in this region of Madagascar, if they are well managed by crop–livestock farmers, with the search for a balance between partial removal for livestock and maintaining a sufficient biomass on the ground. The promotion of CA practices for smallholder farmers can largely improve if the use of cover crops can generate enough cover to improve soil fertility and substantial feed to enhance livestock production. Emphasising synergies between CA and livestock can help the diffusion of CA in Africa. These synergies can be strengthened by different ways. Firstly, it is important to identify at the beginning which farmer and which kind of field can be concerned by sharing biomass between cattle and soil cover. Secondly, farmers and technician still ask for more information about the threshold in term of biomass production and removal in relation with crop performances.

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