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Farm-scale trade-offs between legume use as forage vs. green manure : The case of *Canavalia brasiliensis*

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ABSTRACT

To support a sustainable increase in agricultural productivity, the multipurpose legume Canavalia brasiliensis *was integrated as forage and green manure into the smallholder crop-livestock system of the Nicaraguan hillsides. Through on-farm trials, surveys, and on-station experiments, we investigated the biophysical and socioeconomic trade-offs in balancing livestock feeding with soil fertility management at farm level, including farmers' perception. Use as forage increased milk yields while use as green manure increased nutrient cycling efficiency. Short term net annual income decreased when used as green manure and increased when used as forage. Management options to handle trade-offs and maximize legume benefits are discussed.*

KEYWORDS

Biophysical and socio-economic trade-offs; Central America; crop-livestock systems; farmers' perceptions; multipurpose legume; soil fertility.

INTRODUCTION

Smallholder mixed crop-livestock systems provide over 50% of the world's supply of meat and over 90% of its supply of milk. They are the most important livestock systems in developing countries (Herrero et al. 2010). In the rural poor areas of the Central American hillsides, population is expanding, increasing pressure on arable land resources. For meeting food demands, the expansion of cropland is possible if slopes are taken under plough and/or if cultivation is intensified on existing cropland. As smallholders have no other choice than sticking to continuous staple crop production on sloping lands that are prone to erosion, and as they can hardly afford chemical fertilizers, soil organic matter and soil nutrients are being depleted, resulting in an overall soil fertility decline and a decrease in soil water availability (Johnson and Baltodano, 2004). Indeed, one of the main problems mentioned by farmers in the region is that the soil is "getting tired". This is their way of explaining soil degradation through nutrient depletion (Schmidt and Orozco 2003), mainly of nitrogen (N; Smyth et al. 2004; Pfister and Baccini 2005; Ayarza et al. 2007). As a consequence, the crop and pasture productivity is decreasing, resulting in further expansion of cropland, which in turn further accelerates nutrient depletion, leading to decreased income and higher food insecurity.

The most important current feed resources are constituted by naturalized pastures, i.e., *Hyparrhenia rufa* Stapf cv. "Jaragua", and to a lesser extent *Andropogon gayanus* Kunth cv. "Gamba" and *Panicum maximum* Jacq. cv. "Guinea". During the dry season, pasture growth ceases under severe water deficit and the only available feed resources are dry vegetation and maize residues of low forage quality (Bartle and Klopfenstein 1988). This feed shortage results each year in severe bovine malnutrition (PASOLAC 2002) and in a strong decrease in the production of livestock-source food.

The one commonly promoted approach is the incorporation of multipurpose legumes on cropland, which may function as an efficient interface between crops, soils and livestock.

When used as green manure, legumes can provide a substantial N input into the system through symbiotic N_2 fixation (Peoples et al. 1995) and build up soil organic matter stocks (Vanlauwe et al. 1998), thus acting beneficially to associated or subsequent crops. When used as forage, legumes still provide N input to the system through biological N_2 fixation, but gains are reduced when legume biomass is grazed or cut and carried for livestock consumption. On the other hand, ruminant livestock excrete on average about 80% of the N ingested (Rufino et al. 2006) whereof a significant portion of N is not readily available feces N (Bosshard et al., 2009, 2011), making efficient animal manure management a key issue for sustainable nutrient management. In the case of a lack of forage of sufficient quality, the legume-derived increase in forage availability and nutritional quality of the total diet leads to a net gain in milk and meat production (Peters et al., 2001, 2003; Lentes et al., 2010). Effects are more marked during periods of feed shortage as it is the case when drought tolerant legumes are grown during the dry season. In smallholder systems, livestock often represents the most important asset and means of accumulating capital, which can be readily converted into cash when needed (Stür et al. 2002).

In order to identify a suitable legume for improving the production system of the Nicaraguan hillsides, forage specialists and local extensionists induced a farmer participatory screening and evaluation of a number of potential legume options. Among the legumes tested, *Canavalia brasiliensis* Mart. Ex. Benth (canavalia), also known as Brazilian jack bean, attracted most attention from farmers mainly due to its vigorous growth, good soil cover and outstanding level of tolerance to drought manifested by green forage yield during the dry season (Peters et al. 2003; CIAT 2004).

When using canavalia, farmers face two alternatives: (a) a short-term alternative, where canavalia is grazed together with maize residues to increase milk production and earn an extra income during the dry season when milk prices are highest; or (b) a medium-to-long-term alternative, where canavalia is left in the field to enhance soil fertility in order to improve crop yields in subsequent years. One major drawback is that one usage limits the other. To balance these biophysical and socio-economic trade-offs in resource allocation and use, a good understanding of the effects of the legume on the individual components of the farming system is needed (Tittonell et al. 2007).

The effects of canavalia used as green manure in the Nicaraguan hillsides were already tested through a series of experiments. The results thereof show that drought tolerance of canavalia under low soil fertility conditions is associated with deep rooting ability and vigorous fine root development to explore a greater volume of soil (Polanía et al. 2010). Above ground biomass production varies strongly according to soil depth, slope position, amount of clay and stones in the whole profile, and soil organic carbon and N concentration. Canavalia cannot fully express its potential as a drought tolerant legume on soils with low organic matter content as well as on shallow and stony soils that hinder the deep rooting ability of the legume (Douxchamps et al. 2012). In addition, canavalia fixes significant amounts of N (between 64% and 74% of N in canavalia biomass is derived from the atmosphere) and increases the soil N budget in rotation with maize (Douxchamps et al. 2010). Although canavalia is a source of N for the subsequent crop, no effects were observed yet on the yield of the following maize crop in on-station and on-farm experiments (Douxchamps et al. 2010, 2011).

While the effect as green manure had been documented that way, the use of canavalia as forage still needed to be assessed. In addition, the adoption of a legume for one or the other usage depends on how farmers themselves perceive the legume and their production system. Studies have shown that system perception as well as words and definitions of agricultural terms differ between farmers and the scientific community (Müller-Böker 1991; Blaikie et al. 1997; WinklerPrins 1999; Ericksen and Ardón 2003; Ryder 2003: Schoell and Binder 2009). These differences in perception need to be well understood in order to assess the real potential of the legume for the production system considered, and to increase its chances of adoption. Therefore, the objectives of this interdisciplinary study were to address four key questions: (i) what are the effects of canavalia as forage, (ii) what are the biophysical and socioeconomic trade-offs in balancing livestock feeding with soil fertility management, with a focus on N as a key nutrient in the system, (iii) how do farmers perceive these trade-offs, and (iv) what is the best way to deal with these trade-offs at a farm level?

MATERIALS AND METHODS

Site characteristics

On-farm trials were established at a site representative for the Nicaraguan hillsides: the Rio Pire watershed (Department of Estelí, northwestern Nicaragua), within a 2 km radius around the community of Santa Teresa (13°18′ N, 86°26′ W, 600–900 m a.s.l.). Soils are classified as Udic and Pachic Argiustolls. The climate is classified as tropical savannah according to the Köppen-Geiger classification (Peel et al. 2007). Annual mean rainfall (since 1977) is 825 mm (INETER 2009), with a bimodal distribution from June to August and from September to November. The dry season lasts from December to May with strong winds and high temperatures. Farmers in the region are traditional crop-livestock smallholders, cultivating maize and bean on about 2 ha of land and sharing a low productive pasture area of about 10 ha. Maize (*Zea mays* L.) is grown during the first rainy season, and common bean (*Phaseolus* *vulgaris* L.) on part of their land during the second rainy season. While maize residues are left on the field, bean plants are entirely pulled out at harvest and removed from the field, so that no residues are incorporated into the soil.

Twelve farmers interested in integrating canavalia in their farms planted canavalia in rotation with maize during two successive years (2007 and 2008). All farmers participated in the socio-economic surveys. Half of them tested canavalia as green manure, and the other half tested it as forage. Details of the trials for use as green manure are given in Douxchamps et al. (2010; 2012), whereas the trial for use as forage and the surveys are described below.

On-station experiments were established at two experimental stations of CIAT in Colombia: at its headquarters in Palmira (03°05'N, 76°35'W) and a nearby location in Quilichao (03°06'N, 76°31'W), where the necessary infrastructure was available.

Trials for the utility of canavalia as forage

Trial 1

On six farms in Santa Teresa, the maize-bean and the maize-canavalia rotations were established on two plots of 0.35 ha, to compare the traditional grazing of maize-bean plots with grazing of maize-canavalia plots. Planting density of canavalia was similar to that of beans, 70 cm between rows (in between the maize) and 30 cm between plants. The currently recommended canavalia accession CIAT 17009 was used in the trials. At the beginning of the dry season, three to five lactating cows per farm entered the fields and first grazed the maize-bean plots (covered with maize stover only as bean plants were entirely removed at harvest), followed by the maize-canavalia plots (covered with maize stover and canavalia). Each treatment lasted for 10 days, with 5 days for adaptation and 5 days for data and sample collection. Due to accidental entering of cattle in the fields before the data collection, data were collected on only three of the six farms.

Trial 2

To assess its forage quality, canavalia was planted on fields of the experimental station of Palmira in four replicate plots of 5 m by 3 m in September 2007 and evaluated after 16 weeks of growth, which corresponds to the stage for grazing on-farm, where the whole plant was harvested at about 10 cm above ground.

Trial 3

In 2008, a grazing trial was performed at Quilichao experimental station with three treatments in a replicated 3 × 3 Latin Square design: 1) maize stover alone, 2) maize stover from cultivation where canavalia had been intercropped, 3) maize stover from cultivations where *Vigna unguiculata* (cowpea, know forage of good quality) had been intercropped. Maize was sown at a seeding rate of 40 kg ha^{-1}. Canavalia was sown between the maize rows on 13 May, 27 May and 10 June with 20 kg ha^{-1} seeding rate. Three groups of two lactating Holstein × Zebu crossbred cows, initially weighing 424 kg (± 54) and lactating since 153 days (± 52) subsequently grazed each of the three different experimental treatment plots. Fields of 1 ha size had been subdivided into six plots to provide enough feed for an adaptation period of 5 days and a measurement period of 5 days for each of the three groups. Measurements included total available biomass, milk yields and milk fat content.

Samples analyses

In canavalia samples, crude protein (CP) was determined according to Temminghoff (2010) and expressed as N × 6.25. Neutral detergent fibre (NDF) was determined according to Van Soest et al. (1991), *in vitro* dry matter (DM) digestibility (IVDMD) according to Tilley and

Terry (1963), and total tannins given as tannic acid equivalents according to Makkar (2003a; b). Milk fat was analyzed by the Babcock method (Anonymous 1894).

Assessment of biophysical trade-offs

The biophysical trade-offs in using canavalia above ground biomass for soil fertility or for livestock feeding were assessed by comparing the N cycling efficiencies for the green manure and for the forage management options. Nitrogen follows different pathways from canavalia to the subsequent maize, going through different compartments according to the management options. With the green manure option, N goes straight from the biomass to the soil; with the forage option, it goes first through the animal and the manure before going back to the soil, assuming that manure is deposited directly to the soil, without previous storage. Urine N was not included. The N cycling efficiencies (NCE, %) were defined for each compartments as the ratio of effective or useful output to input in a system component provided that the output can be reused within the system (Rufino et al. 2006). For the soil compartment, NCE varies according to the material considered. NCE were estimated as follows: NCE cow, Rufino et al. (2006); NCE cow manure, Brouwer and Powell (1995), NCE soil and maize, Douxchamps et al. (2011). Overall NCE is the product of the NCE fraction of each compartment. For each pathway, the product of the NCE of each compartment and of the quantity of legume N initially available gives an estimation of the amount of N derived from the legume (Ndff) in the subsequent maize. It was calculated from canavalia above ground biomass compartment size, which is 23 kg N ha^{-1} for the 1^{st} growth cycle (Douxchamps et al. 2010) and 10 kg N ha^{-1} for the regrowth, estimated from Herridge et al. (2008).

Estimation of economic trade-offs

The short term economic benefits of the introduction of canavalia into the crop-livestock system were estimated through a survey carried out with the farmers involved in the on-farm trials. During the survey information on land use, animal inventory, use of fertilizers and pesticides, family and contracted labor, and human food consumption was collected to estimate animal and crop production costs, and income from the sale of milk, meat, maize, and beans. The effects of the introduction of canavalia on farmers' net income were calculated by subtracting the production costs from the incomes for three scenarios: traditional maize system, canavalia used as green manure, and canavalia used as forage. Net income was calculated for a typical farm with 2 ha of maize, 1 ha of bean, 1 ha of canavalia and 3 dairy cows, over one year following the implementation of canavalia. The data on livestock productivity used was taken from the results of the on-farm trials. The data on crop productivity used was that of the trials for green manure use carried on in the same farms (Douxchamps et al. 2010, 2012), except for beans for which grain yields were exceptionally low mainly due to diseases during the two years. Here, the average bean yields for the Nicaraguan hillsides were used (1092 kg ha^{-1}, from local experts). For the extrapolation of milk yield over the whole dry season, we assumed that 1 ha of canavalia produces feed for three dairy cows over 20 weeks. This assumption is based on a canavalia DM yield of 2.2 t ha^{-1} (i.e. average yield from the on-farm trials) and a daily supply of 5 kg canavalia DM cow^{-1}.

Definition and analysis of farmers' perceptions

The Structural Mental Model Approach (SMMA; Binder and Schoell 2010; Schoell and Binder 2009) was applied in order to compare farmers' and experts' perception of the introduction of canavalia into the mixed crop-livestock system. The approach consisted of three steps: (i) definition and weighting of the different livelihood capitals (physical, natural, human, financial); (ii) analysis of livelihood dynamics, and (iii) definition of the social capital. The methodology provides an understanding of farmers' risks and priorities as seen by experts and farmers themselves, and gives insight into the origins of the differences between experts' and farmers' risk perception (Schoell and Binder 2009). The method was applied to define and analyze farmers' perception of the impact of the introduction of canavalia on their livelihood, the impact of the study on farmers' human capital, and of the study experts on farmers' social capital. Fourteen experts were interviewed, as well as 20 farmers, 10 of whom were participating in the study and 10 were representing a control group. The experts can be divided in two groups. The first group consisted of scientists and technical assistance people involved in the study (from ETH, CIAT and INTA). They had specific expertise in agronomy or related fields. The second group included people who were not at all involved in the study. They were selected to represent types of capital (see Binder and Schoell, 2010; Schoell, and Binder 2009) and included, teachers, priest, a representative of the local government and representatives of the local health institution.

The analysis was performed in two steps. In a first step the differences between the cumulated experts mental model and the farmers' mental models were analyzed according to Binder and Schoell (2010). In a second step the differences between the mental models of the farmers participating in the study and the control group were analyzed.

Statistical analysis

Statistical analyses were performed using the program SAS 9.2 for LINUX (SAS Institute Inc., Cary, NC, USA). For the grazing trials an analysis of variance between the different grazing regimes was performed using the Ryon-Einot-Gabriel Welsch multiple range test for detecting statistical differences ($P<0.05$) in the fat corrected milk yield. For the on-farm trials in Santa Teresa, statistical analyses were done using SPSS 9.0 for Windows, option General Linear Model (Analysis of Variance).

For the SMMA, the mean distance and standard deviation of the actors to the farmer were calculated (see Binder and Schoell, 2010 for details on the methodology).

RESULTS AND DISCUSSION

Forage quality of canavalia

The nutritional composition of canavalia pure stand (Trial 2) after 16 weeks of growth was, per kg DM, 89 g CP, 620 g NDF and 645 g IVDMD. When intercropped with maize (Trial 3), canavalia had a CP concentration of 160 g kg^{-1} DM and an IVDMD of 700 g kg^{-1} DM after 14 weeks growth. The NDF concentration was 500 g kg^{-1} DM. Total tannins given as tannic acid equivalents were < 10 g kg^{-1} DM. Basically, this indicates that important potentially antinutritional factors were present only at low levels in canavalia, which is further demonstrated by its positive effects on milk yield (see next section). Canavalia also proved to be a good source of CP. In comparison to low quality feeds like straw and nutrient poor grass species (such as *Brachiaria humidicola,* formerly called *Brachiaria dictyoneura*; Tiemann et al. 2008), digestibility and estimated energy concentration of canavalia were higher than in these low quality feeds though maybe not as high as that of other herbaceous tropical legumes like *Arachis pintoi* (Hess et al. 2002) and cowpea (Heinritz et al. 2012; Tiemann et al. 2008).

Effect of feeding canavalia on milk yields

In the experimental swards, the total available biomass was 3766, 5334 and 3075 kg ha^{-1} DM for maize stover alone, maize stover plus canavalia and maize stover plus cowpea, respectively (Trial 3). The fat-corrected milk yield was 7.5 kg cow^{-1} day^{-1} in the sward with canavalia (~14 weeks old) and 8.2 kg cow^{-1} day^{-1} in the sward with cowpea (~12 weeks old; not significantly different from the canavalia treatment) and these values were significantly higher compared to the 6.1 kg cow^{-1} day^{-1} achieved with maize stover only. Milk fat contents was 4.2%, 4.5% and 4.1% with maize stover alone, maize stover plus canavalia and maize stover plus cowpea, respectively.These values did not significantly differ among each other.
The effects of the canavalia diet on milk yields and milk fat contents were confirmed in the on-farm trials performed in Santa Teresa (Trial 1), during two consecutive years (Table 1). The integration of canavalia increased DM availability from an average value of 4000 kg ha^{-1} by 2000 kg ha^{-1}, and resulted in a significant increase in milk yield of 1 kg cow^{-1} day^{-1} (P <0.01) (Table 1). There were no significant effects on fat content.

Biophysical trade-offs

The N pathways and the NCE for the different options for use of canavalia above ground biomass are presented in Figure 1. These different options are not equivalent in terms of NCE, which is reflected in the N availability for the subsequent maize crop. This approach shows that the use of canavalia as green manure provides a more substantial N input to the subsequent maize than the use of animal manure, although both amounts are small compared to maize total N needs. From the workshops organized during the course of the study and the observations in the field, it is clear that farmers are rather motivated to use canavalia as forage. This use entails a risk of soil N depletion up to 41 kg N ha^{-1}, which could be mitigated by returning animal manure to the soil (Douxchamps et al., 2010). During grazing part of animal's excreta is deposited on the field but its distribution is uneven. The manure produced in corrals is usually collected, but its recycling to the field is generally inefficient, especially when it comes to the urine which contains N with high plant availability. Unless manure is properly stored and managed, its quality is often too poor to be an effective source of nutrients (Rufino et al. 2006). After it has been grazed, canavalia usually regrows during the dry season. Although this regrowth represents less biomass, it can again be used as forage or as green manure. On the long term, the use of canavalia regrowth as green manure represents a more interesting option for crop production than the use of animal manure.

What is not apparent from the NCE approach is how much soil N stocks are built up in each option. Douxchamps et al. (2011a) showed that the N recovery in soil is higher from canavalia residues than from animal manure, which speaks in favor of the regrowth-for-soil option. Additional "losses" from the direct N pathways with the forage option do not necessarily imply a loss to the farmers as this leads to higher milk and meat production. Also, we have not studied the belowground N input by canavalia into the soil. Legume belowground N can be as high as above ground N (Wichern et al. 2008), and can result in a residual N value to subsequent crops (Mayer et al. 2003).

Economic trade-offs

Farmers' net income and its components for the three scenarios is presented in Table 2. The introduction of canavalia increased the annual need for labor by 19 man days per farm compared to the traditional system. This additional labor has to be provided by hired workers or by the family. When canavalia was used as forage, the economic net annual return per farm increased by 8% with respect to the traditional system, mainly due to a 12% increase in milk production and to an 18% increase in milk prices during the dry season compared to the rainy season (Table 2). When used as green manure, a net annual income decrease of 12% was observed compared to the traditional system, which can be explained by the fact that no significant increase in maize yield was observed during the two first years of canavalia cultivation (Douxchamps et al. 2010).

Farmers' perception

From the analysis of farmers' perception, no trend towards one or the other use of canavalia can be deducted. The perception of experts and farmers differed in some specific issues. The most important difference was that farmers did not see any impact of crop harvests on their financial capital. The SMMA also showed that farmers attributed changes observed in their natural capital to their participation in the canavalia trials. Farmers' stated that, due to the cultivation of canavalia, they observed an increase in maize and milk yields. However, one has to consider that six out of ten farmers did not recognize canavalia on a photograph and four out of ten did not understand why canavalia should affect soil fertility.

Farmers claimed an overall improvement of the system, although no significant increase in maize yields was measured after two years of canavalia cultivation in their fields (Douxchamps et al. 2010). On one hand, farmers perceived a positive effect of canavalia on both milk and maize yields; on the other hand they did not yet associate this increase with extra income. However, the economic evaluation showed that the use as forage provides an immediate net income, while the use as green manure provides no economic benefit in the short term. These discrepancies between farmers' and experts' perception of the system have been already reported with the SMMA, and were also reported by other studies (Fischer and Vasseur 2002; Ericksen and Ardón 2003). Farmers and scientists have different reference frameworks: while farmers tend to use their farm and immediate surroundings as the reference framework for observations, scientists mostly use universally accepted reference frameworks, measurement units and classifications (Van Asten et al. 2009). In addition, farmers may intentionally or unintentionally bend the truth by providing 'desired' information, either to attract a project and achieve short-term benefits (Van Asten et al. 2009; Van der Hoek 2009), or because of a temporary enthusiasm or discouragement making them looking at their system with optimistic or pessimistic lenses.

Use of canavalia on-farm

Based on the on-farm experience in Nicaragua, a global on-farm N flow scheme for the smallholder system was developed (Figure 2). It highlights the changes in N flows generated by the introduction of canavalia into the system for the proposed management option: canavalia grazed, animal manure back to the plot, regrowth used as green manure. As canavalia above ground biomass production is strongly affected by the position in the landscape (Douxchamps et al., 2012), the integration of canavalia in farms located on slopes could be ideally complemented by soil conservation technologies such as live barriers to avoid that the N gained is subsequently eroded downhill. The system would benefit from small changes in management like increase in crop planting density and timing of mineral fertilizer application. Indeed, maize productivity may be limited by poor agronomic management and therefore not fully benefit from the N supplied by canavalia. Increased use of improved pastures like *Brachiaria* spp. grasses and/or forage conservation practices would diversify dry season feeding strategies and would allow livestock to be less dependent on canavalia amended crop residues. Better N distribution would be achieved through rotations between pasture area and cropland.

This shows that canavalia has to be seen as one component of a management strategy, possibly comprising also other legumes and aiming at increasing the production of the system and its resilience, based on the progressive restoration of degraded soils and on optimal N flows.

Potential of canavalia to improve the system

Canavalia has the potential to improve the mixed crop-livestock system of the Nicaraguan hillsides. It increases livestock production through increased animal feed availability and quality. The combination of both factors leads to (1) a higher production per animal and (2) an increased carrying capacity (number of animals per area), resulting in an increase in milk production during the dry season. Net income from the use of canavalia as forage may increase over time as costs arising from supplementary feeding and pasture leasing decrease. These trends need to be confirmed for the long-term effects. Although an income decrease has been observed with the green manure usage, canavalia biomass production increases soil fertility with time and it is expected that production costs of maize would decrease due to lower fertilizer application, and that income would subsequently increase due to maize yield increase. The time period until an effect on maize productivity can be perceived depends on the biophysical limitations of each site and the management options chosen by the farmers. It is assumed that canavalia yield is stable during at least for the two initial years. Still, yields of newly introduced legume species may decrease after a few years of cultivation due to a build-up of populations of new pests and diseases, as has been reported in other studies (Bünemann et al. 2004). However, this has not been observed in a 6-year old on-station canavalia experiment carried out at San Dionisio, Nicaragua. Nonetheless, comprehensive evaluation of the maize-canavalia rotation sequence needs on-farm testing over a longer period. More complex rotations combining different legumes with different purposes, like intercropping cowpea with maize during the first rainy season and growing canavalia or bean during the second rainy season, were found to be promising on-station (A. Schmidt, personal communication) and would need to be further tested on-farm. Indeed, the use of various legumes for various purposes on the same farm is consistent with the general trend for high diversity on smallholder farms and has been a successful strategy elsewhere (Stür et al. 2002). There is a need to define the longer-term economic threshold of productivity at the whole farm level for farmers to adopt canavalia as a legume option, as on more degraded soils, canavalia needs to be combined with mineral fertilizer and other soil fertility management practices during the early part of its integration.

In addition to the CIAT 17009 germplasm accession used in this study, a range of other accessions of *Canavalia brasiliensis* are available for testing. Some are being screened in both Colombia and Nicaragua to identify possibly options having properties superior to the accession tested here. Researched traits include agronomic performance (cover, biomass production) during the dry season, fertilizer value and nutritional forage characteristics. An on-farm trial with 12 accessions was established during two growing seasons (2009/2010, 2010/2011) in San Dionisio (Nicaragua). Some accessions (especially *Canavalia brasiliensis*

CIAT 7972, 19038, 17462) showed higher soil cover and produced up to twice as much biomass than the currently recommended accession, CIAT 17009 (CIAT 2010).

Adoption potential

Adoption of legumes by smallholder farmers is generally below its potential (Sumberg 2002; Shelton et al. 2005). Reasons identified for poor adoption include lack of perceived economic benefit (Ali 1999), lack of extension information, limited seed availability, labor shortage, inappropriate land tenure and land scarcity (Elbasha et al. 1999). Other factors are unfavorable policy environment (giving preference to external inputs like concentrates and fertilizer), a lack of farmers' participation in the development of forage germplasm and a lack of coordination between different research disciplines (Horne et al. 2000; Peters and Lascano 2003). Particularly in Nicaragua, failure to take into account local reality and perspectives has been reported as a main factor for non-adoption of soil conservation practices (Shriar 2007). The use of participatory approaches and the evaluation of the whole system into which legumes are to be integrated are indispensable to address both the obstacles preventing farmers' adoption and the complexity of legume-crop-livestock cropping systems (Cherr et al. 2006; Mugwe et al. 2009; Van der Hoek 2009).

In the present study, farmers were involved from the start. On-farm trials and workshops allowed checking for the adequacy of the proposed technology to the local cropping system. The ex-ante socioeconomic survey allowed identifying some important factors to be considered for sustainable adoption of canavalia, like the need for perceived economic benefit and the need for availability of labor. Most farmers who tried to grow canavalia want to continue planting it on their plots. Farmers perceived also an increase in maize and milk yields due to the cultivation and use of canavalia. Still, there is room for improvements in the communication between legume specialists and farmers, so that the knowledge of the farmers on their own production system further increases. This would help guaranteeing a sustainable adoption of canavalia. Indeed, the SMMA analysis found that, to achieve a sustainable adoption, the human capital of farmers should be targeted. This could be attained by providing farm management courses, further intensifying the involvement of the farmers and handing over key responsibilities in the future (Mosimann 2009). In particular, an in depth understanding of nutrient dynamics should be aimed at, whereby one should focus on departing from farmers understanding and complementing their knowledge specifically using their own experience and observations.

To facilitate adoption, information materials on the use of canavalia designed for the farmers (user guide, brochure) have been elaborated in collaboration with extension specialists from INTA, Nicaragua and CIAT headquarters, Colombia (Douxchamps et al. 2011b). Seed production plots have been implemented, and the official cultivar release by the local authorities is in process. Moreover, government and other local institutions have already expressed repeatedly their interest in integrating the new technology in forage production and soil fertility enhancement programs.

PERSPECTIVES AND CONCLUSIONS

Although a decisive push is still needed for widespread adoption, some farmers are currently growing canavalia, seed is being produced by a local NGO, and national research and extension programs and development organizations have started initiatives to scaling this technology through Farmer Field Schools. There are still gaps in the understanding of the trade-offs between the alternative uses of canavalia, mainly of the biophysical and socioeconomic effects on the long-term and at farm level, with different rotational sequences. For example, the water dynamics and the weed suppression in the system have not yet been studied. Risks associated with continuous use over years (nutrient mining if used as forage or pest/development as invasive weed if used as green manure) are still poorly defined.

Under the current high input (N fertilizer and concentrates) prices and growing consciousness of soil fertility decline, smallholder crop-livestock farmers show increasing interest in trying to integrate legumes for sustainable intensification of their production systems. While proposing and testing multipurpose legumes to sustain crop and livestock production and to reduce land degradation, researchers and technicians should monitor closely farmers' perception and implementation of the new technologies to make adjustments when needed and insure that the introduced technology is economically and ecologically sustainable. Multipurpose legume options should be combined with other agricultural intensification technologies or diverse crop rotations. Various alternatives for integration of legumes could be developed for a sustainable management of organic resources that maximize nutrient use efficiency and reduce soil degradation in smallholder crop-livestock systems in the tropics.

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TABLES AND FIGURE CAPTIONS

FIGURE 1 N pathways in maize-canavalia rotation for different uses of canavalia biomass. Dashed arrows indicate the N pathways through various compartments according to the various management options for canavalia. NCE = Nutrient cycling efficiency, ratio of effective or useful output to input in the system component.

FIGURE 2 N flows on a smallholder crop-livestock farm in the Nicaraguan hillsides. Proposed changes to the traditional system are indicated in bold: (1) introduction of canavalia, with above ground biomass of first growth used as forage and the rest as green manure; (2) return of animal manure to the soil; (3) soil conservation techniques like live barriers or stone rows to reduce erosion; (4) improved maize management; (5) return of bean roots, usually pulled out at harvest, to the soil; and (6) introduction of improved pastures

TABLE 1 Influence of management options on biomass availability, and milk yield and milk fat content, Santa Teresa, 2007 and 2008

TABLE 2 Composition of the net annual income for three management options, for a typical smallholder farm, (i.e. 2 ha of maize, 1 ha of bean, seven heads of cattle from which three are dairy cows and 1 ha of canavalia when applicable)

TABLE 1 Influence of management options on biomass availability, and milk yield and milk fat content, Santa Teresa, 2007 and 2008

	Total dry matter t ha^{-1}		Milk yield l cow^{-1} day^{-1}		Fat %		Protein %		Lactose %		Solids non-fat %	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Maize residues + weeds (control)	3.1	4.8	2.9^{a}	3.0^{a}	5.1	4.0	3.2	3.2	4.8	4.8	8.7	8.8
Maize residues + weeds + canavalia	4.0	8.1	3.4^{b}	3.8^{b}	5.2	4.0	3.2	3.1	4.9	4.7	8.9	8.5

Means carrying no equal superscript within the same columns are significantly different at P<0.05, n=12 (2007) and n=11 (2008).

TABLE 2 Composition of the net annual income for three management options, for a typical smallholder farm, (i.e. 2 ha of maize, 1 ha of bean, seven heads of cattle from which three are dairy cows and 1 ha of canavalia when applicable).

	Traditional system (US$ year^{-1})	Canavalia used as green manure (US$ year^{-1})	Canavalia used as forage (US$ year^{-1})
Income			
Income from 2 ha of maize [a]	895	895	895
Income from 1 ha of beans [b]	574	574	574
Income due to milk [c]	507	507	641
Income due to meat [d]	360	360	360
Production costs			
Production costs maize (2 ha) [e]	334	334	334
Production costs bean (1 ha) [e]	96	96	96
Production costs canavalia (1 ha) [e]		163	85
Production costs livestock [f]	480	480	423
Net income (US$ year^{-1})	1426	1263	1533

[a] Calculated with a sale price to producer of US$270/t^{-1}, a productivity of 2.2 t/ha per year, and an auto-consumption of 1 t/farm.year.

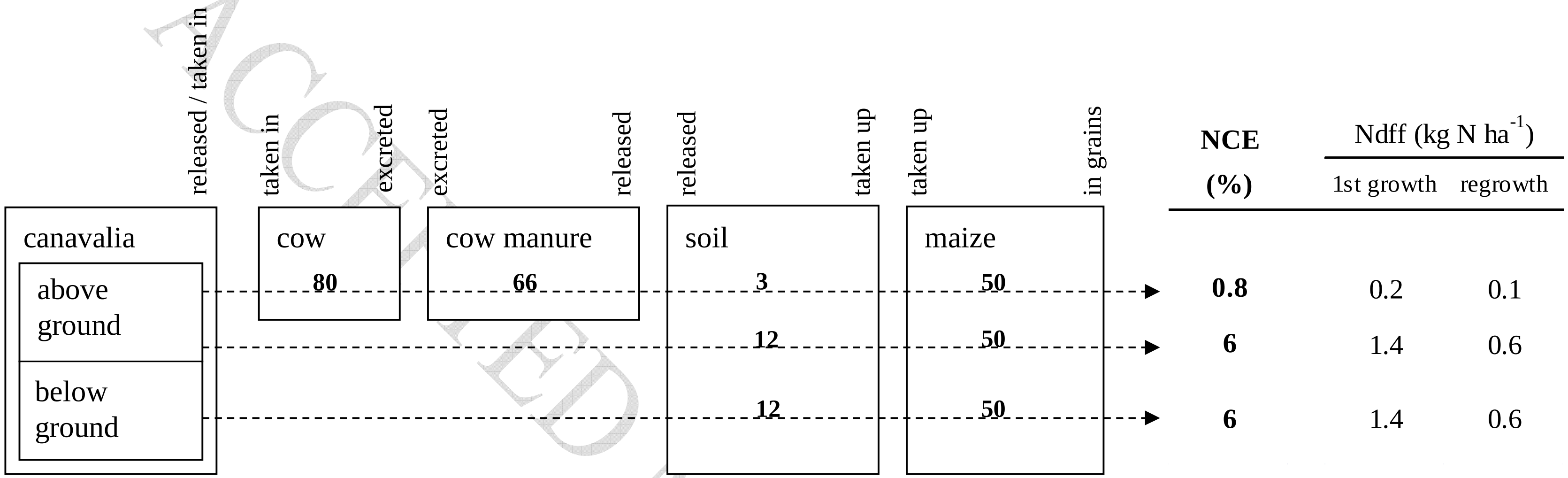
[b] Calculated with a sale price to producer of US$660/t, a productivity of 1.1 t/ha per year, and an auto-consumption of 222 kg/farm.year.

[c] Calculated with a sale price to producer of US$0.27/lt during the rainy season and US$0.32/lt during the dry season, and for 3 milking cows. Milk production is 4.1 l/cow/day during the rainy season and 2.1 l/cow/day during the dry season. With canavalia (forage scenario), milk production increases to 3.1 l/cow/day during 20 weeks for the 3 cows. Auto-consumption is 1789 l/farm.year.

[d] Sale price to producer is US$1.2/kg, and 452 kg/farm.year are sold.

[e] Include fertilizers and pesticides when applicable, land preparation, seeds for canavalia and labour at a rate of 2.7 US$/man.day.

[f] Include pasture leasing during the dry season, for 7 heads of cattle during 5 months at an average cost of US$3.85/head per month. With canavalia, leasing decreases to 4 heads of cattle during 5 months. Family labour contributes for 128 man.days at a rate of 2.7 US$/man.day.



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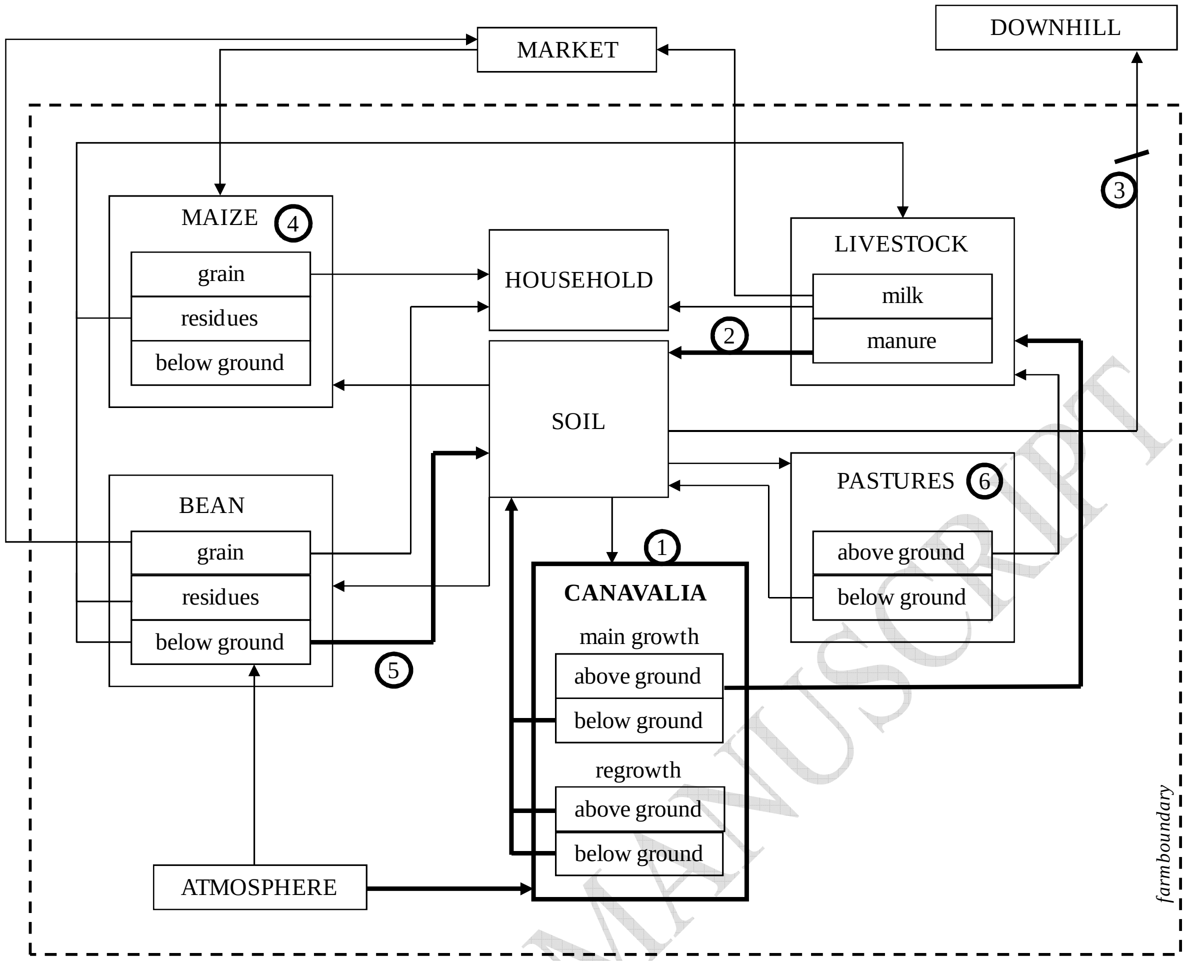

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