Ex ante Analysis of Legumes:

The Dilemma of Using Legumes as Forage for Animal Nutrition during the Dry Season or as Green Manure for Soil Improvement

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Introduction

Soil nutrient depletion is a common problem faced by both subsistence farming and commercial crop production in developing countries and can be attributed to the nutrient uptake by agricultural crops, which is higher than the amount of nutrients available in the soil. This is also a major cause of soil degradation (Frossard et al., 2006). Research carried out over the past decades has clearly evidenced a direct relationship between soil degradation, food insecurity, and poverty (Lipper, 2001).

The most important animal production system in developing countries is the mixed livestock production system (von Kaufmann, 1999) and can be found in Nicaragua as well as other Central American countries, where most farms are small, located in hillside areas undergoing different stages of degradation, and combine livestock production with the planting of subsistence crops such as maize and beans (INTA, 2002).

Natural pastures are the most important source of feed for livestock but their quality and quantity are seriously limited during the dry season, which lasts from 4 to 6 months, causing shortage of forage and animal undernutrition (PASOLAC, 2002). Furthermore, because of the problem of grass shortage, producers allow cattle to freely graze the dry vegetation, which makes the problem of overgrazing—another major source of soil degradation—even worse (FAO, 2000). On the other hand, milk production significantly decreases during the dry season and, as a result, milk prices increase by 40%-50% as compared with its prices during the rainy season. Improved animal nutrition during the dry season would therefore significantly improve family incomes in these mixed production systems.

In the past, several alternatives have been used to correct forage shortage or deficiencies during the dry season. These have included the use of net energy sources, ranging from forage cane to legumes, the latter contributing protein and complementing energy sources and available grasses. However, the competitiveness of using legumes for animal nutrition versus their use to improve soil quality and, as a result, crop productivity has seldom been analyzed.

This study therefore assesses the economic benefits of (1) a short-term alternative, which consists of establishing legumes for use as supplement, mixed with crop residues, to increase milk

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production and farmer incomes during the dry season when milk prices are higher; and (2) a medium-term alternative, which consists of establishing legumes as green manure at the same sites where maize and beans are planted and then incorporate these legumes into the soil to improve its fertility and, accordingly, improve agricultural productivity in subsequent years.

Objective

This study aims to (1) perform an *ex ante* analysis of the expected economic and environmental benefits of using the legume *Canavalia brasiliensis* either as green manure to improve agricultural productivity or as forage to improve milk production during the dry season; and (2) compare these benefits with the subjective perception of producers living in hillside areas of Nicaragua that have mixed maize-beans-livestock production systems regarding these new alternatives.

Current Status of Research on *Canavalia*

Use as green manure

The effect of nitrogen fertilization on subsequent crops is greatest when legumes are used as green manure. However, the N available due to decomposition of crop residues may be released before the roots of the new crop are established and can properly tap this source. The N can therefore be lost due to volatilization, denitrification, or leaching (Millar et al., 2004).

When *Canavalia* was established at the end of the rainy season for subsequent growth during the dry season and then incorporated into the soil, the increase in marginal productivity of the following maize harvest corresponded to an application of 50 kg N/ha (Burle et al., 1999). Although this suggests that *Canavalia* residues supply an important amount of N, the amount of N symbiotically fixed has not yet been determined.

Use as supplement for animal nutrition

The biomass of maize and bean stubble is the most important forage reserve for animal nutrition during the dry season. Although the available dry matter (DM) of these stubbles is relatively high, its low protein content (~ 4%) and digestibility (~ 40%) reduce animal productivity significantly, leading to both lower milk productivity and animal weight loss as compared with the rainy season. The nutritional value of maize and bean stubble can be improved significantly by introducing legumes such as *Canavalia* (Said y Tolera, 1993).

The advantage of *Canavalia* is that it is very tolerant to drought. Preliminary experiments show that *Canavalia* is well accepted by goats and sheep in Nicaragua. Recent results show a raw protein content from 20% to 25% and a digestibility of 80% (CIAT, 2006).

Materials and Methods

Collection of primary data

Data came from a survey of 10 producers of the Pire river watershed, located in the Department of Estelí in northern Nicaragua. The survey, conducted in September 2007, aimed to collect information on land use, animal inventory, use of inputs, and use of family and contracted labor to estimate animal and crop production costs (i.e., maize and beans), productivity, and income from the sale of milk, meat, maize, and beans.

The survey also gathered information on how producers perceive the use of the legume *C. brasiliensis* and what their expectations are to justify the adoption of *Canavalia*, based on the following:

(a) the minimum amount of milk that should be produced in excess of the average dry-season production for producers to adopt *Canavalia* as animal supplement; or

(b) the amount of fertilizer (i.e., urea) that producers considered that could be saved, while maintaining the same maize and bean production, to adopt *Canavalia* as green manure.

Ex ante economic evaluation

Based on average survey results, an *ex ante* economic evaluation was made of the economic benefits that would be produced if this legume was cultivated as green manure or used as animal supplement. The ECOSAUT model was used (Quintero et al. 2006). This optimization model uses linear programming, to evaluate land uses under multiple criteria—social, economic, and environmental. These decision-making criteria or variables are defined according to the production system (land use) evaluated and the evaluation objective.

The agroecosystem is accordingly simulated to better understand the effects that the incorporation of *C. brasiliensis* will have on producers' income and if the expectations producers expressed during the field visit are fulfilled.

To conduct this evaluation, the following scenarios were analyzed over a 5-year period:

- ***Scenario 1. Baseline***

This is the current land use scenario of the farms included in the survey. For this study, the baseline is defined as a farm type showing the average values of production costs, income, and productivity obtained in the survey. The land use system is mixed—maize and beans are grown and both milk and meat are produced. The farm area is 12 ha, of which 10 ha are sown to Jaragua grass *(Hypharrenia rufa)* and 2 ha are planted to maize and beans. The Jaragua grass is not fertilized and its biomass production decreases during the dry season, from 1.6 to 0.6 t DM/ha. Milk production also decreases during these months. Maize is planted first, at the onset of the rains (June). Once the maize has formed ears, the plants are folded for drying and beans are grown in half of the area (1.0 ha), using these dry stalks as support. Beans are planted at the end of the rainy season, around September-October, and are harvested at the beginning of the dry season (December-January).

- ***Scenario 2.* Canavalia *for animal nutrition***

This scenario also corresponds to a combined crop/livestock production system, but *C. brasiliensis* is also grown, intercropped with maize in the area where beans are not planted (1.0 ha). In this case, the legume is used for livestock nutrition during the dry season to increase on-farm milk production. This evaluation assumed an annual production of *C. brasiliensis* of 2 t DM/ha. The same distribution of land in pastures and grasses as found in the baseline is maintained.

- ***Scenario 3.* Canavalia *for soil improvement***

This scenario corresponds to the same scheme described in Scenario 2 above, with the difference that the legume is incorporated into the soil to improve fertility and, as a result, improve the productivity of subsequent plantings of maize and beans. This is why the legume is incorporated into the soil as green manure. It is assumed that the incorporation of *Canavalia* contributes 64 kg N/ha and replaces the traditional application of N in the form of urea (52 kg/ha) in maize and bean crops. It is only necessary to continue applying the complete fertilizer (12-30-12 NPK) at 82 kg/ha.

- ***Scenario 4.* Canavalia *for animal feeding with sorghum***

This scenario was developed because many producers (especially those with more livestock) plant sorghum at the end of the rainy season in order to have sufficient biomass to feed livestock during the dry season, in addition to maize stubble. The main objective is to produce biomass as source of forage for livestock. As a result, producers use a high planting density to maximize forage production and not grain production.

- ***Scenario 5.* Canavalia *in rotation with maize to improve soils throughout the farm***

This scenario explores the maximum potential of the farm in terms of generating income by gradually substituting the area (2 ha/yr) currently under Jaragua grass with a rotation of maize and *Canavalia* over a 5-year period. The purpose of this scenario is to explore the contribution of *C. brasiliensis* as mechanism to improve soil fertility and make the system more sustainable by subsequently introducing improved pastures, such as *Brachiaria brizantha* cv. Toledo, as well as an energy source, for example sugarcane.

***Ex ante* environmental evaluation**

The environmental ex ante evaluation was focused on the effects that the incorporation of *Canavalia brasiliensis* into the crop rotation might have on environmental externalities such us sediment and water yields.

This analysis was conducted applying SWAT (Soil and Water Assessment Tool) for an area with biophysical conditions similar to those found in the visited farms. These conditions refer to soil, climatic and topographic characteristics and that were collected for the study area.

The value of soil characteristics considered in this analysis were obtained from the analysis of local soil samples conducted by the soil research component of this project (personal communication with S. Douxchamps). It includes information of texture and total C for the superficial soil horizon. In addition some information about soil type units was extracted from the Land Use Plan of Estelí (Plan de Ordenamiento Territorial in Spanish) (MARENA, 2001) and use to complement the information on texture and organic matter for subsurface soil horizons.

Using the soil texture information, the hydraulic conductivity, available water content and bulk density values were derived using the Soil Characteristic Tool (Saxton and Rawls, 1985; Saxton et al. 1986) that is applicable to mineral soils. In table 1, the values used in the SWAT modeling are shown.

Table 1. Soil characteristics used for the SWAT modeling

Horizon	Depth (cmm)	Bulk Density (g/cm3)	Available Water Content (cm/cm)	Saturated Hydraulic Conductivity (mm/hr)	% C	% Clay	% Silt	% Sand
A	0-20	1.13	0.15	22.44	23.4	28	32	40
B	20-70	1.32	0.1	1.2	6	54	18	28

The climatic data used consisted on daily values of precipitation, maximum and minimum temperature; and mean monthly temperature, radiation and wind velocity. The data sets for the period of January 1987 - December 2006 were obtained at INETER (Instituto Nicaraguense de Estudios Territoriales)

The topographic data was directly obtained from the Digital Elevation Model of the River Pire watershed at a resolution of 90 m. To do this an area of 154 ha was selected near the farms where experiments on *Canavalia brasiliensis* are being held, and which GPS points where captured during the field visit on 2007.

The climatic, soil and topographic data was integrated in SWAT to derive the values of sediment and water yields, surface runoff, lateral flow, percolation, evapotranspiration, and soil water for the following land use scenarios: 1) current maize-pasture system, 2) maize rotated with *Canavalia brasiliensis* which residues are left on the soil surface as green manure, 3) maize rotated with *Canavalia brasiliensis* that is grazed after 90 days of growth.

In figure 1, the schedule of planting for each scenario is shown. It is worth to note that these scenarios were assessed for the portion of land that is only planted with maize and not followed by other crop such as beans (see above description of scenarios 1-3).

Land use scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov
Tradditional maize rotation											Fallow
Maize rotated with *C.brasiliensis* as green manure											
Maize rotated with *C.brasiliensis* as forage											

Figure 1. Crop rotations scenarios evaluated in the ex-ante environmental evaluation

Results

Tables 2-5 present the average production costs of maize, beans, milk, and meat as well as average values of productivity, farm area distribution in different land uses, use of family and contracted labor, and herd composition. Table 6 presents the producers' expectations regarding the reduced requirement of fertilizers or the increase in milk production expected with the inclusion of *C. brasilensis* as green manure (in the former case) or animal supplement (in the latter). Table 7 presents the production costs and expected productivity of this legume.

ECOSAUT Model results

Table 8 shows the values for each scenario used for the *ex ante* evaluation of potential economic benefits derived from the incorporation of *C. brasiliensis* into the land use system of producers of the Pire river watershed as well as from the incorporation of other potential energy and protein sources that could help overcome the shortage of feed for livestock during the dry season and recover soil fertility.

- ***Benefits of* C. brasiliensis *under the current land distribution scheme (Scenario 1 versus Scenarios 2 and 3)***

Based on the results obtained, the incorporation of *C. brasiliensis* as green manure (Scenario 3) slightly decreased the net income as compared with the baseline (5%). The opposite occurred when this legume was used as animal feed (Scenario 2) because the net income of producers was increased by 5% (Table 8).

The urea applied in the baseline scenario is replaced in Scenario 3 with the incorporation of the legume into the soil. The reduction in net income obtained by using *Canavalia* as green manure can be attributed to the fact that, although the incorporation of the legume reduces the cost incurred for purchasing fertilizers, the requirement of contracted labor to plant the legume increases and the purchase of legume seed implies an additional cost. As a result, the benefit represented in reduced fertilizer costs does not compensate for the additional cost of planting the legume.

On the other hand, the increased income due to the incorporation of *Canavalia* for animal nutrition can be attributed to the increase in milk production, specifically during the dry season. Milk production during the dry season increased from 2 to 3 lt/day, representing a 26% increase in annual production as compared with the baseline. In addition, the increase in income is not only due to a greater volume of milk produced during the dry season, but also the higher price of milk during this time of scarcity (US$ 0,27/lt during rainy season compared with 0.32/lt during the dry season).

Therefore the benefits of using *Canavalia* as animal feed are related to the increases in milk production and not to increases in stocking rate or meat production, which are maintained.

- ***Benefits of using* C. brasiliensis *as animal feed when complemented with sorghum as energy source (Scenario 2 versus Scenario 4)***

The positive effect of complementing *Canavalia* with an additional energy source such as sorghum is reflected in the 80% increase in producers' net income as compared with Scenario 2 where only *Canavalia* is incorporated as additional source of feed for livestock. This increase can be attributed to the fact that milk production increased substantially by 137% due to the merging of three factors: (1) increased production potential from 3.7 to 4.4 lt/day; (2) doubling of animal stocking rate from 7 to 14 cows/farm; and (3) increased sale of milk during the dry season, which took advantage of the better prices that are characteristic of that season. This increase in milk production can be explained by the incorporation of an additional energy source into the system, which allows the additional protein resulting from the incorporation of *Canavalia* during the dry season to be used more efficiently. In other words, sorghum helps balance the additional protein provided by the legume.

- ***Benefits of incorporating* Canavalia *in the rest of the farm (Scenario 5)***

This scenario aims to estimate the benefits of gradually replacing those areas sown with Jaragua grass with an improved pasture, for example, *B. brizantha.* A maize/*Canavalia* rotation is used to gradually improve the soil in all areas sown to native pastures undergoing degradation. In the case of improved pastures, energy usually becomes a limiting factor so it is necessary to plant sugarcane to improve the nutritional balance for the better-quality pasture. These two factors make it possible to increase the number of cows (although not their production potential) in comparison with all other evaluated scenarios. With the renewal of the pasture and the incorporation of sugarcane, a stocking rate of 30 cows/farm can be used, with a milk production potential of 3.5 lt/day per cow. Compared with the baseline, this increases milk production by 17% and stocking rate 4.3 times.

Net income increases 2.8 times as compared with the baseline. The increase in income can also be attributed to the fact that the income derived from maize production increases because the areas that are replaced with *B. brizantha* were previously planted to maize/*Canavalia*. In other words, the maize grown in the area sown to pastures is additional to the area normally planted to this crop on the farm.

Results from the SWAT modeling

The results from SWAT modeling show that the incorporation of *Canavalia brasiliensis* reduces both, the sediment and the water yield by 32 and 10%, respectively. This is related with an important reduction on the surface runoff by 35%. The reduction of the surface runoff is related to improvements on water percolation and water lateral flow and the increment of the evapotranspiration (Table 2 and 3).

However there were not obtained differences between using *Canavalia brasiliensis* as green manure or as forage. These two options have the same effects in terms of water and sediment yields as well as on the other water balance variables (runoff, lateral flow, soil water, percolation and evapotranspiration) (Table 2).

Table 2. Results of SWAT modeling for different maize-based rotations

Land use scenario	Evapotranspiration (mm)	Surface runoff (mm)	Lateral Flow (mm)	Percolation (mm)	Sediment yield (t/ha)	Water yield (mm)	Soil water (mm)
Tradditional maize rotation	---	---	---	---	---	---	---
Maize rotated with *C.brasiliensis* as green manure	4.62%	-35.21%	5.25%	3.63%	-31.91%	-10.64%	3.11%
Maize rotated with *C.brasiliensis* as forage	4.61%	-35.20%	5.25%	3.65%	-32.08%	-10.62%	3.11%

Table 3. Water balance for a 20-yr period: Traditional maize-pasture rotation vs. *C.brasiliensis*-based rotations

	Tradditional maize rotation	Maize rotated with *C.brasiliensis* as green manure or forage	Difference
Surface runoff (mm)	1925.897	1247.801	-678.096
Lateral Flow (mm)	433.047	455.79	22.743
Groundwater (mm)	2316.36	2474.024	157.664
Water yield (mm)	4675.304	4177.615	-497.689
Evapotranspiration (mm)	12398	12970.85	572.85

Although the total annual water yield is reduced with the *C.brasiliensis*-based scenarios, there are increments on it during the dry months (figure 2). In figure 3, the difference on monthly water yields between traditional maize rotation and *C.brasiliensis* rotation is shown.

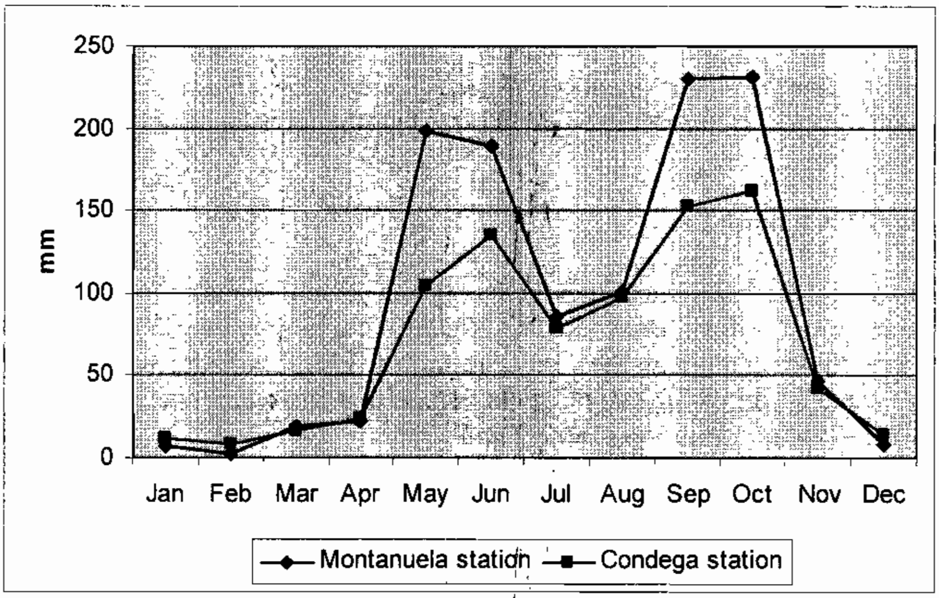

Figure 2. Average monthly precipitation (mm) for two stations near the study area

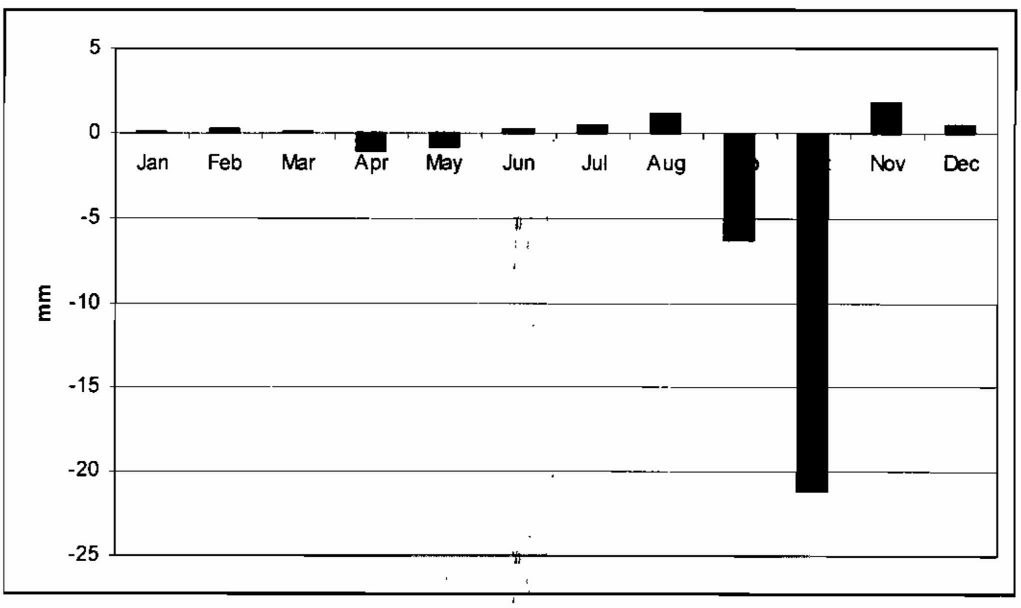

Figure 3. Annual average difference on water yield (mm) from changing traditional maize-pasture rotation to maize-legume rotation

It is worth noting that the effect of *Canavalia brasiliensis* varies throughout the years as the rainfall varies yearly. The precipitation datasets showed that there is a great variation on annual rainfall (figure 4). The lowest rainfall was registered on 1992 with 493 mm/yr and the highest on 1998 with 1384 mm/yr. During the wettest year the sediment yield for the traditional maize rotation is 70 /ha/yr and for the *C.brasiliensis*-based scenarios is 57t/ha/yr. In the driest year it was 9.6 t/ha/yr and 4.5 t/ha/yr for the traditional and legume-based scenarios, respectively.

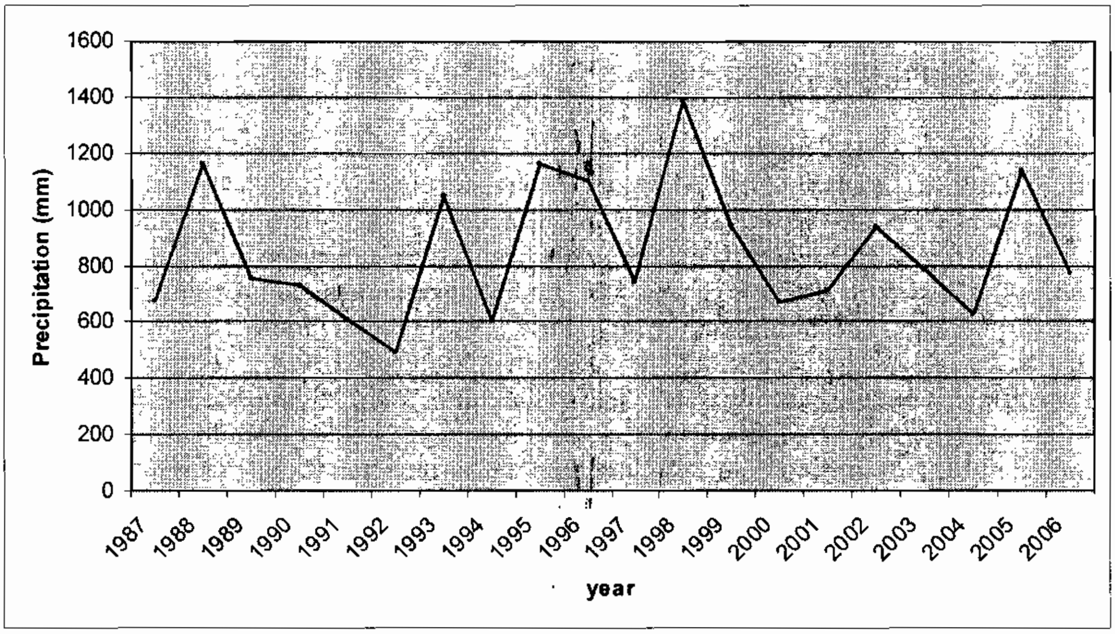

Figure 4. Annual rainfall 1983-2005

Discussion

Is it feasible to achieve this proposed redistribution of land uses in these scenarios? One prerequisite is stability in the prices of maize, beans, and milk, which helps producers perceive greater economic security to incur in the initial investment that this type of change requires. The aversion of producers to assume the risk implicit in the increase of area planted to crops or the introduction of new crops and pastures was confirmed during the field visit, when producers said that price instability was the principal limitation to increasing the area planted to crops. This was corroborated by the fact that the area on farms dedicated to crops is very similar, regardless of the variations in total farm size. For example, a 17-ha farm and an 8-ha farm will always have 2 ha planted to crops. In farms under 5 ha, the area planted to crops is only slightly less.

Another factor that could limit the feasibility of incorporating the proposed changes in these scenarios is the local availability of labor. Contracted labor would necessarily increase from 90 to 384 man-days as compared with the baseline, or the family labor dedicated to agriculture activities would increase by more than 100%.

Another factor that could currently be hindering the expansion of the agricultural area and the purchase of livestock are the high interest rates reported by producers. These rates range between 10% and 26% in real terms. As a result, the system never generates sufficient surplus to support higher investments in the future. The effective term is substantially reduced, which especially affects long-term investments in livestock.

By expanding the area planted to crops, the stocking rate could be increased on several farms of the Pire river watershed and, as a result, the inventory of cattle available in the area could dwindle. This, in turn, would have an impact on the prices of livestock and would not only curtail the feasibility of Scenarios 2, 4, and 5 but also affect foreseen economic benefits. In this sense, it would be better to improve the birth rate of livestock using better-quality forage, for example *C. brasiliensis*, and improved pastures, such as *B. brizantha.*

Environmental Impacts

The results from SWAT modeling permit to quantify the environmental effects that the incorporation of *Canavalia brasiliensis* would have on environmental externalities that are important to society such as sediment and water yields. It is clear that the main benefit of incorporating this legume to the current land use system is that the sediment yields could be reduced. This effect is related with the fact that the legume provides some cover to the soil during the wettest months (September and October) (Figure 2).

However this is not the case for water yield[4]. According to the results, the water yield is reduced when *C.brasiliensis* is either planted as forage or as green manure. This reduction is directly related with a reduction on the surface runoff that is too high and is not compensated by the improvements on lateral flow and groundwater. The reduction on runoff might be explained by the improvement on land cover provided by the legume and by an important increment on the evapotranspiration (table 3) with respect to the traditional maize rotation were the only crop is maize.

Although this total water yield reduction, the *C.brasilliensis* scenarios increase it during the drier months (November to March) where water yield is most important as an externality. The benefits of modifying this externality should be valuated to determine if that increment at the watershed level could be significant if the legume is introduced in several farms.

In another hand, the lack of differences between using the *Canavalia brasiliensis* as a green manure or as forage has to be done with the rainfall behavior. It was simulated that both, the cut of green manure and its posterior deposition on soil surface or the grazing of the legume, occurs after December when the crop biomass is high enough for these purposes. Due to on December the rainfall is minimal; the marginal impact of having a cover crop is insignificant because the soil is not exposed to the impact of rain drops.

It was expected that the soil water content might change with the incorporation of the legume as green manure. However there were not changes with respect to the scenario where the legume is grazed. Probably the contribution as a green manure is not big enough to counteract the effect of high temperatures and water deficit. The ongoing field measurements of soil moisture and organic matter in the experimental plots will permit to confirm or reject this ex-ante results. An eventual rejection will provide insights for calibrating the model for future ex-ante analysis.

[4] Water yield (mm H_2O). Total amount of water leaving the land and entering main drainage. Water yield= Surface runoff + Lateral flow + Groundwater + Transmission losses. Transmission losses are minimal in this case.

In consequence, from the farmer perspective, the environmental benefits of incorporating the legume to its current land use system could be only the reduction of soil loss during the rainy season since the effects on soil water appear to be not greater (only an increment of 3%). However these predicted impacts need to be verified during the implementation of the *C.brasiliensis*-based scenarios in the selected farms. Besides the farm-level environmental impacts the effects of the legume on subsequent maize harvests need to be measure in the field since the incorporation of OM, N and the possible increment on soil water could increment the maize yields.

Apart from the farm-level effects, the aggregated effect of having several farms under the *C.brasiliensis*-based scenarios in the watershed could be greater and significant in terms of soil loss reduction and water yields. For this purpose it is still indispensable to obtain soil data for all existing soil types in the watershed and river flow measurements in order to run and calibrate SWAT at this scale.

This step will be crucial to establish the trade off between reducing sediment yields vs. water yields. In case of confirming the potential reduction on total water yields after the incorporation of *C.brasiliensis* to the production systems, it will be necessary to compare the total benefits of introducing the legume to the system (economic farmer benefits derived from improvements in dairy or maize productivity + society benefits derived from sediment retention) with the cost for the society derived from total water yield reduction.

Also it would be necessary to analyze the cost of reducing total water yield and compare it with the value of benefits derived from the increments of water yields during the dry season.

Conclusions

Producers' expectations regarding the benefits of *C. brasiliensis* and its adoption potential

In the survey producers expressed that they would be willing to adopt *C. brasiliensis* as green manure if the use of fertilizers was reduced in 112 kg urea/year (i.e., 51 kg N/ha) and 112 kg NPK/year (i.e., 12-30-12). Taking into account that legume productivity in this *ex ante* evaluation was considered to be 2 t DM/ha per vegetative cycle and that this legume presents 20% protein, producers' expectations would be satisfied because this represents 64 kg N/ha (without counting the N fixed through *Rhizobium*.

Regarding the adoption potential of *C. brasiliensis* as animal feed, producers said that they would be willing to incorporate this forage into their systems if the daily milk production increased by 1.95 kg/cow during the dry season. If Scenario 1 (baseline) is compared with the other scenarios, the incorporation of *Canavalia* alone increases daily milk production, but does not succeed in meeting producers' expectations. Production barely increased by 0.7 lt/day in Scenario 2, 1.4 lt/day in Scenario 4, and only 0.5 lt/day in Scenario 5.

However, on-farm milk production can be increased beyond the expectations of producers by increasing the carrying capacity of farms as result of incorporating other technologies such as sugarcane and improved pastures.

Possible disparities between *ex ante* and *ex post* analyses

This study is framed within a broader experimental study that tries to measure changes in maize and milk productivity when *C. brasiliensis* is incorporated into the production systems of selected farms in the Pire river watershed in Nicaragua. The data derived from these experiments will allow these same scenarios to be evaluated *ex post*.

Taking into account the interdependences between income and the different characteristics of production systems, the possible variations in the value of several of these regarding those used in the *ex ante* evaluation could imply changes in the net income of producers—the objective of this evaluation. These characteristics are listed below and should be taken into account when collecting data during the experimental phase:

(a) Increase in maize productivity per ha, due to increases in biomass caused by the incorporation of *C. brasilensis* as green manure. This study did not assume any increment on maize productivity after incorporating the legume into the soil.

(b) Contribution of N made by *C. brasilensis*. This study assumed a legume production equivalent to 2 t DM/ha, with 20% protein.

(c) Frequency of planting of *C. brasiliensis* necessary to maintain the increases in maize and bean productivity over time. This study assumed that it was necessary to rotate the legume with maize every year.

(d) The amount of N supplied by *C. brasiliensis* that is really tapped by the crop. The study assumes did not discount from the total N contributed the part that may be lost either by leaching or volatilization.

(e) Maximum milk production potential of cows on selected farms. This study estimated that these cows would reach a maximum production of 4.4 lt/day with better-quality feed using *C. brasiliensis* and sorghum.

In relation to the *ex-ante* environmental analysis the results may vary as some input data could change after experimentation and *ex-post* measurements. These data is related with the following variables:

(a) Soil characteristics for the different scenarios: Saturated hydraulic conductivity, organic matter content, organic carbon, available water content and bulk density. Any variation on these parameters will affect the water balance.

(b) The real estimation of % of residues remaining on the soil surface after cutting the *C.brasiliensis*. This will affect specially the surface runoff and sediment yields.

(c) Any improvement of maize biomass after the incorporation of the legume as green manure. If the biomass is increased it could reduce the runoff.

The improvement on data and a hydrological modeling at the watershed scale will permit to determine accurately the impacts on water and sediment yield in order to establish the trade off between these two environmental externalities derived from different land use scenarios.

Table 2. Land use and labor of small livestock producers in the Pire river watershed, Estelí, Nicaragua.

Variable	**Average (n = 10)**
Land use (ha)	
Natural grasses	8.90
Improved grasses	0.65
Crop area (maize + beans)	2.10
Forest	0.95
Total	12.6
Use of labor (no. of permanent annual workers)	
Family members (no.)[2]	1.0
– Dedicated to agricultural activities (%)	65
– Dedicated to livestock production (%)	35
Contracted (no.)[3]	0.19
– Dedicated to agricultural activities (%)	100
– Dedicated to livestock production (%)	0

[1] Same area used (i.e., the same lot) to plant maize and beans.
[2] Generally the head of the household.
[3] For agricultural activities related to the planting, cleaning, or harvesting of maize and beans.

Table 3. Animal inventory and milk production on small cattle farms of the Pire river watershed in Estelí, Nicaragua.

Variable	Average (n = 10)
Livestock inventory (no.)	
Milking cows	2.4
Dry cows	2.2
2-year-old heifers	1.8
1- to 2-year-old heifers	1.1
0- to 1-year-old calves	2.5
Bulls	0.2
Total animal units (AU)[1]	7.7
Stocking rate (AU/ha)	0.81
Milk production (kg/cow per day)	
Dry season	2.1
Rainy season	4.1
Milk prices ($/kg)	
Dry season	0.32
Rainy season	0.27

[1] Animal units (AU) per hectare of grass. 1 cow = 1.0 AU; one 2-year-old heifer = 0.8 AU; one 1- to 2-year-old heifer = 0.6 AU; one 1- to 2-year-old calf = 0.3 AU; 1 bull = 1.3 AU.

Table 4. Milk and meat production, income derived from livestock production, and production costs of milk and meat on small cattle farms of the Pire river watershed, Estelí, Nicaragua.

Variable	Average (n = 10)
Milk production	
Total (kg/farm per year)	3,624
Per day (kg/farm)	9.93
Per cow (kg/day)	4.14
Meat production (kg/farm per year)[2]	452
Value of livestock production	
Milk	1,029
Meat	360
Total	1,389
Production costs	
(a) Supplementation costs ($/farm per year)	
Hay	111
Concentrate	18
Molasses	4
Subtotal	132
(b) Lease of pastures during the dry season (US$/farm)[1]	195
(c) Family labor	
Allotted to livestock-related activities (no. full-time workers)	0.35
Opportunity cost of family labor (US$/farm per year)[3]	345
Total livestock production costs	
Farm (US$/year)	673
Per kg milk	0.18
Per kg meat	0.31
Pay for day's work ($/day)	8.3

[1] 80% of the producers interviewed regularly lease pastures during the dry season. The average was 9.1 heads of cattle during 2-3 months, at an average cost of US$3.85/head per month.

[2] Sale of weaned calves.

[3] 128 days of work, estimated on the basis of the commercial value of a day's work in the area of $2.70/day.

Table 5. Production costs, productivity, and income due to the sale of maize and beans on small cattle farms in the Pire river watershed, Estelí, Nicaragua.

Variable	Maize (n=10)	Beans (n=10)
Production costs ($/ha)		
(a) Inputs		
Land preparation (animal power)[1]	14.8	0
Herbicides[2]	13.2	15.1
Fertilizers[3]	71.3	45.2
Subtotal	99.3	60.3
Area planted (ha)	2.1	1.9
(b) Labor		
Contracted[4]	102.6	81.0
Family member[5]	335.8	335.8
Subtotal	438.4	416.8
Total production costs ($/ha)	308	280
Unit production cost ($/kg)	0.19	0.43
Production (kg/ha)	2,387	1,308
Sale price ($/kg)	0.27	0.66
Total production value ($/farm per year)	1,340	1,448
Self-consumption		
Destined amount (kg/family per year)	1,079	222
Value self-consumption (US$)	581	283
Income due to sale of agricultural surplus ($/farm per year)[6]	759	1,165
Payment of day's work ($/day)[7]	8.3	10.1

[1] Land is not previously prepared for bean cultivation because beans are planted immediately after maize harvest.
[2] Glyphosate.
[3] 82 kg complete fertilizer and 82 kg urea/ha are used in the case of maize; 52 kg complete fertilizer and 52 kg urea/ha are used in the case of beans. Price of complete fertilizer = $0.45/kg; price of urea = $0.42/kg.
[4] 38 day's work contracted for 2.1 ha of maize and 30 day's work contracted for 1.9 ha of bean, at a cost of $2.70/day's work.
[5] Equivalent to 124 day's work for 2.1 ha of maize and 124 day's work for 1.9 ha of beans, assuming an opportunity cost of $2.70/day's work.
[6] Does not include the cost of family labor.
[7] Value of production minus the cost of contracted labor and purchased inputs.

Table 6. Reduction in the use of fertilizer in maize and bean crops or increase in the amount of milk produced during the dry season that producers perceive as necessary to adopt the legume *Canavalia brasiliensis.*

Item		Amount
Milk production		
• Increased productivity/cow to justify the adoption of *Canavalia* as forage		1.95 (kg/cow per day)
• Value of additional milk production		$ 112.30 (per cow)
Green manure		
• Reduction in use of fertilizer/ha in maize and beans, maintaining the same productivity to justify the adoption of *Canavalia*		112 kg NPK 112 kg urea
• Value of reduced use of fertilizers		$ 104.2 (per ha)
Preference		
• Producers who preferred to adopt *Canavalia* (%)		
(jjjjj)	Only for producing maize and beans	30
(kkkkk)	Only for milk production	20
-	For both alternatives	60

Table 7. Estimated production costs, expected productivity, and unit production cost of *Canavalia brasiliensis* in Nicaragua.

Category	**Amount (US$)**
Production cost (US$/ha)	
Labor[1]	121.5
Fertilization	0
Herbicides	28.5
Seed[3]	35
Total	185
Production (kg DM/ha)	2,000
Unitary production cost (US$/kg)	0.0925

[1] 45 day's work distributed as follows: 17 for planting and 28 for cleaning and herbicide application, at a cost of $2.70/day's work.
[2] 3 lt/ha at $9.50/lt.
[3] Based on 35 kg/ha, at a cost of $1/kg.
[4] Around 1750 kg of leaves and 250 kg of grain.

Table 8. Characteristics of production systems in each scenario evaluated (annual value).

Characteristic	Scenario 1 Baseline	Scenario 2 *Canavalia* for animal nutrition	Scenario 3 *Canavalia* as green manure	Scenario 4 *Canavalia* + sorghum	Scenario 5 Rotation of paddocks with maize/*Canavalia*
Net income	2,994	3,169	2,849	5,700	8,383
Income due to maize[1]	1,098	1,098	1,147	1,098	1,098
Income due to beans[2]	798	798	807	798	798
Income due to milk[3]	1,277	1,692	1,261	4,068	6,770
Income due to meat[4]	631	641.48	631	1,218	2,561
Family labor[5]	266	266	266	266	266
Contracted labor[6]	90	141.05	135	365	384
Crop/grass distribution (ha/year)					
Beans	1	1	1	1	1
Maize	2	2	2	2	2
C. brasiliensis as green manure	----	---	1	---	---
C. brasiliensis for animal nutrition	----	1	---	1	1
Sugarcane	---	---	---	---	1.5
Cratylia argentea	---	---	---	---	---
Sorghum	---	---	---	4	---
Jaragua grass	10	10	10	6	---
Brachiaria brizantha	---	---	---	---	8.5
Milk production (lt/year)	4,470	5,740	4,470	13,640	23,102
Milk production (lt/day per cow)	3	3.7	3	4.4	3.5
Meat production (kg/year)					
No. cows/year[7]	7	7	7	14	30

1 Calculated with a sale price to producer of US$270/t and a productivity of 2.4 t/ha per year intercropped in the same plot with beans. The same productivity is expected if maize is grown with *C. brasiliensis* as green manure (2 t DM/ha). If used as green manure, *C. brasiliensis* replaces 100% of the urea traditionally used. The estimated contribution of N of *C. brasiliensis* is equivalent to 38 kg N/ha, which surpasses current levels of application of urea (128 kg/ha per year). If *C. brasiliensis* is used as forage, it does not have any impact on maize productivity and is assumed to have 20% protein content, 50% protein digestibility, and 2.0 Mcal of metabolizable energy/kg.

2 Sale price to producer is US$660/ton and productivity is 1.3 t/ha per year. A similar productivity is expected if beans are grown after *C. brasiliensis* is incorporated into the soil as green manure.

3 Sale price to producer is US$0.27/lt during the rainy season and US$0.32/lt during the dry season.

4 Sale price to producer is US$1200/t.

5 Family labor is the total of annual day's work required for all farm activities minus the number of day's work contracted per year indicated by producers during the field visit.

6 Price of contracted day's work is US$2.70.

7 Calculated taking into account that a cow requires 0.034 t digestible protein/semester and 2400 Mcal metabolizable energy/semester.

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