GENERATION OF ALTERNATIVE LAND USE OPTIONS: EXAMPLES FOR THE LIVESTOCK SECTOR

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Abstract

The dominant feature of pastures established after forest clearing is pasture degradation, this being the main factor contributing to the low biological and economic efficiency of cattle production in Costa Rica. Over the past years the REPOSA project collaborated with international and national institutions for developing improved pasture/silvopastoral technologies for the humid tropics of Costa Rica. The research focused on 1)identifying improved forage germplasms; 2) developing grass legume mixtures; 3) developing silvopastoral systems; and 4) modelling land use options.

High yielding forage species (herbaceous and woody) adapted to different ecological zones of Costa Rica were selected. *Arachis pintoi* was found to be the most grazing tolerant of the legumes evaluated and it formed compatible mixtures with *Brachiaria brizantha*. Grazing studies showed that annual LW gains on Arachis-brizantha pastures was 937 kg/ha which is four fold the level of production reported for native pastures. Legume-based pastures contributed to improvement in soil fertility and biological activity. Furthermore, improved pasture/silvopastoral systems were important land use options for sequestering C.

The results on modelling showed that legume based pastures were attractive land use options for cattle production especially when prices for beef and milk were increased. Silvopastoral options with timber trees planted in borderlines of natural and improved pastures were also important for increasing farm income and for diversification of livestock farms. It is concluded that improved pasture and silvopastoral technologies have the potential for increasing the biological and economic efficiency of livestock farms while contributing to the ecological sustainability of these systems

INTRODUCTION

Over the past decades the humid tropics of Costa Rica had been deforested mainly for cattle ranching. The dominant feature of pastures established after forest clearing is pasture degradation, this being the main factor contributing to the low biological and economic efficiency of cattle production in Costa Rica and in Latin America. About 77% of the total area under pasture in the humid tropics of Costa Rica is dominated by very unproductive native and natural grasses, the main species being ratana (*Ischaemum cilare*), carpet grass (*Axonopus compressus*) and *Paspalum* spp (Morales 1992). Domesticated animals, particularly cattle, are often regarded as a destabilising factor in land use and a major contributor to environmental degradation.

Over the past years the REPOSA project collaborated with international (CATIE and CIAT) and local institutions (Ministry of Agriculture, University of Costa Rica, Technological Institute of San Carlos, etc.) to conduct research on low-input pasture/silvopastoral technologies for improving animal production in Costa Rica. The main objective is to increase animal production in a profitable manner without suffering unfavourable social and ecological consequences. Research was conducted on several sites that are representative of pasture production in the country. Examples include 1) high rainfall areas with infertile soils (San Isidro); 2) High rainfall areas with fertile soils (Guapiles); and 3) Dry Pacific regions (Atenas). Research activities focused on 1) selection of forage germplasms that are well adapted to local edaphic and climatological conditions 2) development of grass-legume mixtures and 3) development of Silvopastoral systems. Pasture/silvopastoral land use options were modelled considering economic and sustainability indicators. This paper reports on main findings of research conducted to generate alternative land use options for cattle production in Costa Rica.

Germplasm selection

Improved high yielding forage species were selected for different ecological zones in Costa Rica. The grasses ***Brachiaria brizantha*** and ***Panicum maximum*** CIAT 16061 are well adapted to fertile, well-drained soils whereas ***Brachiaria humidicola*** and ***Brachiaria dictyoneura*** do well on acid, infertile soils in the humid tropics. These species have the potential to produce more than 20 tons DM/ha/year of moderate to high quality and are capable of supporting higher stocking rates (2 to 3 AU/ha; 1 AU = 400 kg LW) than existing species (Ibrahim and Mannetje 1998). ***Brachiaria dictyoneura*** is known to maintain a good soil cover and is recommended for hillside areas with grazing to reduce soil erosion. Herbaceous legumes identified for pasture improvement were ***Stylosanthes guianensis***, ***Arachis pintoi*** and ***Centrosema macrocarpum*** (Roig 1989; Ibrahim and Mannetje 1998).

Additionally research efforts were made to select fodder shrubs and trees for feeding ruminants since these species generally are more adapted to dry conditions, and some are of higher nutritive value than most natural or native grasses. Agronomic studies with ***Gliricidia sepium*** and ***Erythrina berterona*** showed that they are capable of producing more than 10 tons edible

DM/ha/yr (Table 1), with a crude protein content of more than 20 percent and *in vitro* dry matter digestibility (IVDMD) ranging from 52 to 60% (Flores 1998; Abarca et al., 1999). These species are commonly found on most cattle farms in the humid tropics of Costa Rica. ***Gliricidia*** is more adapted to dry conditions, and it is also found on pastures in the Guanacaste region. Other species with high fodder potential are ***Morus alba*** and ***Cratylia argentea*** the latter is well adapted to seasonally dry areas.

Table 1. Seasonal dry matter (DM) production of some tropical fodder tree/shrub species

Fodder species	**Edible DM yields (tons/ha/yr)**		**Management regime (references)**
	Humid zones	**Dry zones**	
Gliricidia sepium	12 – 16	8 – 12	Dry matter production measured with pruning every 3 months and different grazing intensities (CATIE 1995; Mochiutti 1995)
Erythrina berteroana	12 – 18	-	Production measured under browsing conditions every 3 months (Abarca et al., 1999; Ibrahim *et al* 1999).
Morus alba	10 – 15	7 – 9	Measured under cutting regimes and different N fertilizer rates (Espinosa 1996).
Cratylia argentea	15 – 18	8 – 12	Pruning every 3 to 4 months (Argel 1995; Bazil *et al* 1995)
Acacia angusstissima	19	-	Pruning every 4 months (Herrera 1990)
Albizia sp.	22	-	Pruning every 4 months (Herrera 1990)
Trichantera gingatea	9- 16	-	Pruning every 3 months (Flores *et al.* 1999)

Legume-based pastures

Lack of legume persistence under grazing conditions has been one of the main reasons for failure of grass legume mixtures in the tropics. A long term experiment funded by the EU was conducted at the Los Diamantes Experimental station, Guaplies to select compatible grass legume mixtures. The legumes *Stylosanthes guianensis* CIAT 184 *Centrosema macrocarpum* CIAT 5713 and *Arachis pintoi* CIAT 17434 were evaluated in mixtures with Brachiarias (*Brachiaria brizantha* CIAT 6780 and *Brachiaria humidicola* CIAT 6339) grazed at two stocking rates (3 and 6 animals/ha). The results showed that *Arachis* pintoi was the most persistent of the three legumes evaluated and it resulted in stable mixtures with *Brachiaria brizantha* grazed at 6 animals/ha. *A. pintoi* accounted for 26% of total DM yields (21.7 tons/ha) measured with this mixture (Table 2).

Table 2. Mean annual dry matter yield (t/ha) of the sown grass and legume and volunteer spp.

estimated from *B. humidicola* (*Bh*) and *B. brizantha* (*Bb*) associations with *A. pintoi*, *C. macrocarpum* and *S. guianensis* grazed at 2 stocking rates (LSR = 1.75 AU/ha; HSR = 3.00 AU/ha).

	LSR		HSR	
	Bb	*Bh*	*Bb*	*Bh*
+ *Arachis pintoi*				
Sown grass	25.7	16.2	15.6	6.0
Sown legume	2.7	5.6	4.9	6.8
Volunteer spp.	0.9	4.6	1.2	5.0
Total	29.3	26.4	21.7	17.8
+ *Centrosema macrocarpum*				
Sown grass	27.1	2.1	18.5	5.7
Sown legume	0.3	1.8	0.4	1.8
Volunteer spp.	2.6	15.6	1.1	7.9
Total	30.0	19.5	20.0	15.4
+ *Stylosanthes guianensis*				
Sown grass	28.0	16.5	17.7	12.4
Sown legume	0.4	4.8	0.5	1.6
Volunteer spp.	0.9	3.8	1.4	1.6
Total	29.3	25.1	19.6	15.6

Mean total DM of SR over grasses and legumes (t/ha)		Mean total DM of grasses over legumes and SR (t/ha)	
LSR	26.6	*Bb*	25.0
HSR	18.3	*Bh*	20.0
LSD ($P < 0.05$)	4.3		3.6

Source: Ibrahim and Mannetje, 1998

The establishment of legume-based pastures resulted in significant improvements in animal production on existing pastures in the humid tropics of Costa Rica. Studies conducted in the Atlantic Zone of Costa Rica showed that annual liveweight gains on ***Arachis*** mixture was 937 kg LW/ha (Table 3) which is fourfold the values reported for liveweight gains on native pastures for the Atlantic zone of Costa Rica (Jansen *et al.*, 1997). The legume mixture sustained 6 animal /ha which is threefold those reported for native pastures in the region (Jansen *et al.* 1997). This means that cattle production can be practised on reduced area and thereby liberating land for reforestation programs. On farm studies conducted in the Atlantic zone also demonstrated significant improvements in animal production with the use of *Arachis* based pastures. Milk yields of dual purpose cattle grazing traditional pastures increased by 20% when animals grazed *Arachis* mixtures (Ibrahim unpbl.). Some farmers in the Atlantic zone have established *Arachis* mixtures especially in dual cattle production systems.

Table 3. Mean annual liveweight (LW) gain per animal and per ha on *Brachiaria brizantha* alone or with *A. pintoi* at two stocking rates.

	Liveweight gain (kg) Per animal		per hectare	
Stocking rate	3 an/ha	6 an/ha	3 an/ha	6 an/ha
Pasture				
B. brizantha	159	119	478	716
B. brizantha + *A. pintoi*	178	154	534	937
LSD (P = 0.05)	NS	27.4	NS	145

NS = not significant
Source: Hernandez et al., 1995.

The legume mixtures also contributed in improvement of soil fertility and biological activity. Ibrahim noted that ***Arachis*** fixed 128 kg N/ha/yr in the humid tropics of Costa Rica, which is of significant importance for sustaining high DM yields in cattle production systems. Under similar conditions Torres (1995) found that legume based pastures had higher earthworm population than the grass monoculture (371 vs 195 m^2) and these results demonstrates that legume based pastures can contribute to ecological restoration of degraded pastures in the humid tropics.

Silvopastoral Systems

Most farming systems in Costa Rica include some agroforestry practices that contribute partially to their economic and biotic sustainability. Systematic research was conducted to evaluate silvopastoral options for improving animal production and for diversification of livestock farms.

Living fences. Multipurpose tree species (eg. *Gliricidia sepium* and *Erythrina* spp) are commonly used as live fence post on cattle farms in Costa Rica. Studies conducted in the Atlantic Zone of Costa Rica showed that living fences of *Erythrina* (poro) and *Gliricidia* managed with three coppice/year, produced a significant amount of feed (2.4 kg DM/tree/year) that was of high nutritive value (IVDMD = 60%; CP = 23%). Milk yields increased by 15 to 20% when foliage of these plants were used to supplement dairy cows (Abarca 1989; Ibrahim unbpl.).

Protein/energy fodder banks. There had been considerable research on the use of woody perennials for establishing protein/energy banks for supplementing ruminants. Agronomic studies showed that woody species managed as protein/energy banks are capable of producing 10 to 15 tons edible DM/ha/yr (Ibrahim 1998; Ibrahim et al., 1999). However most of these studies were conducted under cut-carry management which has a high demand for labour. A grazing trial carried out at the Los Diamantes experimetal station, Guaplies showed that DM yields of Eryhtrina protein banks declined by more than 50% under a 2 months resting period but high yields were sustained with 3 months resting (Ibrahim et al., 1999).

The results in table 4 shows that the use woody fodder species contributed to improvements in animal performance. There use of mulberry a non-leguminous woody perennial, as a supplement for dairy cows resulted in relatively high milk yields (: 11 liters/cow/day) but be should be indicated that this species has a high demand for soil nutrients. High doses of fertilizer are required to sustain high DM yields of this species.

Table 4. Quality and animal response of some tropical fodder tree/shrub species managed as protein/energy banks.

Fodder species	Quality		Animal response	References
	CP (%)	IVDMD (%)		
Erythrina Berteroana	18 – 24	48 – 55	Steers grazing natural pastures in the humid tropics, increased LW gains from 0.39 to 0.51 kg/day when they browsed *E. berteroana* fodder bank two hours daily.	Ibrahim *et al.* 1999.
Erythrina poeppigiana	18 - 23	50 – 55	Dairy cows grazing *C. nlemfuensis* in the humid tropics increased milk yields linearly from 8.75 to 9.5 l/cow/day as the level of *E. Poeppigiana* in the diet was increased linearly from 0 to 0.53% LW.	Tobon 1988
Morus alba	12 – 18	70 to 85	Studies in the humid tropics of Costa Rica showed that dairy cows grazing *C. nlemfuensis* pastures and supplemented with 1 kg concentrate /100 kg LW or morera (1 kg DM/100 kg LW) produced 12.4 and 12.1 kg milk/cow/day respectively. Studies in the humid tropics of Costa Rica showed that dairy goats fed a basal diet of *P. Purpureum* and supplemented with morera (3% LW) produced 2.4 kg milk/day. Research conducted in the humid tropics showed that steers fed morera silage at 2.5 kg DM/100 kg LW) had LW gains of 600 – 650 g/day	Oviedo and Benavides 1994 Benavides *et al.* 1994 Gonzalez 1996
Trichantera gigantea	11 - 15	> 60	Not available	Flores *et al.* 1997
Cratylia argentea	19 – 23	48 – 58	In the humid tropics, dairy cows fed a diet of 25% sugar cane and 75% *C. argentea* produced 8.2 kg milk/day	**Franco 1997**
Hibiscus rosasinensis	12 – 15	> 70	In the humid tropics, dairy goats produced more than 3 liters milk/ day with supplementation of *H. rosasinensis* at 1 to 3% LW	Mochiutti *et al.* 1994

Alley pasture farming

Some research was also conducted to develop management strategies for tree/pasture alley silvopastoral systems. The results demonstrated that integration of multi-purpose trees in pastures contributed in improving pasture productivity and soil quality. At CATIE's experimental farm, eight improved grass species were evaluated in full sunlight and in managed poro (*Erythrina poeppigiana*) plantations. The results showed that six of the eight species evaluated produced significantly higher (11 to 52%) DM yields in the silvopastoral systems with poro; the most productive species being *Panicum maximum* and *Brachiaria brizantha* (Table 5). In association with poro these grasses had higher leaf area index which partially explained differences in yields.

Trees were also found to have significant effects on the quality of grasses. The results of Bustamante (1991) showed that improved grasses increased CP by to 2 to 3.8 unit percent in association with poro. Similar results were reported by Abarca *et al* (unpbl) in an experiment to determine the effect of shade on the quality of tropical grasses.

Table 5. Accumulated production (kg DM/ ha/5 cycles) of eight improved grass species established in full sunlight and in *Erythrina poeppigiana* plantations pruned every six months, Turrialba, Costa Rica

Species	With trees	Without trees	Dif, % (1 –2)/2
Panicum maximum CIAT 16061	29804 a	20791 b	43
Panicum maximum CIAT 16051	27780 a	24987 b	11
Brachiaria brizantha CIAT 6780	14437 a	10471 b	38
Penninestum purpureum (dwarf)	14343 b	16061 a	-11
Brachiaria humidicola 6369	9787 a	8162 b	20
Brachiaria brizantha 664	8885 a	6175 b	44
Brachiaria dictyoneura 6133	8393 b	9467 a	-11
Cynodon nlemfuensis	6818 a	4490 b	52

Values with the same letter in the same column are not statistically different ($P < 0.05$)
Source: Bustamente *et al*., 1998

The successful establishment of trees in pastures depends on the palatability of the species and the level of physical damage caused to trees during grazing. An experiment was conducted at the Los Diamantes experimental station during four years to determine grazing tolerance of trees (*Erythrina berteroana* and *Gliricidia sepium*) sown in a silvopastoral system with *Brachiaria brizantha/A. pintoi* mixtures. The results showed that *E. berteroana* tolerated high stocking rates (> 3.0 AU/ha; 1 AU = 400 kg Lw) and it sustained high DM yields (> 7 tons/ha/yr) during the grazing period (Abarca *et al*. Unpbl). On the other hand *G. sepium* was overgrazed and it disappeared in the pasture after the second grazing year. Stem densities (Y) of Gliricidia declined linearly in time (X) ($Y = 504 - 234X$).

Ecological studies conducted in Guaplies showed that soil microbial carbon and N in a grazed legume based systems (herbaceous and trees) was higher than those observed for the pasture alone treatments. Microbial N measured on soils sampled under primary forest, *B. brizantha* + poro, *B. brizantha* + *A. pintoi* and *B. brizantha* alone pastures were 186.6, 117.8, 131.2 and 69.9 mg/kg, respectively (Abarca unpbl).

Contribution of improved pastures to environmental sustainability

Over the last years there has been increasing interest in studying the role of tropical pastures in emitting and sequestering CO_2. In the Atlantic zone of Costa Rica large areas of tropical lowland forest have been cleared in the last 40 years, releasing large quantities of carbon to the atmosphere from the tree biomass destroyed (Veldkamp *et al.* 1992). A study on the dynamics of the soil organic carbon using the ^{13}C method showed that deforestation, followed by 25 years of low productive pasture, caused an additional net loss of soil organic carbon between 1.5 Mg C ha^{-1} and 21.8 Mg C ha^{-1}, depending on soil type (Veldkamp 1994). This is equivalent to a net soil organic carbon loss of 2 to 18 percent, and is roughly 10 percent of the losses directly from biomass.

While degraded and unproductive native pastures have been important sources for CO_2 emissions, studies with improved grasses in the humid tropics of Costa Rica showed that in contrast they can be important for carbon sequestration under favourable management. Most of these grasses have the C_4 krantz pathway and under favourable climatic (i.e. temperature and rainfall) and soil conditions they are capable of producing up to 30 tons DM ha^{-1} yr^{-1} (Ibrahim 1994), unlike unimproved grasses that can only yield 10 to 12 tons DM ha^{-1} yr^{-1} (Veldkamp 1994).

Introducing improved pastures of ***Brachiaria*** to replace native pastures can reduce the net CO_2 emission by about 60 percent depending on soil types. Veldkamp noted that gross emissions from ***Brachiaria*** pastures were higher on Andisols than on Inceptisols, but the highest net emission was found for the unproductive ***Axonopus*** pasture on the Andisols. In other studies, grass legume and silvopastoral mixtures grown on volcanic soils in the Atlantic Zone generated soil organic carbon levels similar to those measured under primary forest found in similar environments (Veldkamp 1993; Ibrahim 1994; Abarca *et al.*, 1999).

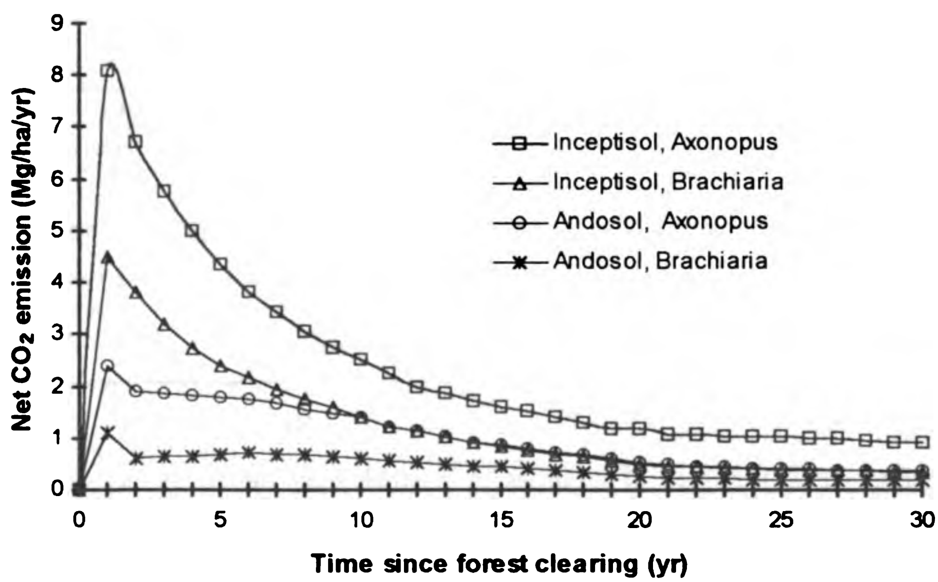


Figure 1. Simulated net CO_2 emissions for two soil types under a low productive (*Axonopus*) and high productive (*Brachiaria*) pasture. Source: Veldkamp, 1993.

There has also been some studies on emission on other greenhouse gases from pastures in the Atlantic Zone of Costa Rica. Working in the Atlantic lowlands of Costa Rica, Keller *et al.* (1993) found that N_2O emissions first increased greatly, and then declined with time following the conversion of forest to pasture. Keller and Reiners (1994) investigated further the patterns of trace gas fluxes following deforestation, pasture use and secondary succession of pasture to forest. They found that following forest clearance, soils of recently formed (i.e. young) pastures have nitrous oxide (N_2O) and nitric oxide (NO) emissions equal to or greater than emissions from undisturbed forest soils. In pastures older than 10 years, however, N_2O and NO soil emissions drop below levels observed from forest soils. These dynamic changes in N_2O and NO emissions are caused by a combination of rapid decomposition of soil organic matter (SOM) following deforestation (Veldkamp, 1994) and high soil water content in pastures related to compaction of the topsoil (Keller et al.,1993).

Nitrogen management affects soil-atmosphere nitrogen oxide fluxes depending on the source. Studies conducted on pastures in the humid tropics of Costa Rica showed that N_2O flux from the fertilized pastures was significantly higher than from the legume and traditional pastures (Table 6). Although the mean annual N_2O flux from legume pastures was almost twice as high as the flux from traditional pastures, this difference was not significant. On an annual basis, N_2O-N loss from the fertilized pastures was 22.6 kg N ha^{-1}, which corresponds to 6.8 percent of the applied 300 kg N ha^{-1}. The annual NO-N losses from fertilized pastures were 4.64 kg N ha-1 which corresponds to 1.3 percent of applied fertilizer.

Table 6. Annual mean and standard deviation of soil atmospheric N_2O and NO fluxes by pastures type.

Pasture Type	N_20 Ng N cm^{-2} h^{-1}	NO Ng N cm^{-2} h^{-1}	WFPS (%)
Traditional pasture	2.67^a (2.88)	0.94^a (0.59)	80.4^a (5.4)
Legume pasture	4.88^a (4.12)	1.29^a (0.74)	80.8^a (7.6)
Fertilized pasture	25.82^b (10.60)	5.30^b (1.19)	72.9^b (7.2)

Source: Veldkamp *et al.*,1996 .

These results show that use of legumes in pasture may be an attractive alternative to lower nitrogen losses. However, successful implementation of grass-legume combinations also requires good grazing management to ensure stability of the legume mixture.

Modelling land use options

Significant research efforts were made to halt pasture degradation, mostly focusing on the grass-legume mixtures, fertilised improved grass species and silvopastoral systems (Ibrahim, 1994, Hernandez 1995; Holmann *et al* 1992 ab). These alternative technologies, however, also have implications for the various dimensions of sustainability. First of all, economic viability is a prerequisite for adoption by farmers (Jansen et al 1997). Most of the new technologies halt soil mining by supplying extra N input via fixation by micro-organisms in symbiosis with legumes or directly via fertilisers.

Land use pasture options were modelled using an integrated approach to assess trade-offs among the various dimensions of sustainability (Bouman *et al.* 1999). Sustainability dimensions for current degrading and alternative non-degrading pastures in the NAZ of Costa Rica were quantified: economic viability, soil N balance CO_2, N_2O and NO emissions, pesticide use and N leaching. The methodology employed is based on an integrated systems-analysis and consider all aspects of a beef production systems (pastures, herds, and feed supplements). Tools used include an expert systems (PASTOR), dynamic simulation modelling and linear programming techniques (Appendix 1 and 2).

Three components were considered in a beef production system: 1) herd generating marketable product and characterized by feed requirements, ii) pasture supplying feed and characterised by sustainability indicators and iii) feed supplements An expert system called PASTOR (PASture and livestock Technical coefficient generatOR) (Bouman et al., 1998, Bouman Nieuwenhuyse) was used to compute input and output technical coefficients for a number of alternatives for each of these components. Alternatives were based on production levels and management technology.. Pastor was extended to compute sustainability indicators for the alternative pastures. Next, a linear programming (LP) wa used to quantify the economic viability of the whole beef production system. The LP model maximizes economic surplus by combining selected alternatives from each of the three sub-systems based on their technical coefficients.

The model was run for different cattle production systems and scenarios of meat prices and level of pasture production and it included sustainability indicators. Bouman *et al.* (1999) noted that with both 1996 and 1997 meat prices, fattening systems generated a higher economic surplus than breeding systems. The use of grass-legume was economically an attractive alternative over natural pastures when the latter production decreased from 15 to 10 t DM ha^{-1}, however it should be indicated that natural pastures rarely produce 15 tons DM ha/yr in the Atlantic zone.. Legume based pasture were more attractive options for cattle farmers with higher prices paid for beef in 1997 (Table 7). This is supported with results of Jansen *et al* (1997) which calculated internal rates of return of fattening animals on legume based pasture of 122% (10 years) whereas the silvopastoral systems had IRR of only 32%. High establishment and maintenance cost were associated with low IRR estimated for the silvopastoral system.

The scenarios developed for sustainability indicators showed that grass-legume and fertilised Brachiaria pastures were non-soil N mining, had low PEII (Pesticide Environmental Impact Index) and were CO_2 sinks, but high N leaching loss was observed on fertilised *Brachiaria* pastures (Table 7).). Based on these data, Bouman *et al* (1999) calculated that the the replacement of degrading pastures by grass legumes or fertilised improved grasses could change the CO_2 balance of pastures over a 20 year period from 30 t ha net emission to up to 20 t ha_{-1} net sequestration, implying a total sequestration 'gain' of 50 t ha_{-1}

In another study silvopastoral land use options for dual cattle production systems were modelled using PASTOR and linear programming as tools (Botero *et al*, 1999). For this study a representative cattle farm (70 has) which have different soil types (SFW = soil fertile well drained; SIF = soil infertile well drained; and SFP = soil fertile poorly drained). The pasture/silvopastoral options modelled were: natural pastures (NPT) improved grass monocultures with (tanner (TF), Brachiaria (BF), *C. nlemfeunesis* (CF)) and without fertilisation (T, B and C), *B. Brizantha/A. pintoi* (BbAp-T), poro protein bank (BP), alley farming pastures with poro and *Brachiaria brizantha* (Bb-P) and grazing in Teak plantations (PL). Besides in pasture systems teak grown in borderlines was considered except with poorly drained soils. The results showed that milk price was the variable which had the most striking effect on economic surplus of the system . A large percentage of the farms was selected with natural pasture and legume based pasture (SFW) that were enriched with teak planting (Figure 2). This demonstrates that the integration of timber trees in silvopastoral systems can play an important role in income generation and diversification of cattle farms in the Atlantic zone of Costa Rica. Establishment of large areas of forest (Teak) plantations on cattle farms were only viable when prices of timber were increased by 10 to 25% (Figure 4).

The results of modelling land use options shows that PASTOR and linear programming and can be used as tools for modelling land use options considering economic and sustainability indicators. However, it should be mentioned that most of data on herd requirements and pasture information used for generating technical coefficients in PASTOR was obtained from secondary information and in many cases the results were generated in different ecological and environmental conditions and with different cattle production systems. Research should have been conducted to better understand changes in quality of pastures which is affected by climate and soil type. Additional information is also needed to understand how botanical composition affects selectivity and intake of animals. DM Intake calculated by the model was 15 to 16 kg DM/anima/day which rarely occurs with tropical pastures. With respect to ecological data, there is need for more research to 1) quantify N fixation on different soil types 2) Nutrient cycling and 3) Carbon fixation.

CONCLUSIONS

Based on the results obtained on research for generation of technologies it is concluded the following:

1) The present management of livestock using extensive, unimproved pasture systems is not a very efficient or sustainable use of the land because the productivity of the land degrades as the original nutrient inventory is used up.

2) Improved pasture and silvopastoral technologies have the potential for increasing the biological and economic efficiency of livestock farms while contributing to the ecological sustainability of livestock production systems

3) Improved pasture/silvopastoral land use options can play an important role in C sequestration considering the vast areas under pastures.

2) Improved pasture and silvopastoral technologies have the potential for increasing the biological and economic efficiency of livestock farms while contributing to the ecological sustainability of livestock production systems

3) Improved pasture/silvopastoral land use options can play an important role in C sequestration considering the vast areas under pastures.

Table 7. Economic viability and sustainability parameters in beef breeding an beef fattening systems. Prices 1997.

Name	Ec. surplus (US$ $ha^{-1} y^{-1}$	SR[1] (AU ha^{-1})	NBAL[2] (kg N $ha^{-1} y^{-1}$)	PEII[3] ($ha^{-1} y^{-1}$	NLEA4 (kg N $ha^{-1} y^{-1}$)	CO_2-C[5] (Mg C ha^{-1})	N_2O-N[6] (kg N $ha^{-1} y^{-1}$)
Breeding							
Nat15	162	2.6	-63	9	59	18	10
Nat10	88	1.6	-32	14	36	25	6
Nat05	-[7]	-	-	-	-	-	-
Gleg	141	3.0	0	1	68	-10	12
Brfert	28	4.9	0	5	223	-30	23
Fattening							
Nat15	325	2.7	-63	9	62	14	12
Nat10	183	1.6	-32	14	36	25	6
Nat05	13	0.7	-3	27	16	31	3
Gleg	326	3	0	1	68	-10	12
Brfert	366	4.75	0	6	228	-27	21

[1]: Stocking rate; [2]: soil N balance; [3]: Pesticide Environmental Impact Index; [4]: amount of N leached; [5]: amount of CO_2 –C emitted (positive values) or sequestered in soil organic carbon (negative values) at 25 years after forest clearing; [6]: rate of yearly N_2O-N emission, [7]: economic surplus in negative and no farming occurs.

Source: Bouman *et al*, 1999

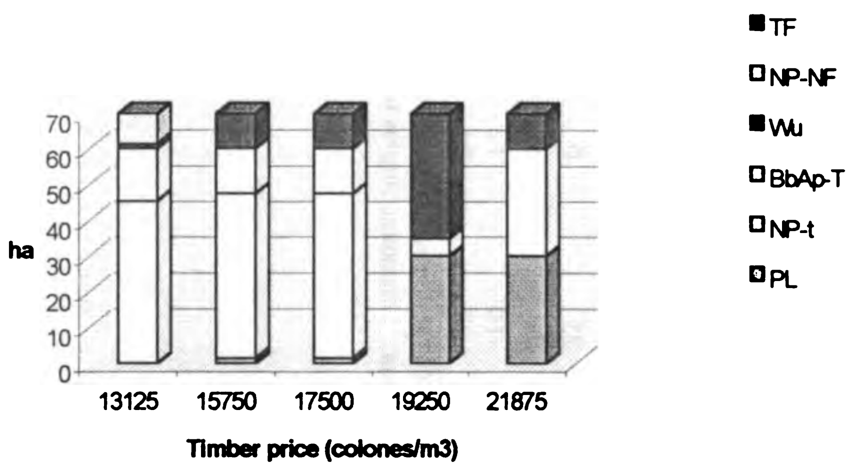


Figure 3. Effect of timber prices on the use of pasture/silvopastoral technologies for dual purpose cattle proudction in the Atlantic Zone of Costa Rica (june 1988). Source: Botero, 1998.

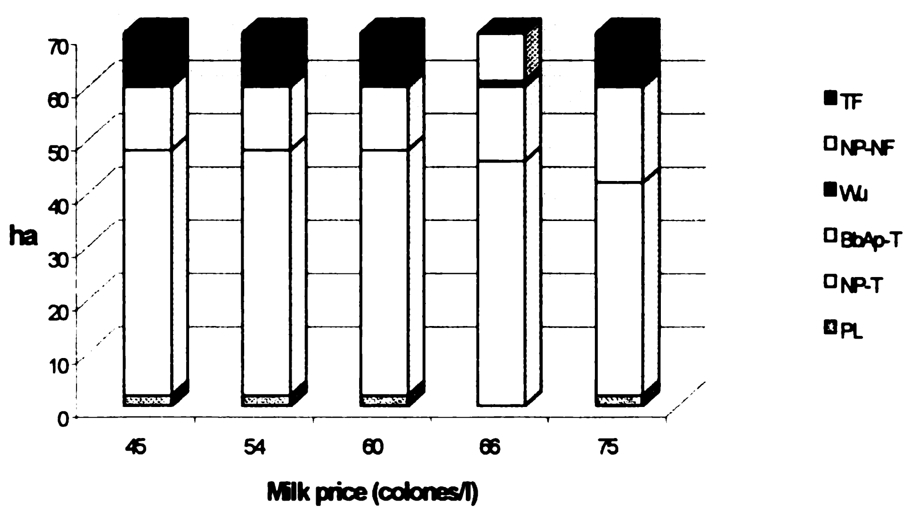


Figure 2. Effect of milk prices on the use of pasture/silvopastoral technologies for dual purpose cattle production in the Atlantic Zone of Costa Rica (june 1998). Source: Botero, 1998.

REFERENCES

Botero JA. 1998. Exploracion de opciones silvopastoriles para la sostenibilidad del sistema doble proposito en el tropico humedo. MSc. Thesis, CATIE, Turrialba, Costa Rica, CATIE. 99 p.

Bouman BAM; Plant RAJ and Nieuwenhuyse A. 1999. Economic and environmental sustainability trade-offs in cattle farming: Application to tropical Costa Rica. Submitted to Ecological modelling.

Bouman BAM; Nieuwenhuyse A and Hengsdijk H. 1998. PASTOR: a technical coefficient generator for pasture and livestock systems in the humid tropics; version 2.0 . A users guide. Quantitative Appraches in systems analysis, no. 18. AB-DLO-PE, Wageningen, The Netherlands 59 p

Bustamante, J. 1991. *Evaluación del comportamiento de ocho gramineas forrajeras asociadas con poró (Erythrina poeppigiana).* Tesis M. Sc. CATIE, Turrialba, Costa Rica, 130 p.

Bustamente J., Ibrahim MA and Beer J. 1998. Evaluacion agronomica de ocho gramineas mejoradas en un sistema silvopastoril con poro (*Erythrina poeppigiana*) en el tropico humedo de Costa Rica. *Agroforesteria en las Americas* **5** (19): 11- 16

CATIE (Centro Agronomico Tropical de Investigacion y Ensenanza). 1990. *Projecto Sistemas Silvopastoriles para el Tropico humedo. Informe annual 1990.* Turrialba, C.R., CATIE 170 p.

CATIE (Centro Agronomico Tropical de Investigacion y Ensenanza). 1991. *Projecto Sistemas Silvopastoriles para el Tropico humedo. Informe annual 1991.* Turrialba, C.R., CATIE 148 p.

Franco MH. 1997. *Evaluacion de la calidad nutricional de Cratylia argentea como suplemento en el sistema de produccion doble proposito en el tropico sub-humedo de Costa Rica.* M.Sc thesis CATIE, Turrialba, Costa Rica, CATIE. 75 p

Hernandez M., Argel P., Ibrahim MA and Mannetje LT. 1995. Pasture production, diet selection and liveweight gains of cattle grazing Brachiaria brizantha with or without Arachis pintoi at two different stocking rates in the Atlantic Zone of Costa Rica. *Tropical Grasslands* (Australia) 29, 134 -41

Holmann F; Estrada RD; Romero F Villegas L. 1992a. Technology adoption and competitiveness in small milk producing farms in Costa Rica: A case study. *Journal of Livestock Research for Rural Development.*

Holmann, F; Romero F; Montenegro J; Channa C; Oviedo E and Banos A. 1992 b. Rentabilidad de Sistemas Silvopastoriles con Pequenos Productores de Leche en Costa Rica: Primera Aproximacion. *Turrialba* 42(1): 79 –89.

Huising EJ. 1993. *Land Use Zones and land use patterns in the Atlantic Zone of Costa Rica. A pattern recognition approach to land use inventory at the sub-regional scale, using remote sensing and GIS, applying and object-oriented and data driven strategy*. Ph.D thesis, Agricultural University, Wageningen, 222 pp.

Ibrahim, M. 1994. *Compatibility, persistence and productivity of grass-legume mixtures for sustainable animal production in the atlantic zone of Costa Rica.* PhD Thesis. Wageningen Agricultural University. Wageningen, The Netherlands. 129p.

Jansen H., Ibrahim M; Nieuwenhuyse A and Abarca S. 1997. Evaluacion economica de la incorporacion de leguminosas en pasturas mejoradas, comparada con sistemas tradicionales de alimentacion en la Zona Atlantica de Costa Rica. *Agroforesteria en las Americas* 4 (15): Pp 9-13

Keller, M and Reiners, W.A. 1994. Soil-atmosphere exchange of nitrous oxide, nitric oxide and methane under secondary succession of pasture to forest in the Atlantic lowlands of Costa Rica. *Global Biogeochemical Cycles* 8(4): 399-409.

Keller, M.; Veldkamp, E.; Weitz, A.M.; Reiners, W.A. 1993. Effect of pasture age on soil trace-gas emissions from a deforested area of Costa Rica. *Nature* 365: 244-246.

Morales JL. 1992. *Distribucion del pasto ratana (Ischaemum ciliare) en las tierras de pastoreo de Costa Rica. In Seminario Taller, El pasto ratana (Ischaemum ciliare) en Costa Rica, Alternativa o problematica en nuestra ganaderia? San Carlos*: Costa Rica, Cooperativa de Productores de Leche Dos Pinos.

Pezo D; Kass M; Benavides, J; Romero F and Chavez C. 1990. Potential of legume tree fodder as animal feed in Central America. In: Devendra P (ed.*) Shrubs and tree fodders to farm animals. Proceedings of a workshop held in Denspar, Indonesia, July 24-29, 1989*. IDRC, Ottwa, Canada. Pp 163-175.

Roig C. 1989. *Evaluacion preliminar de 200 accesiones de leguminosas forrajeras tropicales en el ecosistema de bosque tropical lluvioso en Costa Rica (Guaplies, Costa Rica*). Tesis Mag. Sc. Turrialba, C.R. CATIE. 179 p

Romero F., Benavides J., Kass M and Pezo D. 1994. Utilization of trees and brushes in ruminant production systems. In:Homan JE (ed.) *Animal Agriculture and Natural Resources in Central America: Strategies for Sustainability*. Proceedings of a Symposium/Workshop held in San Jose, Costa Rica, October 7 –12 1991. Turrialba, Costa Rica, CATIE. Pp 205-218

Torres M. 1995. *Caracteristicas fisicas, qumicas y biologicas en suelos bajo pasturas de*

Brachiaria brizantha sola y en asocio con Arachis pintoi despues de cuatro anos de pastoreo en el tropico humedo de Costa Rica. M.Sc thesis CATIE, Turrialba Costa Rica, CATIE. 98 pp

Vallejos, A. 1988. *Caracterización y evaluación agronómica preliminar de accesiones de Brachiaria y Panicum en el trópico húmedo*. Tesis M. Sc. CATIE, Turrialba, Costa Rica, 127 p.

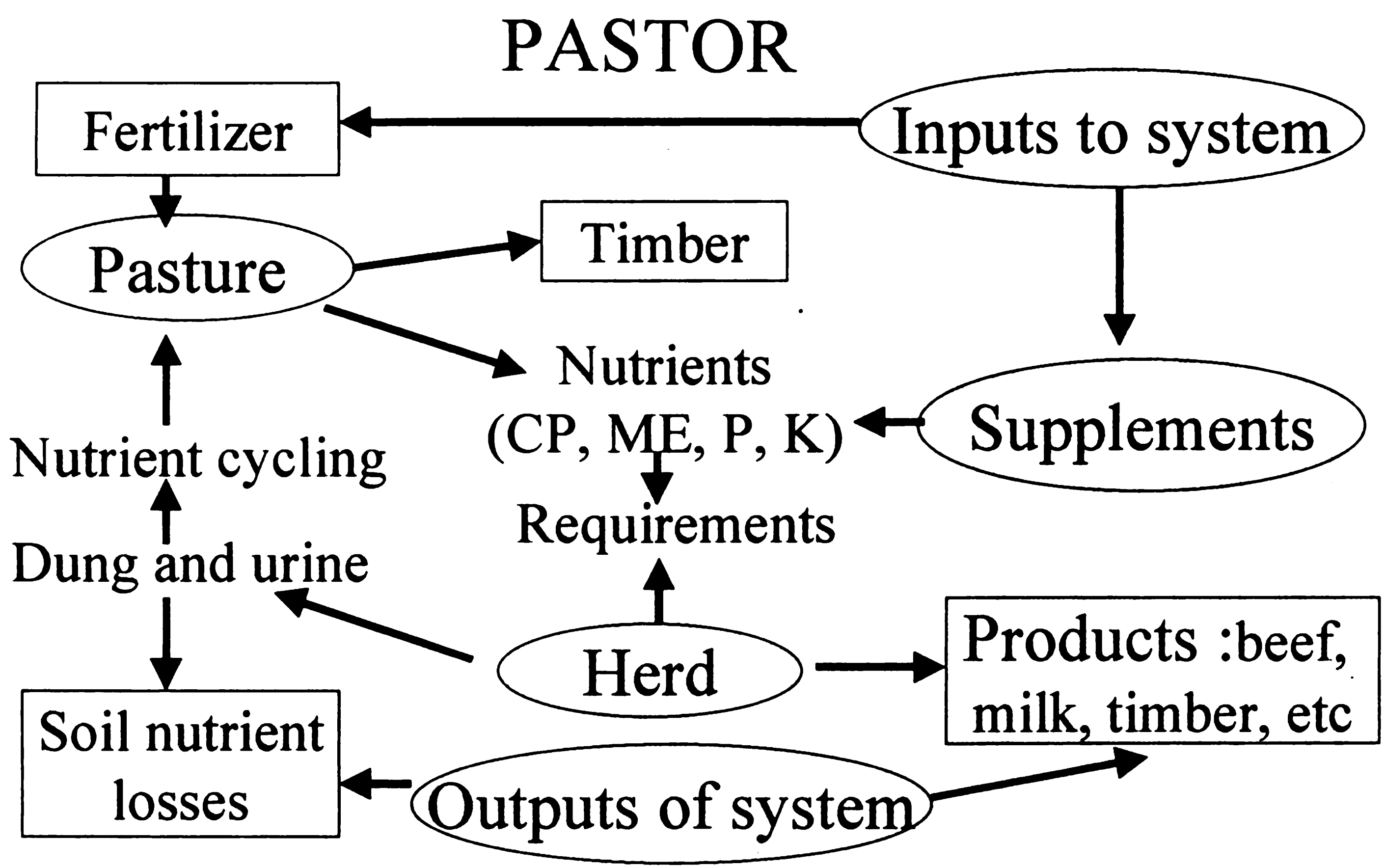
Veldkamp, E. 1994. Organic carbon turnover in three tropical soils under pasture after deforestation. *Soil science of America Journal* 58: 175-180.

Veldkamp, E. 1993. *Soil organic carbon dynamics in pastures established after deforestation in the humid tropics of Costa Rica*. Thesis Wageningen. pp 3-6

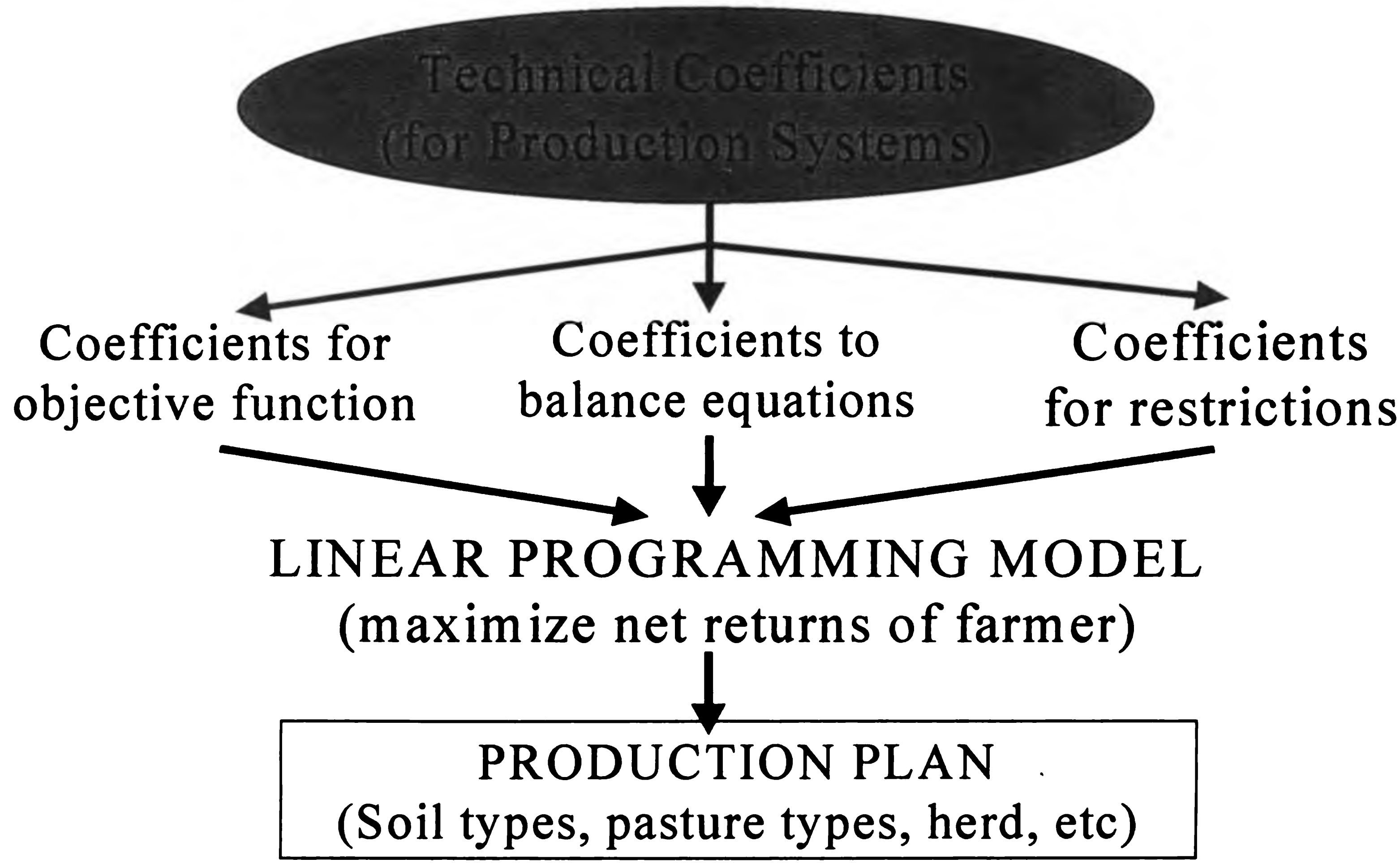
Veldkamp E., Keller M and Nunez M. 1996. Effects of management on N_2O and NO emissions from pasture soils in the humid tropics of Costa Rica. *Global Biogeochemical Cycles* (submitted).

Veldkamp, E.; Weitz, A.M.; Reiners, W.A. 1993. Effect of pasture age on soil trace-gas emissions from a deforested area of Costa Rica. *Nature* 365: 244-246.

Veldkamp E., Weitz AM., Staritsky IG., and Huising EJ. 1992. Deforestation trends in the Atlantic Zone of Costa Rica: a case study, *Land Degradation and Rehabilitation*, 3, 71-84.



Appendix 1. Flow of input/output data for generation of technical coefficients (CP: Crude Protein, ME: Metabolizable Energy).



Appendix 2. Flow of information for modelling objective function.