Turning Carbon into Cash: Economic Model of Payments for Carbon Sequestration in the Dry Tropical Forest of Costal Ecuador

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Introduction

Carbon payments have been receiving attention in the tropics because of their ability not only to mitigate climate change but also incentivize the conservation of forests (Angelsen et al. 2009). Some of these programs in developing countries have been promoted as providing additional income for the poor (Pfaff et al. 2007). One particular program under the Kyoto Protocol is the clean developing mechanisms (CDM), which offers financial incentives for carbon sequestration for afforestation and reforestation (Davidson et al. 2001). A new approach that seeks to provide compensation for carbon storage in standing forests has been referred to as Reduced Emissions from Deforestation and Degradation, and increased carbon sequestration from improved forest management (REDD+) (Macedo et al. 2012) . Even though these schemes have garnered much attention, evaluation of carbon-based conservation interventions outside the lowland moist tropics and in landscapes dedicated to commercial activities are relatively scarce.

Some previous work has examined the economic and ecological impact of carbon sequestration programs. The economic research has looked at the costs of implementing programs to reforest or establish tree plantations (Wunder and Albán 2008; Algoni 2011), how much farmers would have to be paid per ton of carbon sequestered to adopt agroforestry practices in the Phillipines (Shivery et al. 2003), what Brazilian Amazonian households would need to be paid to prevent further deforestation (Carpentier 2000),how payments can extent the rotation cycle of plantations (Olschewski and Benítez 2010), and how payments should be delivered to the communities or individuals (Skutsch et al. 2011). The research on the ecological impacts has studied how carbon payments can provide other environmental benefits such as biodiversity (Stephen et al. 2002; Venter, Laurence et al. 2009) or species protection (Venter, Meijraad et al. 2009). These studies provide a good understanding of how carbon payments impact environmental outcomes for forest conservation of standing forests. However, they fail to examine the complex mosaic of land use choices facing landowners of degraded tropical landscapes. In Ecuador where carbon sequestration schemes have been started (Wunder and Albán 2008), work has not examined how much carbon payments would need to be in order to obtain the desired outcome given the opportunity cost of landowners for other land use options. This paper fills this gap by examining the role of carbon payments to promote secondary forest conservation and/or induce raising monoculture tree plantations in a highly fragmented tropical landscape of semi-deciduous forest in costal Ecuador, where land users have been forgoing forest conservation to maximize profitability.

This paper is divided into five sections. The first section examines the current situation in Ecuador for payments for forest conservation and efforts to conserve the forest remnants in the study site. The second section explains the biological and social study methods used to measure the carbon captured by different land uses. This section includes the factors that influence the households in the area to use/ adopt certain practices including profits from various land uses. The fourth section explains the model developed to determine how much landowners would need to be paid in carbon payments in order to be no worse off in order to adopt forest conservation practices. The final section discusses the results produced by the model and their implications for developing a carbon payment scheme.

Forest Conservation Efforts in Costal Ecuador

The semi-deciduous forest of coastal Ecuador provides a unique opportunity to study carbon payments in fragmented landscapes since less than 5% of the native vegetation cover remains in this region (Dodson and Gentry 1991; Sierra 2002). However, the area between the towns of Pedernales (0°03’50’’N 80°03’06’’W) and Canoa (0°27’45’’N 80°27’27’’W) of approximately 125,000 ha is estimated to be 20% forested and constitutes the largest patch of forest remnants of this vegetation type (Neill 1999). The area is part of the Chocó/Darien western Ecuador biodiversity hotspot and is a priority for conservation (Myers *et al*. 2000; Cuesta-Camacho 2006; MAE 2011). Besides the area that has been dedicated to native forest preservation, the land uses in this area include pasture for livestock production, Teak *Tectona grandis* and Balsa *Ochroma pyramidale* plantations, and some afforested and reforested areas. From our analysis of our plots of primary and secondary forests, we found that these forests are made up of 20 different tree species much less than the 74 in primary forests but much higher than other land use types with *Albizia guachapele*, *Cocholospermum vitifolium*, and *Guazuma ulmifolia* being the most prevalent species in these forests.

The Ecuadorian government has recently, since 2008, made a concentrated effort to preserve the country's forested areas through the Socio Bosque Program. Indeed, many landowners in the region have already joined the program (MAE 2010). Secondary forests 30 years or older are eligible for the program (MAE 2010). Due to the fragmented nature of the current forested areas, an Ecuadorian nongovernmental organization, the Ceiba Foundation, and Conservation International have been active in encouraging landowners near these forest areas to convert their land use form pastures to secondary forests. The objectives of this effort are to provide corridors between the forests, preserve the regions biodiversity, and enhance other environmental services provided by these forests.

Payments for carbon sequestration in secondary forests have been seen by the Ecuadorian governmental, Conservation International, and the Ceiba Foundation as an avenue to encourage these landowners to switch their land use from pasture land to secondary forests. The payments would have to be large enough so that the land owner who earn as much by having a secondary forest as she would receive by ranching. However, monoculture tree plantations also sequester carbon and could receive these payments. Thus, these payments might actually encourage the landowner to convert her land to a plantation instead of a secondary forest, which would mean that the additional benefits from the forest such as enhanced biodiversity and the protection of endangered or threatened species would not be realized. The following section discusses our research methods to determine how much landowners would need to paid in order to reforest.

Methodology

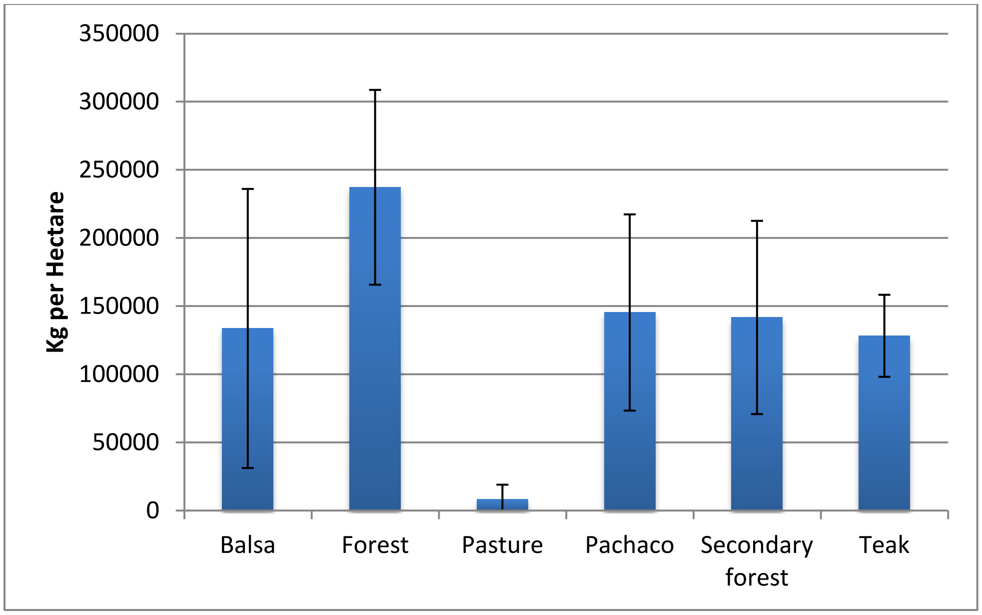
Field data was gathered on the species composition and tree diameter size in 38 plots of 60 by 60 meter in June of 2010 and in May and June of 2012. The data includes three Balsa plantation plots, eight forest plots, seven pasture plots, thirteen secondary forest plots, four Teak plantation plots, and three Pachaco *Schizolobium parahyba* plantation plots. Our estimates of the average above ground biomass estimates for the various land uses form our plots, *AB*, were based on the equations developed by Brown et al. (1989) and Chave et al. (2005). D represents wood density and *Dm* diameter and *H* height of the tree *i* in plot *j* with 0.0509 being the conversion factor.

$$B_i = 0.0509 * (D * Dm^2 * H) \tag{1}$$

$$AB = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} B_i}{\sum j} \tag{2}$$

Figure 2 shows how biomass accumulation and, thus, the amount of carbon stored differed by land use from based on data we gathered from our plots.

Figure 1. Average biomass in various land use types

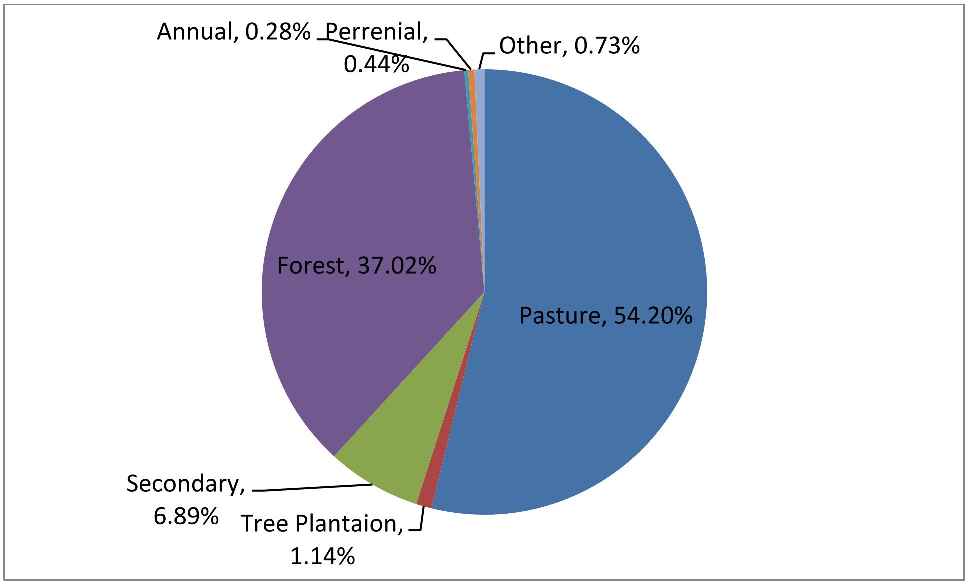


In addition to the test plots, twenty-four households including the landowners of the plots were interviewed about their land use including production costs and profits for each land use type, future and past land use of each parcel, opinions about the ecological benefits of primary and secondary forests, participation in the Socio Bosque program, and household composition and demographics. One clear distinction between households was the difference between land poor and land rich households. The landholdings held by the households included in the study ranged from just 1 hectare to 2,730 hectares of land. Ten households own less than 25 hectares of land while 11 own 180 hectares of land or more. The last three households own between 50 and 125 hectares of land.

Although this sample cannot be considered a representative sample of households in the county of Jama, this discrepancy in landholdings mimics the inequality in landholdings between wealthy and poor households in Ecuador and Latin America as Ecuador still struggles with land reform (Deere and León 2001).These land disparities will have a large impact on conservation policy as efforts to have the largest impact on afforestation, reforestation, and conservation will need to target the large landowners in order have the largest impact which limits the ability of the programs to alleviate poverty. Furthermore, large landowners have the space to dedicate to forest or secondary forest as they have other land to use for economic activities. In fact, only 3 households that have less than 25 hectares in the sample have forested land with the rest owned by households that own 90 hectares or more. This result is bolstered by fact that the households that participate in the Socio Bosque program in this county as smallest forest area registered in this program is 20 hectares and the largest 230 hectares (Madden 2012).

There is also a distinction in the land uses adopted by households with limited landholdings and those with more extensive land areas. The tree plantations are held by households that own more than 200 hectares of land. Pasture land is owned by all classes of household from the smallest group to the largest, which provides an opportunity for all these households to reforest this land. Figure 3 displays the land use preferences of the households included in the survey. Clearly, landowners prefer to dedicate their land to pasture, primary forest, and secondary forest make up nearly the entirety of land use of the participants. As pasture land is a majority of the land use, it provides the clearest opportunity for reforestation efforts.

Figure 3. Land use of land owners surveyed in Jama, Ecuador



Model

The carbon conversion equations are based on the model utilized by the Shively *et al.* (2003). This model expands on this work by including a net present value estimation of land use types to determine how much a landowner would have to be paid for each ton of carbon sequestered in order to be indifferent between land use options. As Figure 1 demonstrates pasture areas have very little biomass. Therefore, they have little potential for sequestering carbon. Furthermore, the household surveys revealed that it is common practice to burn the pasture every three years, which would release the stored carbon in these landscapes. Thus, the carbon sequestration rate of pasture is set to zero. For computing the carbon stored each year in a secondary forest the following model was utilized

$$V_t = 10^{2.94469-\left({}^{1.4139}/_{A_t}\right)-0.210044*ln(S)-\left({}^{7.8248}/_{Q}\right)} \tag{3}$$

$$B_t = V_t * D \tag{4}$$

$$E_t = e^{3.123-B_t} \text{ for } B_t\text{<190, otherwise 1.74} \tag{5}$$

$$M_{at} = E_t * B_t \tag{6}$$

$$M_{rt} = \left(\frac{M_{at}}{3.88}\right)^{\frac{1}{1.02}} \tag{7}$$

$$T_t = M_{at} + M_{rt} \tag{8}$$

$$C_t = (M_{at} + M_{rt}) * F \tag{9}$$

$$C = \frac{\sum_{t=0}^{T} C_t}{T} \tag{10}$$

V_t is the board volume of stand at time *t*. A_t is the age in years of the stand at time *t*. *S* is the product of the space between tree rows and between trees within a row. *Q* represents soil quality index with an average value of 30 used for the sites from indications provided by Shively et al. (2003). B_t is the merchantable tree biomass at time t. D represents the wood density. The densities for all the tree species in the secondary forest were determined and a weighted average that took into account species abundance was utilized. F provides a conversation of biomass to carbon with 0.474 utilized as indicated by Martin and Thomas (2011) as the correct value for tropical forests. E_t is the expansion factor to convert merchantable biomass to total biomass at time t. M_{at} is the total above ground biomass at time t. M_{rt} measures the root biomass with T_t providing an estimate of total biomass. C_t determines the accumulation of carbon at time t and C is the average accumulation of carbon per year. T is the time period at the end of the cycle which is twenty years in our study as carbon sequestration contracts in Ecuador and Socio Bosque contracts are twenty years long (Wunder and Albán 2008).

Estimation of the payments for only Balsa and Teak plantations and not Pachaco area estimated as these are the dominate types of plantations in this region. Since much of the carbon stored in the soil is lost when the trees are harvested, wood is the only product that provides a permanent carbon sink. Thus, the equation has been modified to only consider board volume for carbon storage. In addition, the densities used are different with 0.6013 used for Teak and 0.14 for Balsa. Balsa is a very fast growing low density wood often used for ship building, thus, the large difference in densities between the two species.

The following net present value model provides an estimation of the price that needs to be paid to a landowner to change her land use from pasture to secondary forest or Teak or Balsa plantations.

$$NPV = \frac{b_1}{(1+r)^0} + \frac{b_2}{(1+r)^1} + \dots + \frac{b_{20}}{(1+r)^{19}} \qquad (14)$$

$$NPV_{SF,T,or\ B} + NPV_C = NPV_P \tag{15}$$

$$NPV_P - NPV_{SF,T,or\ B} = \frac{b_P - b_{SF,T,or\ B}}{r}(1 - e^{-rT}) \tag{16}$$

$$\frac{(C_{SF,T,or\ B}) * P}{r} * (1 - e^{-rT}) = \Delta NPV \tag{17}$$

$$P = \frac{\Delta NPV * r}{C(1 - e^{-rT})} \tag{18}$$

NPV is the net present value with the subscript of *SF* representing secondary forest, *P* pasture, *T* Teak, and *B* Balsa. ΔNPV is the difference in net present value between two land uses. The net present value for secondary forest is set to zero, since none of households earn money from the products they obtain from the secondary forest. *b* is the annual benefit from the land use. *C* is the average carbon sequestered by the land use. *P* is the price per ton of carbon necessary for the landowner to switch to be indifferent between the two land uses. *r* is the discount rate.

Three different discount rates were utilized as the opportunity costs would be different for wealthy and poor households. Poor households are more concerned about meeting their immediate needs so they would value current consumption more over future income and, thus, would have a higher discount rate than wealthier households (Thomas 1995). Wealthy households would have money on hand and their opportunity cost would be the interest they could gain from interest on a savings account. Five percent was utilized is the deposit interest rate as established by the Ecuadorian Central Bank (http://www.bce.fin.ec). Sixteen percent was used as it is the credit rate for basic consumption goods, which provides a good base for the interest rate of middle income households that have to borrow money to invest. Finally, 25 percent is used for the poorest households as it is the microcredit loan rate which would be the only credit they would be able to access.

The net present values were calculated on the profits in one hectare of each of the economic activities. Balsa is raised in five years cycles so the cycle was repeated four times in the net present value estimations to determine the net value over the 20 year term of the carbon contracts. Since Teak plantations are harvested at 20 years time, one cycle was run for this scenario. However, the thinning of the Teak was considered in the carbon estimates as well as the thinned trees that are sold at a low market price when the trees are 12 years old. The net present value of for a hectare of pasture was estimated for a cow-calf pair as one hectare can support one cow-calf pair in this region. The model includes both the value of cheese, which is the most common product of those who raise livestock, as well as that of the calf sold each year valued over the life of cow, about 10 years. So, the cycle was repeated twice to estimate the net present value of a hectare of pasture. Refer to Appendix A for the production data for these different land uses.

The landowners told me that Ecuador is facing a particularly difficult marketing situation for livestock as the country has foot and mouth disease. Thus, Ecuador has not been able to export its livestock for the last five years and the price has dropped nearly in half since exports have closed. Several of the landowners are hopeful that Ecuador may be able to rid itself of the disease through its vaccination program in the next two or three years. However, a local veterinarian claims that the disease appears to be endemic and there is little possibility that the export ban will be lifted soon. Five interviewees disclosed that many families are only raising cattle out of "tradition" rather than for the economic benefit provided by this activity. Although this depressed livestock market has been a hardship for families in this area, it provides an opportunity for the forest to come back as pasture land has been abandoned and the forest is taking it over, or these families are switching to more lucrative land uses such as Balsa production that is becoming a popular activity in the province of Manabí ("La Balsa" 2011). In addition, carbon payments would not need to be as high if the alternative economic activity is not as attractive.

Results and Discussion

The average amount of carbon sequestered in secondary forest over the twenty years 56.65 metric tons per hectare in a year. The amount sequestered by Teak plantations is estimated to be 26.62 metric tons per hectare in a year. Balsa plantations are estimated to sequester 13.43 metric tons of carbon per hectare in a year. The net present values of each activity for each land use are displayed in Table 1. Balsa production is the most profitable land use for lower discount rates. However, pasture has the highest net present value for poor landowners who have the highest discount rate. Another noticeable result is that of Teak plantations. This land use has negative values for the highest discount rates because a landowner must wait a long time in order to reap the benefits from selling the wood. Thus, only land owners with a low discount rate such as wealthy landowners would choose to raise Teak.

Table 1. Net present value per hectare over twenty years (US dollars)

Activity	5% Discount	16% Discount	25% Discount
Pasture	9979.66	4855.41	3218.82
Balsa	14831.66	5352.71	2637.82
Teak	9264.51	-160.92	-1423.12

Given the net present values for the different activities and the carbon that sequestered in each activity, the amount that landowners would have to be paid per ton carbon sequestered to switch from pasture to secondary forest, a Balsa plantation or a Teak plantation are displayed in Table 2. The positive values for secondary forest show how much a landowner would have to be paid per ton of carbon sequestered to change her land use preference from pasture to secondary forest. The negative values for Balsa production reveal the landowner would be willing to pay this amount per ton of carbon in order to still grow Balsa. Thus, landowners with lower discount rates would not need to be paid anything in carbon payments to raise Balsa instead of owning cattle.

Table 2 Carbon payments per ton of carbon to switch from pasture (US dollars)

Activity	5% Discount	16% Discount	25% Discount
Secondary Forest	13.24	13.58	13.59
Balsa	-28.57	-6.18	10.89
Teak	2.21	31.43	43.88

As conservationists have begun to target reforestation, afforestation, and conservation efforts that provide for additional ecological benefits for carbon, some carbon payment schemes are paying only for reforestation of native forest and not monoculture plantations. Thus, these programs would need to pay enough so that the landowner values the payment more than he would get with any other activity. The amount that would need to be paid to a poor landowner is just 13.59 since the value for the carbon payment for Balsa and Teak is positive. However, the payment size for landowners with lower discount rates would be determined by summing the absolute value of the Balsa carbon payment with that for secondary forest. Thus, these landowners would need to be paid between 19.76 US dollars and 41.81 US dollars per metric ton of carbon sequestered to convert their pasture to secondary forest.

The necessary payment is much lower for landowners with a high discount rate, which would be poorer landowners. Thus, the most cost effective way to promote reforestation would be to pay poor landowners to reforest which means these payments could be used as a method to poverty alleviation. However, the poor landowners do not own much land. In order to meet conservation goals wealthier landowners may have to be encouraged to reforest as well at a higher cost to the program.

If the export restrictions were removed from the Ecuadorian livestock industry, the price of cattle could double. This scenario would change the net present value for pasture and the carbon payments necessary for a landowner to be incentivized to switch land use to secondary forest. If cattle prices doubled, the net present value for pasture would increase to 13,523.26 US dollars with a 5 percent discount rate, 6450.88 US dollars with a 16 percent discount rate, and 4217.89 US dollars with a 25 percent discount rate. The amount that would need to be paid per metric ton of carbon sequestered would increase as shown in Table 3. The necessary price for carbon payments for the poorest households would increase to 17.80 US dollars per ton of carbon while it would fall to 25.64 US dollars per ton of carbon sequestered for the landowners with the lowest discount rate.

Table 3 Carbon payments per ton of carbon to switch from pasture with higher livestock prices (US dollars)

Activity	5% Discount	16% Discount	25% Discount
Secondary Forest	17.94	17.89	17.80
Balsa	-7.70	13.64	29.61
Teak	12.65	41.42	53.33

These carbon sequestration values really would overestimate the carbon payments would need to be for a landowner to conserve secondary forest and, thus, only provide an upper limit of the necessary payments. Landowners obtain additional benefits outside of the economic benefits that would influence their production decisions. Households that participated in the study stated that their forested areas provide them with nonmarket benefits such as clean air and water, protection from soil erosion, and aesthetic pleasure. When these nonmarket goods are included in the land use decision, the net present value of the secondary forest would be positive lowering the amount that needs to be paid to landowners to reforest. These nonmarket values influenced the land use decisions of Ecuadorian smallholder cacao producers who were willing to adopt less profitable agroforestry systems instead of the more profitable monoculture production methods because of the additional benefits from biodiversity and soil quality they obtained from the agroforestry system (Blare 2010). Because of these values, the landowners would be willing to receive a lower payment for the carbon sequestered. To fully understand the necessary price that needs to be paid to the landowners these additional values need to be explored through contingent valuation methods. Further work should examine the carbon sequestration rates as well and the net present value of the permanent cropping systems such as diversified cacao or coffee production methods, even though these land uses make up little of the landscape in this area. These cropping methods provide some of the ecological services of the forest while still allowing the family to earn an income (2010).

The implementation of payments for carbon sequestration in the dry land forests of coastal Ecuador could have several effects. Unless these payments were directly solely to conservation and reforestation projects, the economic profitability of Balsa plantations would induce all but the poorest households to plant Balsa. However, if Balsa was not included the payment schemes would have to pay considerably more to wealthier households to participate in forest conservation. The results do reveal that poorer households could be the most cost effective avenue to reforestation as the value they need to receive in carbon payments is much lower than that of wealthier landowners. Thus, payment for carbon sequestration may be able to ensure conservation of threatened forest habitat while providing an income source for the poverty stricken communities in these degraded tropical landscapes.

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Appendix A

Table 1 Production costs and income from a hectare of Balsa (US dollars)[1]

	Year 1	Year 2	Year 3	Year 4	Year 5
Costs					
Planting	620	0	0	0	0
Weeding	200	200	100	50	50
Pruning	0	200	200	100	0
Pesticide Application	50	50	50	50	50
Harvesting	0	0	0	0	750
Transportation	0	0	0	0	1200
Administration	174	90	70	40	410
Total	1044	540	420	240	2,460
Revenue	0	0	0	0	11,250
Profit	-1044	-540	-420	-240	8,790

1. Ecuador Forestal. Ficha Técnica No. 5 Balsa. Website 03 Oct 2012 http://www.ecuadorforestal.org/download/contenido/balsa.pdf

Table 2. Production costs and income from a hectare of Teak (US dollars)[2]

	Year 1	Year 2	Year 3-4	Year 5	Year 6-10	Year 11	Year 12-19	Year 20
Costs								
Planting	620	0	0	0	0	0	0	0
Weeding	200	200	200	200	50	100	0	0
Pruning	0	400	200	200	200	200	200	200
Pesticide Application	50	50	50	50	50	50	50	50
Harvesting	0	0	0	600	0	200	0	400
Transportation	0	0	0	240	0	400	0	800
Administration	174	130	90	258	60	190	50	290
Total	1044	780	540	1548	360	1140	300	1740
Revenue	0	0	0	2775	0	4675	0	29,600
Profit	-1044	-780	-540	1227	-360	3535	-300	27,860

2. Ecuador Forestal. Fincha Técnica No. 1 Teca. Website 03 Oct. 2012 http://ecuadorforestal.org/fichas-tecnicas-de-especies-forestales/ficha-tecnica-no-1-teca/

Table 3. Production costs and income from livestock produced on one hectare (US dollars)

	Year 1	Year 2-9	Year 10
Costs			
Purchase Cow	400	0	0
Vaccine	4.20	4.20	4.20
Wormer	80	80	80
Labor	53	53	53
Bull Costs	30.64	30.64	30.64
Transportation	28.08	28.08	28.08
Total	595.91	167.58	167.58
Revenue			
Cheese	850.50	850.50	850.50
Calf	225	225	225
Cow	0	0	400
Bull	0	0	13.33
Total	1075.50	1075.50	2118.83
Profit	479.59	907.92	1951.25