CROP MODELLING OF EUCALYPTUS PLANTATIONS IN NICARAGUA

Monique Hoogwijk

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Summary

Background

In Nicaragua, at this moment, there is a potential for sugarmills to extend their power production and sell power to the national grid, both during and outside the sugarcane crushing season. During the sugarcane crushing season bagasse can be used as an energy source. An off-season fuel is eucalyptus from dedicated energy plantations.
In Nicaragua two sugarmills (“San Antonio” and “Victoria de Julio”) have taken the initiative to implement this concept.

Objectives:

1. To estimate the eucalyptus yield for power generation at the plantations of the sugarmill San Antonio in Nicaragua.

A further objective is:

2. To analyse the ecological impact of the large scale energy plantations at the area of the sugarmill San Antonio in Nicaragua.

Methodology:

For the yield estimation a mathematical model was used, based on well-established principles for the estimation of the potential and the water limited yield with the radiation, precipitation and soil retention capacity as input parameters. For the determination of the actual yield, harvest results from plantations of the sugarmill Victoria de Julio were used. By using these data and the potential and water limited yield at Victoria de Julio, an extrapolation for the sugarmill San Antonio could be made.

The environmental impacts were mainly determined qualitatively and obtained from literature. The impact of the energy plantation on the fertility status of the soil was assessed by using a nutrient balance.

Results and conclusions

The estimated potential yield was higher for the plantation of Victoria de Julio compared with San Antonio. The same was observed for the estimated water limited yield, in spite of the much higher precipitation at San Antonio. This could be explained by the higher potential yield. When the water limited yield was estimated for the whole lifetime of the plantations, the mean annual estimated water limited yield was higher for the plantation of San Antonio than for Victoria de Julio. This could be explained by a higher rotation time and a higher total estimated lifetime of the plantation of San Antonio.
The actual yield, determined by the extrapolation of the harvest results of Victoria de Julio to the actual yield of San Antonio, resulted in a mean annual actual yield over the whole lifetime of almost 10 $ton_{0\%}$/ha/yr.
The actual yield of San Antonio was not very sensitive for the radiation utilisation coefficient and the water use efficiency, because these parameters are used for the extrapolation of the actual yield as well. The soil profundity and the actual yield of the plantations of Victoria de Julio were more sensitive on the actual yield of San Antonio.
Because the model was not validated and no reliability analysis was done, it was not possible to draw conclusions on the reliability of the model and its results.

It was concluded that the environmental impacts of the energy generation from eucalyptus were less than of the energy production by fueloil. The use of fossil fuel, the emission of CO_2 and the emission of acidifying gasses are much lower for the energy generation from eucalyptus as for power from fueloil. The emission of dust is higher for eucalyptus, but this can be reduced by using flue gas-cleaning.

The nutrient balance that was constructed for the plantation of the sugarmill San Antonio had a deficit (for N: 14.7 kg/ha/yr.), but it was not possible to determine the effect on the fertility status over the whole lifetime because the effect on the actual yield was not modelled.

Preface

This report is the result of my graduation research for the master of science programme Chemistry at the Utrecht university in the Netherlands. The research was carried out at the Department of Science, Technology and Society (STS), Utrecht University.
The fieldwork for this study was done at the sugarmill San Antonio in Chichigalpa, Nicaragua.

I would like to thank the people in Nicaragua that were very helpful during the fieldwork. Ricardo Coronel of the sugarmill Victoria de Julio, Tipitapa, and Mayro Antón of the Los Maribios Project in León, for their time and information. As well the NGO Proleña: Serafín Filomeno Alves-Milho, María Engracia Detrinidad and Rogerio de Miranda, who especially helped me finding the right persons in the beginning and made me feel comfortable and welcome in Nicaragua.
Above all I would like to thank Pedro Silva de la Maza, head of the forestry project of the sugarmill San Antonio. Without him, only half the project could have been done, ¡muchas gracias Pedro!

In The Netherlands I am very grateful for the information of the nutrient balance that was supplied by Bert Janssen of the Department of Soil Science and Plant Nutrition and Laurence Ganzeveld en Geert-Jan Roelofs of the Institute for Marine and Atmospheric Research Utrecht (IMAU) for the supplying of the atmospheric deposition data.
Finally I would like to thank Leo Vleeshouwers of the Department of Theoretical Production Ecology at Wageningen Agriculture University and Jos Dekker and Richard van den Broek of the Department of Science Technology and Society. Leo for his large contribution to the model and thanks for answering a lot of my questions. Jos thanks for your didactic contribution and being a perfectionist. Above all Richard for being a passionated, enthusiastic scientist and main supervisor from beginning till end.

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APPENDICES:

1: Introduction

1.1: Biomass-energy

Biomass is a rather simple term for all organic material that stems from plants (including algae), trees and crops. Its various sources are therefore diverse. Biomass has always been a major source of energy for mankind. Quantitatively the main part of the biomass energy was and is still used in the developing countries [1]. At present most biomass energy in developing countries is used inefficiently and produced non-sustainably, but biomass can also be converted into modern energy carriers such as gaseous, liquid fuels and electricity, which can be used more efficient.

Within the framework of sustainable development, in relation to energy-supply, renewable energy-sources should fulfil a major position, as is described in the Brundtland report 'Our common future'.[2]

If biomass is grown sustainably (which means that the rate of biomass harvest equals the biomass regrowth) it can be seen as a renewable energy-source. Its production and use creates no net build-up of carbon dioxide (CO_2) in the atmosphere, because the CO_2 released during combustion is offset by the CO_2 extracted from the atmosphere during photosynthesis [3]. Because of this neutrality, biomass can be a sustainable energy-source in the near future. The potentials of biomass as an energy source are high because a lot of waste products can be used as an energy source as well. An example can be found in the sugar-industry where bagasse (a by-product of the process of producing sugar out of sugarcane), can be used as a source for electricity.

1.2: Biomass use at sugarmills in Nicaragua

In the past, against the background of low energy prices and high sugar prices sugarmills in Central America did not have the intention to use their bagasse to generate energy. The combustion of bagasse was seen as a method to get rid of this residue. With the collapse of the sugarmarket and higher energy prices, the power generation during sugarcane crushing season by bagasse has become more financially viable.

In Nicaragua, at this moment, there is a potential for the sugarmills to extend their power production and sell power to the national grid, both during and outside sugarcane crushing season. An off-season fuel is eucalyptus from dedicated energy plantations [4].

In 1997 van den Broek compared a.o. the socio- and macro-economic impacts of the use of biomass as an energy source by sugarmills in Nicaragua with the generation of electricity by fueloil, the most common source for electricity at this moment. He concluded that:

- The electricity production from eucalyptus at sugarmills would have a significant lower cost price (3.8 $cent/kWh) than power from fueloil in Nicaragua (5.5 $cent/kWh)
- Electricity from eucalyptus implies that a much larger part of its selling price (including profit) (62%) remains within the Nicaraguan economy than is the case with electricity from fueloil (17%)
- The electricity production from eucalyptus creates a manifold of low-cost labour job as compared with fueloil power (32 versus 1.5 job/MWe) [5]

In Nicaragua two sugarmills (the "San Antonio" sugarmill in Chichigalpa and the "Victoria de Julio" sugarmill in Tipitapa) have taken the initiative to implement this concept.

At this moment the first power (generated on bagasse) has been sold to the national grid and there are plans to extend the production of both bagasse (by extending the sugarcane production) and eucalyptus. The extensions of the production of power by eucalyptus will be done both by buying wood and by extending the energy plantations [6]

The species that is used at both sugarmills in Nicaragua is *Eucalyptus camaldulensis* Dehn. From 1980 until 1995 CATIE has been researching the multi-purpose of tree species throughout Central America, including a number of eucalyptus varieties. [7] They concluded that E. camaldulensis is the best growing species in the Pacific region. The highest growth can be obtained at soils with good drainage and an annual precipitation of more than 1200 mm. This is the case in the region León and Chinandega [8] where the San Antonio sugarmill is situated. *E. camaldulensis* also has proven to be well adapted to a wide range of soils (particularly those of low fertility), to be tolerant of drought, to suffer of few insects, pests or diseases, and to grow rapidly. It has the ability to coppice vigorously after harvesting for a number of rotations.[9]

1.3: This project

In studies on the possibilities of biomass crops as an energy source the yield per hectare of these crops emerges as a key factor. Van den Broek et all [10,11] showed in two cases that low yield has a great negative effect on the kWh costs. The expected yield per hectare determines whether the use of crops for energy supply will be a realistic option or not and is one of the main determinants for the success of the project. Therefore it is very important to have a good method for yield estimation of biomass crops. The yields that are reported in literature from E. camaldulensis vary between 1.2 $ton_{0\%}$/ha/yr. till 17.7 $ton_{0\%}$/ha/yr. (coppiced crops) see Table I.

Table I: Obtained yield of E. camaldulensis in different parts of the world[a] [12] from literature

Yield ($ton_{0\%}$/ha/yr)	*Country*
11.8-14.8.	Argentine
17.7	Israel
10.0 -11.8	Turkey
14.8 - 17.7	Turkey
1.8 - 6.5.	Marocco
1.2 - 5.9	Portugal
3.5 - 4.1	Italy

The yield obtained at plantations in Nicaragua are within this range. Data were found for plantations at the sugarmill Victoria de Julio, where a mean yield of 6.3 $ton_{0\%}$/ha/yr for the first five years and 9.3 $ton_{0\%}$/ha/yr for the four years after the first harvest (coppiced crop) were obtained. By using volume measurements of some small plantations in NW Nicaragua an actual yield of around 10 $ton_{0\%}$/ha/yr. was concluded [13]

Objectives

The main objective of this paper is:

> To estimate the eucalyptus yield (for power generation) at the plantations of the sugarmill San Antonio in Nicaragua on the basis of crop growth models.

At this moment volume-tables are mainly used for the estimation of the actual yield of the plantations in Nicaragua. These tables do not give understanding in the processes that are responsible for the growth. A crop growth model could be used in the future as a management tool for the sugarmills. The model used in this study estimates the potential and water limited yield of the plantations of both sugarmills, San Antonio and Victoria de Julio. The actual yield of San Antonio is estimated by extrapolating the actual yield of Victoria de Julio. The model will be described in section 3.

A further objective is:

> To analyse the ecological impact of the large scale energy plantations at the area of the sugarmill San Antonio in Nicaragua.

It is important to take as well ecological impact into account. The ecological impact is mainly done qualitatively and based on literature. The nutrient status is discussed quantitatively by constructing a simple nutrient balance.
It was not possible to study the ecological impact in detail in this study, because of time shortness. It is tried to give a indication of the possible impacts.

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[a] These data are calculated from m^3/ha/yr, density of eucalyptus on dry basis: 0.59 $ton_{0\%}/m^3_{solid}$ [5]

This paper starts with a definition of the case; a description of the two plantations. The second section describes the mathematical model used to estimate the biomass production of the eucalyptus at the plantations of the sugarmill San Antonio (and Victoria de Julio), as well the method used for the determination of the environmental impact. After the results which are presented in the fourth part, a sensitivity analysis is given after which the study will be discussed. The conclusion is given at the end of this paper.

2: Case definition

As mentioned in the introduction there are two sugarmills in Nicaragua that have launched plans to sell power to the national grid by increasing their power generation capacity during the harvest season and by extending power generation in the non-harvest season, thus becoming full power plants. [14] In this section both the sugarmills will be discussed, the focus in this study will be on the eucalyptus plantations.

An extensive description of the sugarmill is given by van den Broek, et al [4,5]

2.1: The San Antonio sugarmill

The San Antonio sugarmill in Chichigalpa (at the pacific coast, 150 km NW of Managua), owned by Nicaragua Sugar Estates Ltd., is the largest and oldest sugarmill in Nicaragua.

<u>The Eucalyptus plantations:</u>

The first eucalyptus plantations were established in the area of the sugarcane plantations, at those soils that were not suitable for sugarcane. The latter ones were established in an area about 15 km north of the sugarcane area and at this moment the expansion is going on by renting soil within a distance of about 50 km of the sugarmill. [5] The total area of plantation is around 2500 ha.
The plantations are located from near the Pacific coast till north of León. Appendix 1 gives an overview of the different plantations at San Antonio.

<u>Soils</u>

The types of soils can be divided in three main types:
- heavy clay
- loam
- sandy loam.

They can be divided in several subtypes.
The chemical and physical characteristics of the soils at the plantations are shown in Appendix 2. The profundities of the soils are mentioned to be between 100 and 200 cm.[6]

<u>Climatological characteristics</u>

The climatological characteristics differ per year but in general it can be said that the annual precipitation is around 2000 mm and the global radiation varies between 11.3 and 16.8 $MJ/m_2/day$.
See Appendix 3, for precipitation data and Appendix 4 for radiation data. The mean temperature does not vary a lot during the year and is between 25^0 and 28^0 C.

<u>Management</u>

Appendix 5, gives some principal technical details on the eucalyptus plantations both of San Antonio and Victoria de Julio.

2.2: The Victoria de Julio sugarmill

The Victoria de Julio sugarmill is the second largest sugarmill in Tipitapa owned by “Agroinsa”, which at its turn is partly owned by the employees of the sugarmill. The plantations of this sugarmill are used for the extrapolation of the actual yield of San Antonio.

<u>The Eucalyptus plantations</u>

The unique concept of the sugarcane plantations of the Victoria de Julio sugarmill is that they are all irrigated by circular pivot systems. The eucalyptus plantations make use of the soil between the circular sugarcane plantation. This means that about 20 ha can be used in each square (of 1 by 1 km) containing a circular pivot irrigation system. Beside this, the soils that are not suitable for sugarcane, are used too. [5]

Soils

The soils of the sugarmill Victoria de Julio can be typed as heavy soils with a large percentage of clay. In general they can be divided in two main types:

- red soils
- black soils

The profundity of these soils is much lower than the soils of the sugarmill San Antonio and can be expected to be between 50 cm and 100 cm.[6] For the model-calculation a profundity of 100 cm is used, because the exact profundities of the soils is doubtful. The main differences between the two types of soil is the amount of clay (the black soils have a much higher amount of clay) and the nutrient concentration (which is lower in the black soils as well). The characteristics of these two main types are shown in Appendix 2: Chemical and physical characteristics of the soil.
When the soils are compared with the soils at the site of the sugarmill San Antonio it can be seen that the most pronounced difference between the two sites is the amount of nutrients in the soils. The soils of the plantations of the sugarmill Victoria de Julio are much poorer than the site of the plantation of San Antonio. This is the case for both the micro and macro nutrients. In general the percentage clay in the soils of Victoria de Julio is much higher as well, the black soils have a higher percentage of clay then the clay soils at the sugarmill San Antonio.

Climatological characteristics

The radiation and the temperature of the Victoria de Julio plantations do not differ a lot with those of San Antonio. The radiation is a little higher and lies between 12.6 and 17.6 $MJ/m^2/day$ and the mean temperature is between 25^0 and 28^0 C. The precipitation differs more and is much lower at the sites of Victoria de Julio where the annual precipitation can vary between 650 and 1500 mm a year, see Appendix 3, where the monthly precipitation of Victoria de Julio is shown and daily precipitation data of San Antonio.

Management

In general the management that is used at the plantations of the Victoria the Julio sugarmill can be compared with the management of the San Antonio sugarmill, see Appendix 5. Still some differences can be found. Both the sugarmills have guarding to inspect the plantations at robbers and workers for cleaning the plantations so the amount of fires will be reduced. The Victoria de Julio sugarmill though does not have sufficient capacity for both these activities, as well has insufficient weeding capacity and still has problems with robbery and fires. [15]

3: Methodology

This section describes the methodology used for the yield estimation at the plantations of the sugarmill San Antonio in Nicaragua and those used for the determination of the environmental impact of the power generation by eucalyptus.

3.1: Description of the model

<u>Factors that influence crop production</u>
The factors that influence crop production may be divided schematically into three broad categories, reflecting the production situations (Figure 3.1).

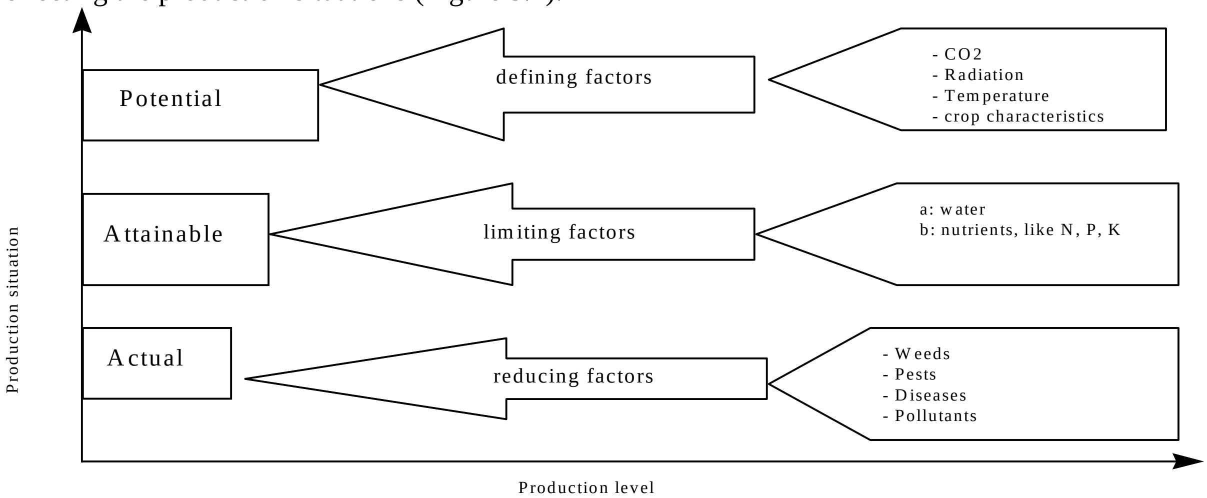

Figure.3.1: The three different production situation of the crop [16]

<u>Production situation 1: Potential Yield</u>
Potential yield is determined by CO_2, radiation, (for the photosynthesis) temperature and crop characteristics. These factors are called the growth defining factors. The potential yield is the maximum yield that can be obtained.

<u>Production situation 2: Attainable Yield</u>
Attainable yield is defined by the amount of water and nutrients available for the crop. These factors are called the growth limiting factors. This production situation depends on soils characteristics and precipitation; the amount of nutrients available in the soil, the water retention capacity and the main water input. Yield only determined by water-limitation without lack of nutrient will be called "water-limited yield" in this study.

<u>Production situation 3: Actual Yield</u>
Actual yield is defined by weeds, pests, diseases and pollutants. These factors are called the growth reducing factors. These growth reducing factors depend on characteristics other than soil and climate, like management and influences from outside the system.

The model used in this study is based on well-established principles for the estimation of the potential growth based on the photosynthesis. For the estimation of the water limited growth simplified principles are used by using a waterbalance. Instead of the attainable growth, the water limited yield will be estimated. The effects of the nutrient limitation is incorporated in the calculation of the actual yield. This determination uses yield data from comparable plantations. The actual yield of Victoria de Julio could be extrapolated to the actual yield of San Antonio.

At first this section describes the equations used in the model after which the input parameters are discussed.

This model:
The principles of the diagram in Figure 3.1. can be rewritten in one equation based on [17].

$$G_a(t) = f_n(t)f_m(t)\ G_{watlim}(t) = f_n(t)f_m(t) \sum f_\theta(d)\ G_p(d) = f_n(t)f_m(t)\ h\ \varepsilon\ \kappa(t) \sum \varphi_{pa}(d)\ f_\theta(d) \qquad (1)$$

The summation is done per day over 365 days.
t = year
d = day

in which:
$G_a(t)$ = the net primary dry mass actual yield (in $ton_{0\%}$/ha/yr.)
$G_{watlim}(t)$ = the net primary dry mass water limited yield (in $ton_{0\%}$/ha/yr.).
$G_p(d)$ = the net primary dry mass potential yield (in $ton_{0\%}$/ha/day.).
κ (t) = the reduction factor for the ability of the radiation absorption
For the first 2 years of growth κ is assumed to be 0.4 and for the next 4 years 0.7. The first year after harvest the κ is assumed to be 0.5 and the other years κ is assumed to be 1 (canopy closed) [6] In this study the canopy (and so the absorption) is assumed to be constant during the year. So it is assumed to have no variation in the dry and wet season.
ε = the radiation utilisation coefficient (in $ton_{0\%}$/MJ)
For the ε a search was done in different kind of literature. An ε for E. camaldulensis was not found. It is assumed is that it does not differ significantly from the ε that was used for other Eucalyptus species. Landsberg and Hingston suggested that an ε 2,2 g/MJ (above-ground biomass, based on the absorbed PAR) is a good working value for actively growing Eucalyptus plantations with adequate soil, water and nutrition.[17]
φ_{pa} (d) = absorbed photosynthetically active radiation[b] (in MJ/ha/day.)
f_θ (d) = the reduction factor for the water limitation per day
f_n (t) = the reduction factor for the nutrient limitation
f_m (t) = the reduction factor for all other reducing factors (weeds, pests, diseases and pollutant)
h = the harvest index, the part of the tree that will be used as an energy source, here an h of 0.85 will be used [6]

The $f_\theta(d)$, the reduction factor for the water limitation, is calculated with the use of Equation (2) (Figure 3.2)

$$f_\theta(d) = (\theta(d) - WP)/(CR - WP) \quad \text{if } WP < \theta(d) < CR \qquad (2)$$
$$f_\theta(d) = 0 \quad \text{if } WP > \theta(d)$$
$$f_\theta(d) = 1 \quad \text{if } CR < \theta(d) < FC$$

where: f_θ = Reduction factor by waterlimitation at moment t
$\theta(d)$ = water content in the soil at day = d
WP = Wilting Point
CR = Critical Point that lies exactly between the Wilting Point and the Field Capacity [18]
FC = Field Capacity

[b] it is assumed that 80% of the total photosynthetically active radiation (PAR) is absorbed and that PAR is 50% of the total amount of radiation [16]

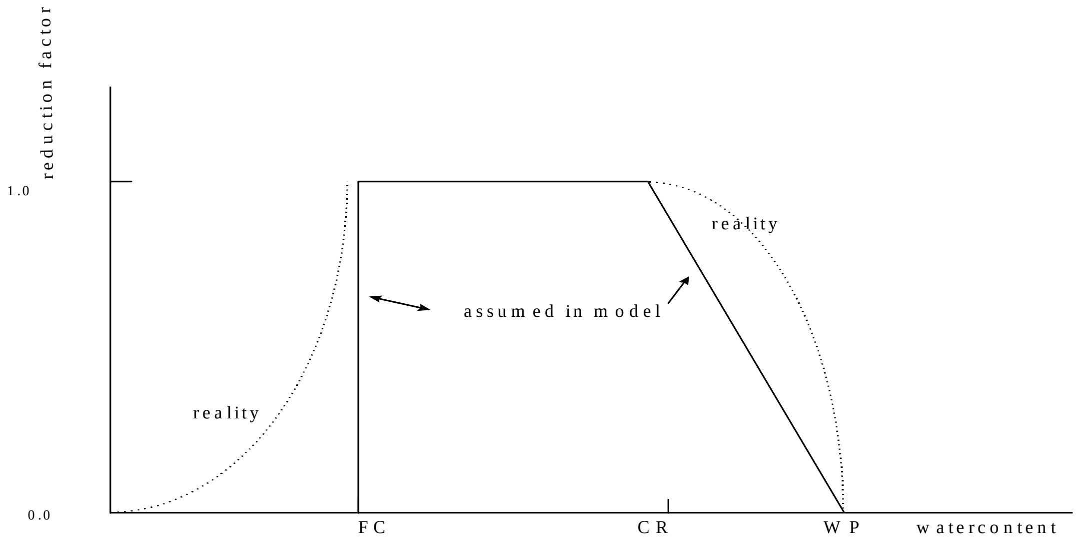

Figure 3.2.: The reduction factor for the water limitation[16]

For the use of the water balance it is assumed that water can only enter the soil by irrigation or precipitation and leave the soil by transpiration. This implies that the interception of water by the tree is ignored because all the precipitation is assumed to enter the soil. As an output, the evaporation of the soil is also neglected[c]. Because the plantations are not irrigated, precipitation is the only water input. Differences between the waterstock in the soil is determined by FC, WP and the profundity. The input en output that influence the waterbalance are shown in Figure 3.3., the waterbalance used in this model is show in Figure 3.4

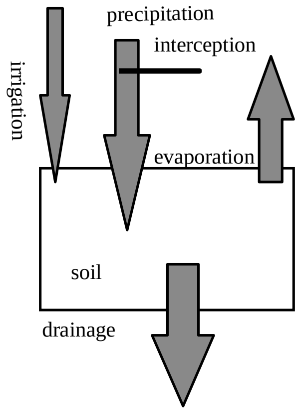

Figure 3.3: The total water balance, interception can be seen as a reduction of the precipitation

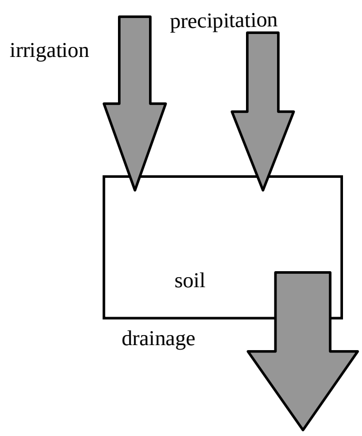

Figure 3.4: The water balance used in this model

[c] the extra evaporation because of the fact that the canopy is not closed during the whole lifetime is implicit taken into account by multiplying the κ with the waterlimiting yield and so with the WUE. When the canopy is not totally closed, from the soil leaves more water because of evaporation than when the crop has a closed canopy, this is taken into account by this multiplication.

The watercontent θ of equation (2) is calculated by the waterbalance (Figure 3.4 and Equation 3)

$$\theta(d) = \theta(d-1) + P(d) - T(d) \quad (3)$$
$$\theta(d) = FC \qquad \text{if } \theta(d) > FC$$

Where:
θ(d) = the watercontent in the soil (in mm) per day
P(d) = the precipitation at that day (in mm)
T(d) = the transpiration that depends on the water limited yield (in mm)
FC = Field Capacity

in which the transpiration is expressed by equation (4)

$$T(d) = G_{waterlim}(d-1)/(\kappa)WUE \quad (4)$$

where
T (d) = the transpiration that depends on yield (in mm)
$G_{waterlim}(d-1)$ = the water limited yield of the day before(in ton0%/ha/day.)
WUE = the Water Use Efficiency of the plant (in g/kg)

The f_m (t)* f_n(t) of eq (1) is captured in one factor, named Reality Reduction Factor; (RRF) by using data of comparable plantations of the sugarmill Victoria de Julio. The harvest results of Victoria de Julio are shown in Appendix 6. The $f_m * f_n$ used in this model is calculated by equation (5)

$$f_n(t) * f_m(t) = RRF_i = \frac{G_{a,\text{Victoria de Julio}}}{G_{watlim,\text{Victoria de Julio}}} \quad (5)$$

i denotes a rotation

The $G_{a,\text{Victoria de Julio}}$, is not estimated by the model, but obtained from harvest data.
The RRF factor can be seen as a factor that takes all the other reducing and limiting factors into account.

$$G_{mean} = RRF_i \; 1/n\sum G(t) \quad (6)$$

The summation is over n years

The model input:

The model does not have many input parameters. The parameters can be divided into climatological data, crop characteristics and physical soil data. The climatological data are used with a daily timestep, sometimes derived from monthly data (as for the precipitation at the site of Victoria de Julio). Table II shows the main input data and there origin.

Table II: The main input data of the model and there origin

	Input data	*reference*
φ_{pa}, radiation	Appendix 4	INETER, Managua
ε, radiation utilisation coefficient	2.2 g/MJ	Landsberg and Hingston [17]
P precipitation	Appendix 3	INETER, Managua
h, harvest index	0.85	Silva [6]
WP, FC	Appendix 3	Analyses of soil samples in Nicaragua
profundity of the soils	100 cm	Silva [6]
WUE	2.7 g/kg[d]	Schneider, Kinzig and Solórzano [19]
harvest results of Victoria de Julio	Appendix 6	Colonel [15]

3.2: The environmental impacts:
The environmental impacts of the short rotation forests in general and the eucalypt plantation in Nicaragua specific, are not easily assessed. The effects of using eucalyptus for energy generation on the environment will be measured with eight criteria, which are divided in the criteria on the impacts from the conversion step and impacts from the production step of the process. In the conversion step the main environmental impacts that can be found are the emission of greenhouse gasses and the use of fossil energy. As well in this study the emission of acidifying gases and the emission of dust is taken into account. It was assumed that these emissions might differ compared to the conversion step of a fossil fuel. It was not possible to take all the environmental impacts of the production step into account. There were not sufficient data of the use of pesticides and of the impact of the crop on organic matter in the soil. As well, no research was done among the area about the contribution of the plantations to landscape values. Table III shows the remaining criteria used in this study for the assessment of the environmental impacts.

Table III: The criteria used in this study for the determination of the environmental impacts

Conversion step	*Production step*
a. The use of fossil energy b. The emission of greenhouse gases c. The net emission of acidifying gases d. Emission of dust	e. The nutrient balance of the soil (leaching and deficit) f. Soil erosion g. Biodiversity h. Groundwater depletion

An integrated view of the environmental impacts should include
1. An analysis of the effects of the production of the biomass compared with a reasonable alternative for landuse or compared with the situation before planting.
2. An analysis of the effects of the conversion of the biomass into energy compared with a reasonable alternative for power generation
As an alternative of landuse in Nicaragua different options can be considered. The plantations of both sugarmills were first planted on degraded soils where no alternative agriculture could grow. The more recent plantations are grown on areas that were not used for agriculture, but could serve for that. Both the landuses before planting as agriculture can serve as alternative for landuse. The plantations will be compared with the situation before planting, because the exact impact of an agriculture crop could not be assessed. For the power generation the most logical alternative on the short term is fueloil [5]. The comparison of the landuse will be based on the impact on 1 ha, the impact on the conversion step will be based on 1 kWh electricity

[d] A range was given of 2.0 - 2.8 g/kg [19]

To determine the environmental impacts a review from literature was done. Where possible the impacts were considered quantitatively, if not possible a qualitative consideration was done.
For the assessment of the potential problem of nutrient depletion a simple nutrient balance was constructed. This nutrient balance of soils encloses a sizeable number of processes that have to be taken into account. In Figure 3.5. the nutrient inputs and outputs of a soil-system are shown.

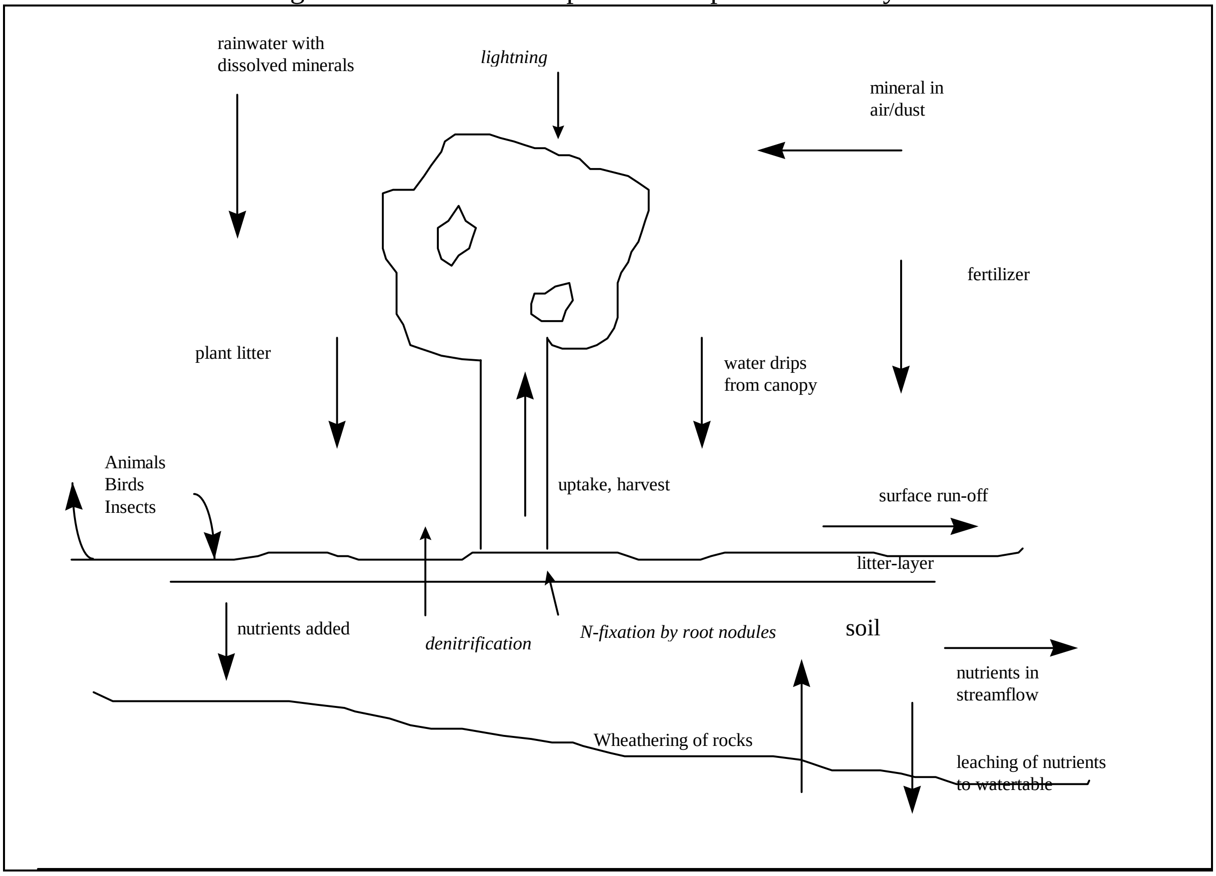

Figure 3.5: The nutrients inputs and outputs of a soil-system *Based on: 20*
All the *italic* flows are only N flows

In this study the borders of the system will be set on the tree and the soil including litter layer, so the plant litter is an internal flow. It was not possible to quantify all the inputs and outputs shown in figure 3.5.

<u>The concentration of nutrients in the soil (the available stock):</u>
The concentration of nutrients at sampling-time was determined by analyses that were done for the different blocks of the plantation at the sugarmill San Antonio see Appendix 7 and Appendix 2for the analyses of the soilsamples and the chemical and physical characteristics of the soils. The amount of nutrient in the soil is estimated with an assumption that the amount of nutrient in the A-horizon is the same as the amount in the B-horizon [6]. The amount of P was determined by the assumption that C:N:P = 100 : 10 : 1 [21] for the organic P and the assumption that the amount of organic P equals the amount of inorganic P . The amount of N could be estimated at the same way, next to the analyses shown in Appendix 2. The amount of nutrients in the soils is not the same amount that is available for the plant. The part that is available depends on different factors like the pH of the soil. In general it can be assumed that 2 to 8% of the total N is mineralised (mobile, and thus available for take-up). For P and K this amount is less then 1%.[21]

The input

The input by chemical and physical weathering will not be considered, as well as plant litter (internal flow) and as the nutrients in water that drips from canopy. The plantations of the sugarmill San Antonio are not fertilised, so the input because of fertilisation is zero in this study but taken into account. No data were found of the input because of lightning and N-fixation by root nodules. The total atmospheric deposition taken into account in this study includes both the inputs of nutrients by rainwater with dissolved minerals, and the inputs of minerals in air and dust. The total atmospheric deposition of nitrogen was determined by running a circulation model for Nicaragua . [22]

The output

It was not possible to quantify the interaction of the animals, the birds and the insects with the soil-system, as well as the surface run-off, the streamflow and the denitrification. The amount of nutrients that leaves the system because of leaching could only be determined for nitrogen, it is estimated by a regression equation empirically determined for Africa (6) [23, 24]

$$2.3 + (0.0021 + 0.0007 * F) * R + 0.3 * (In_{fertilizer} + In_{manure}) - 0.1 * UN \qquad (6)$$

Where:
F = soil fertility class (1 low; 2 moderate; 3 high)
R = annual average rainfall (mm)
$In_{fertilizer}$ = the input because of mineral fertilizer (kg/ha/yr.) (= 0)
In_{manure} = the input of animal manure (kg/ha/yr.) (= 0)
UN = the nitrogen uptake (kg/ha/yr.)

Therefore, the output consists mainly of the amount of biomass that leaves the field by harvesting. The sugarmill intends to harvest only the stem and leave the leaves and branches behind. With the assumptions made in this study it leaves a total of two inputs and two outputs, for the litter-layer/soil-system, shown in Figure 3.6.. With the use of this nutrient balance, it is not possible to draw conclusions on the fertility status of the plantation after its lifetime of the plantation because the interaction between the nutrient fertility and the actual yield has not been modelled. Still it possible to draw general conclusion on the nutrient balance per year.

To determine the amount of nutrients in the stem, leaves and branches, 20 trees of four different ages were weighted by parts (leaves, branches and stem) and of every age a sample of 3 trees was analysed for the concentration of the nutrients. These measurements were done in the dry season at the plantation of the sugarmill San Antonio. If the analyses were done in the wet season, a higher amount of leaves would have been found.

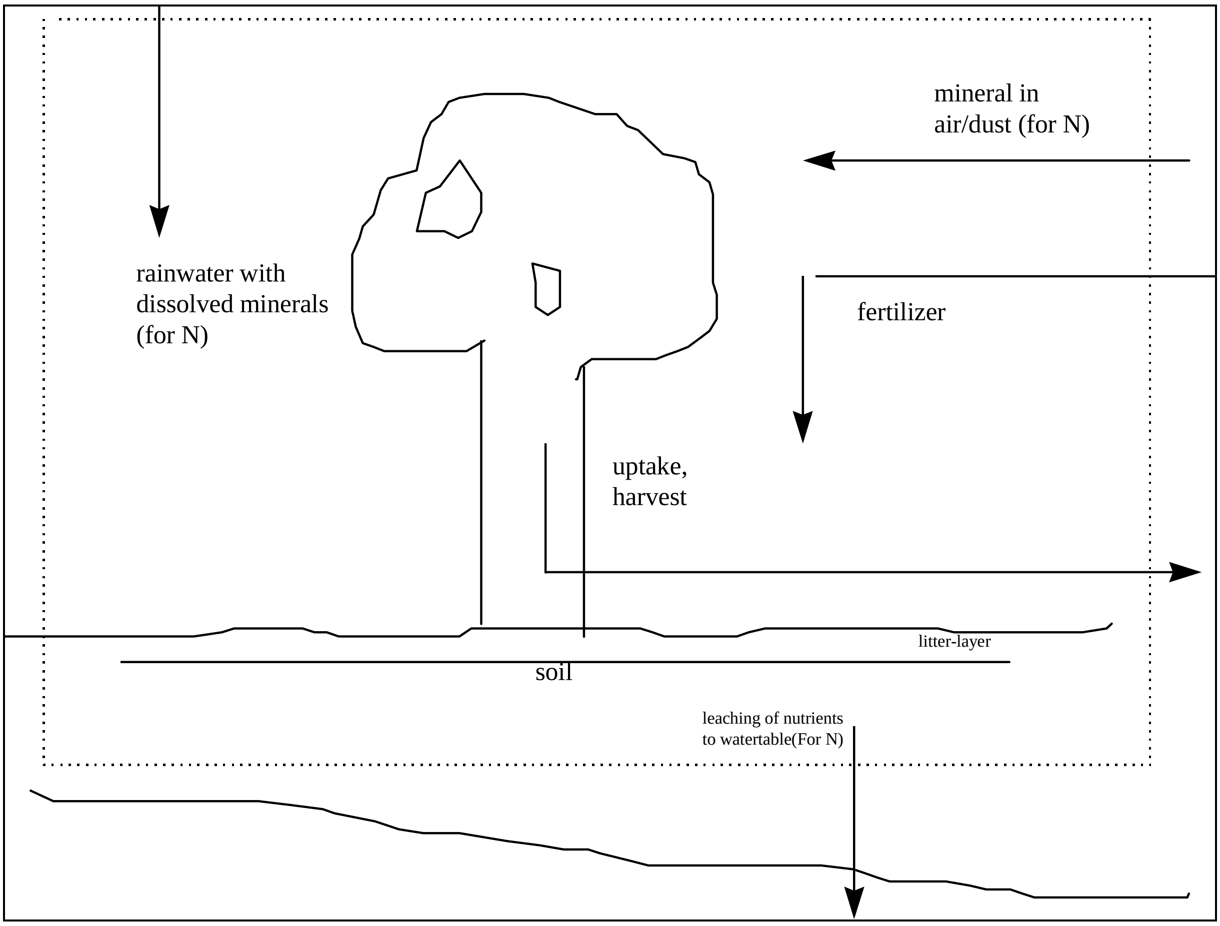

Figure 3.6: The nutrient input and output in this study.

To consider the impacts on the nutrient balance in the soil for the eucalyptus plantations, it is recommended to compare the nutrient balance of the plantations with the nutrient balance of the situation before planting. This was not completely possible because there were no data available of the situation before planting. In this study the conclusion could only be drawn on the results of the balance of the present plantation.

4: Results

In this part the results of the estimation of the Eucalyptus production at the plantations of the sugarmill San Antonio and its environmental impact are presented.

4.1: Results of the model estimations

In Appendix 8 the results on the various yields of the plantations are shown.
The actual yield (real data) after the first and second rotation for the plantation of Victoria de Julio are shown in Appendix 6. Only the mean results are used for the calculation of the RRF in Appendix 8.
The differences between the potential, water limited and actual yield (k = 1) for the two different plantations are shown in Figure 4.1, the mean over the total lifetime is shown in Figure 4.2. [e] . For the calculation of the actual yield over the lifetime, for the first 6 years, the RRF_1 was used, for the years 7 until 26, the RRF_2. The potential and the water limited yield at the plantations of the sugarmill Victoria de Julio is higher than for the plantations of San Antonio. The potential yield is mainly determined by the radiation, which is higher at the plantations of Victoria de Julio. The water limited yield is mainly determined by the difference between the Wilting Point and the Field Capacity and the profundity. The latter is assumed to be equal for the plantations of both sugarmills. The water limited yield of Victoria de Julio seemed to be higher than San Antonio in spite of the higher precipitation at San Antonio. Partly this can be explained by taking the distribution over a year of the precipitation into account. The excessive precipitation (June-November, see Figure 4.3) will be lead away by drainage, so cannot be used by the crop. The water limited yield still depends strongly on the potential yield, that is higher for Victoria de Julio. The lifetime of the plantations of the sugarmill San Antonio are estimated to be 26 years [6], which is one rotation more than the plantations of Victoria de Julio. The lifetime of the plantations of Victoria de Julio is estimated to be 21 years. [15] Because of this extra rotation the mean actual yield over the total lifetime is slightly higher for the plantations of the sugarmill San Antonio.

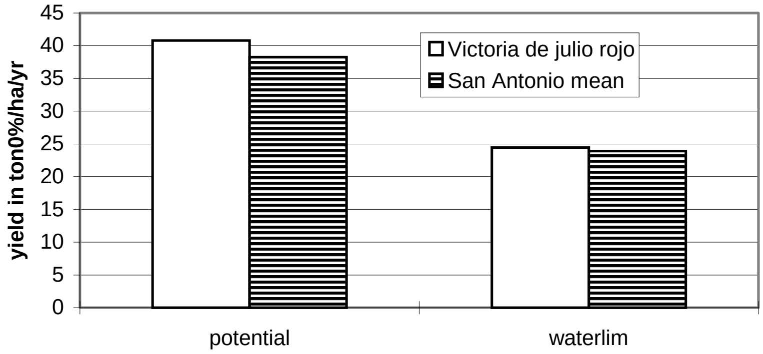

Figure 4.1: The estimated potential, water limited and actual yield of the plantations of both the sugarmills, with $\kappa = 1$.

[e] It is noticeable that the actual yield of the plantation of the sugarmill Victoria de Julio is based on real data and was not estimated by the model.

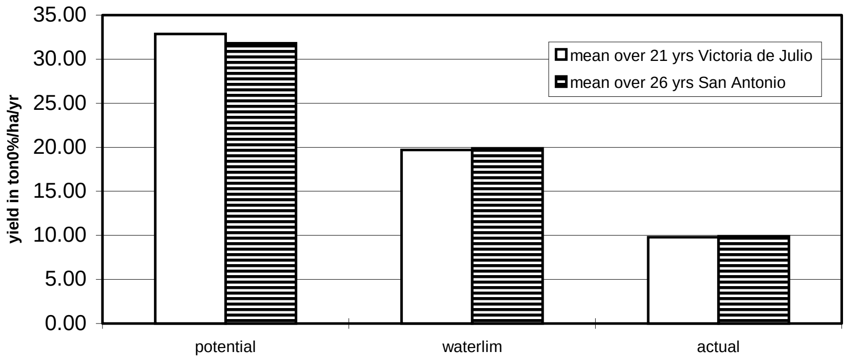

Figure 4.2: The mean estimated potential, water limited and actual yield of the plantations of both the sugarmills, over the total estimated lifetime.

Next to the differences between the two plantations, the model makes as well good distinction between the growth over the different month. Figure 4.3 shows the water limited yield distribution over a year for the two plantations. Around five month a year the growth is mainly determined by the potential growth, and so by the radiation (from June until November). In the other months the precipitation and the soil characteristics of the plantations are more important. It can be seen that the higher water limited yield over a year of Victoria de Julio can mainly be explained because of the higher potential yield and partly because of the higher estimated amount of water in the soil (determined by the Wilting Point and the Field Capacity)(January). Further, the plantations of San Antonio grow more at the end of the dry season and beginning of the wet season (March, April, May), where the difference in precipitation between the plantations is noticeable. (see for the radiation and the precipitation data Appendix 3 and 4)

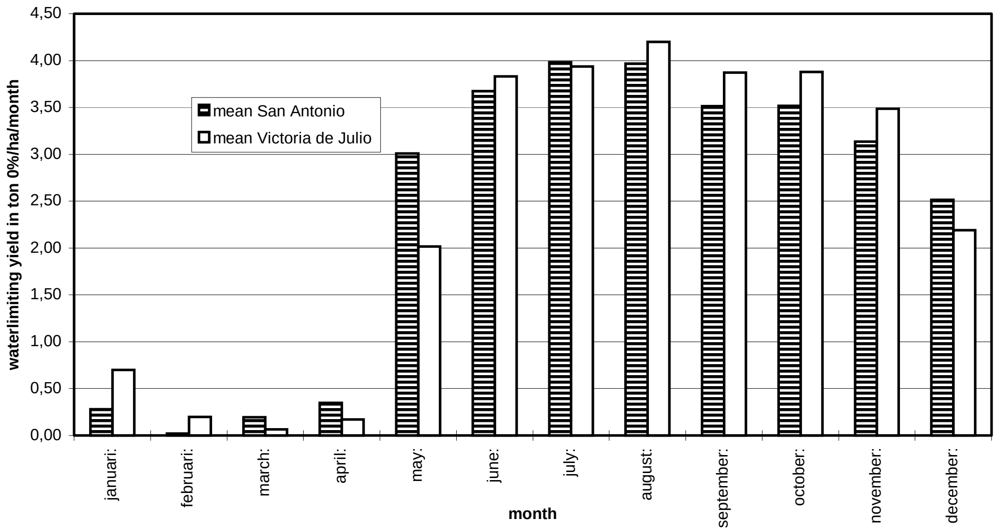

Figure 4.3: The mean water limited yield distribution of both the plantations over a year.

Appendix 9 shows the distribution for different soil types of the plantations of the sugarmill San Antonio. It can be seen that the model does not give significant preference to a type of soil and the differences are small.

4.2: Results of the environmental impact evaluation:

Nutrient depletion:
The results of the analyses of the tree samples are shown in Appendix 10.
The amount of nutrients that leave the soil per year is shown in Table IV. The nutrients excluding N do only have one output and no input in this study.

Table IV: The inputs and outputs and relative reduction of the nutrient balance of the plantations of San Antonio

Nutrient	*mean total in soil (ton/ha)*	*output (leaching) (kg/ha/yr.)*	*Input (kg/ha/yr.) (atm.dep.)*	*output (stem) (kg/ha/yr.)*	*balance (kg/ha/yr.) Deficit*
N	20[f]	5.25	0.6 - 2.3	14.7	17.65 - 19.35
P	4	-	-	5	5
K	13	-	-	18.8	18.8
Ca	28	-	-	154.2	154.2
Mg	6	-	-	6	6

These concentration in the tree can be compared with data from literature (Table V):

Table V: Nutrient concentration in tree parts for different eucalyptus species from literature

Tree specie	*age (yr.)*	*part of tree*	*N kg/ha*	*P kg/ha*	*K kg/ha*	*Ca kg/ha*	*Mg kg/ha*	*reference*
E. saligna	-	stem	33.02	14.56	67.84	73.19	19.09	Poore and Fries [20]
E. Saligna	10	whole tree	21.9	5.8	19.1	95.4	8.1	Paula Lima de. W [25]
E. grandis	3.5	whole tree	58.1	3.7	14.7	13.2	4.8	Paula Lima de. W [25]
E. grandis	10	whole tree	42	1.6	15.6	76.7	5.1	Paula Lima de. W [25]
E. globulus	-	whole tree	18.3	2	9.9	21.3	3.7	Pereira, et al [26]

It can be seen that the nutrient concentration of the trees of the plantation in Nicaragua does not differ significantly with the concentrations mentioned in literature, although the output after five or six years is for all the nutrients in Nicaragua higher than the values in Table V. It is noticeable, that the yield does have a large impact on the concentration in kg/ha.

From Table IV it can be seen that the balance, as expected, has a deficit. This can be compensated by a.o. fertilisation, by planting N-fixation crops or by returning the ash of the trees on the field. Compared to the total amount of nutrients available in the soil it can be seen that the reduction of the nutrients in the soil is higher for N and P. It is difficult to estimate the impact of the deficit on the fertility status of the soil in the future and on the actual yield of the plantation and so, of the benefit of fertilisation. The amount of N that leaves the soil by leaching is far less then the assessment of environmentally acceptable nitrogen losses for grassland in Holland; 20 - 45 kg/ha/yr[27].

Fossil energy use
The power generated by eucalyptus results in a total (direct and indirect) use of fossil energy input of 0.27 GJ_{fossil}/kWh, which is 3% of the energy output. This can be compared with the power by fueloil; 9.6 GJ_{fossil}/kWh, which is 109% of the energy output. [5]

[f] When the analysis of the soilsamples were used for the determination of the total amount of nitrogen in the soil, it results in a uptake of more then 8% a year. This is in general not possible [18], so we used the assumption that C:N:P = 100 : 10 : 1 [18]. This includes the assumption that the analysis of the organic material are reliable

CO_2 emission

Van den Broek compared as well the specific CO_2 emission. The specific CO_2 emission of fueloil was almost 40 times more then the emission of the power production by eucalyptus (resp. 748 g/kWh and 20 g/kWh) [5]

The net emission of acidifying gases

The emission of SO_2 equivalents is about ten times higher for the power production by fueloil then by eucalyptus. The emission for the fueloil electricity production is 23 g/kWh and for eucalyptus 2.5 g/kWh. The emission of acidifying gases is mainly caused by the fuel combustion; 92% in the case of power production by fueloil and 85% with eucalyptus. [28]

Emission of dust

The dust emission without gas cleaning filtering is much higher for the combustion of the eucalypt compared with the emission of the fueloil plant. It is possible to reduce the emissions of the combustion of eucalyptus by gas cleaning which will result in a much lower emission of dust. [5]

Soil erosion

In many locations in Nicaragua the specific aim of planting eucalyptus was the potential reduction of wind erosion. Trees can play a role in preventing soil erosion by the establishment of ground vegetation. Experiences with eucalyptus on this field are relatively poor, because of its strong tendency to suppress ground vegetation [5]

There is almost no experimental evidence in the literature comparing soil erosion under eucalyptus with that of other forms of vegetation.

The only quantitative data found of soil loss of eucalyptus are from West Java and have been reported within the acceptable limits (12.6 tons/ha on a 40% slope under 2,500 mm rainfall) [29] But this is not representative for this study.

Biodiversity

In this study we define the biodiversity as the amount of flora and fauna or the amount of different species.

Generally eucalyptus is known for its relatively poor wildlife value. This is mainly caused by its small hard fruit and very tiny seeds, which are poor for birds and by its leafs being unpalatable to deer. Further the effects on biodiversity will depend on the previous vegetation cover and cultivation and changes in the surrounding landscape. [30]

If, for example, on a large scale natural forests (or meadows and pastures), unaffected by fertilisers are transformed to short rotation plantations, biodiversity is likely to be negatively affected and endangered and rare species may be threatened.[31]

Further it makes a different if a bioenergy crop is a native species. Crops that are native species, may provide greater biodiversity on a landscape level than typical agricultural crops, and thus may enhance wildlife habitat.[32] The eucalyptus is not a native species in Nicaragua, on the other hand it can be said that because of this the flora has increased with new species. The biodiversity would increase more when more different species are planted.

Groundwater depletion

Poore concluded that compared with other tree genera the effect of eucalypts in reducing water amount in the soil is probably less than that of pine and greater than that of other broad-leaved species; but all species of trees reduce water amount compared with scrub or grass. [21]

As well he mentioned a possible interception loss of the precipitation of 20% [21] , this will be considered in the sensitivity analysis in section 5. Davidson compared the water use by plants through evaporation for different crops as well, from this it can be seen that the water use per harvested biomass for eucalyptus does not rise above the water use of other tree genus investigated or agriculture crops. [33] It is important to notice that the groundwater depletion for eucalyptus can be pushed back by a lower plant density.

5: The sensitivity analysis.

5.1: The sensitivity analysis of the model

The sensitivity analysis is shown in Appendix 12. It can be seen that the water limited yield increases when the WUE or the ε (= RUC) increases. The effect of the variation of the WUE on the water limited yield is less than the effect of the variation of the ε, so the radiation seems to be limited instead of the precipitation. The same effect of the ε variation would be obtained for the effect on the potential yield. The effect on the actual yield is different for the variation of the two parameters. The variation of the ε does have a positive but less sensitive effect on the actual yield. This can be explained, because the ε is also used for the calculation of the water limited yield of Victoria de Julio. The water limited yield of Victoria de Julio is used for the calculation of the RRF, which at its turn is used for the estimation of the actual yield of San Antonio.

The impact on the actual yield by the variation of the WUE is negative. The differences with the impact on the water limited yield are completely determined by the use of the RRF for the estimation of the actual yield. The plantations of Victoria de Julio have less water input by precipitation and will arrive earlier at a critical point where the influence of the water availability is the main limiting factor and will reduce the yield (lower WUE means more transpiration). Because of this effect the impact on the actual yield of San Antonio is very sensitive for lower WUE, the WUE range used in this study can be found in the less sensitive part.

Of the sensitivity analysis of the interception loss can be seen that the effect of the interception is not very large. When an interception is found of 20% (as mentioned in section 4), the water limited yield is decreased from 23.9 $ton_{0\%}$/ha/yr to 23.2 $ton_{0\%}$ /ha/yr. and 30% loss decreases the water limited yield to 22.8 $ton_{0\%}$ /ha/yr.

This can be explained because of the high annual precipitation at the plantation of San Antonio. The large part of the growth occurs in the wet season when there is excessive amount of water input by precipitation. In this season a reduction of the water input of 20% does not has a large impact on the actual yield over the whole year. Figure 3 shows the impact on the actual yield. When the interception loss is more than 20%, the actual yield of San Antonio will increase. This is caused by a higher RRF, because the water limited yield is more reduced by the interception loss (less precipitation, more impact of interception) than the water limited yield of San Antonio.

The variation in the actual harvest data of Victoria de Julio (and therefore in the RRF) has a high impact on the actual yield of the plantations of the sugarmill San Antonio which is shown in the third figure of Appendix 12. This can be explained directly from the methodology as well, because the RRF is multiplied by the waterlimiting yield to calculate the actual yield of San Antonio. Its sensitivity implies that the variation in the harvest data has a direct influence on the estimated actual yield of the plantations of the sugarmill San Antonio.

The last figure in Appendix 12 also shows the sensitivity of the soil profundity. The water limited yield can be directly extrapolated from the soil profundity and is highly sensitive. It was assumed that the profundity of the plantations of both sugarmills are equal (100 cm). It is mentioned that in reality this is doubtful, the profundity of San Antonio should be higher then of Victoria de Julio (upto 200 cm, see section 2). [6] In Appendix 12 where the profundity of the soil of San Antonio was varied, it can be seen that this can have a large impact on the results of both the water limited and actual yield. These will be higher for San Antonio. Figure 3 in Appendix 12 shows only the effect on the plantations of San Antonio.

6: Discussion of the results and evaluation of the model

6.1: Discussion of the yield estimations

The model that is used in this study to calculate the actual yield under conditions with ample nutrients is simplified in many ways.

The main shortcomings of the model can be divided in assumptions that are made with the parameters and inputs used, and the assumptions that are made by ignoring some influences that exist on growth.

<u>Assumptions made with the input and parameters used in the model for the estimation of the water limited yield:</u>

- The analyses done at the soils are sampled only in the first 35 cm of the soil, it was assumed that this first layer was representative for both the A- horizon as the B-horizon, the profundity where the roots live. This assumption does not have a great effect on the water content because the texture and therefore the water content does not differ significantly between the A and the B-horizon. For the nutrient content this is different, the content of nutrients differs in the first meter of the soil. So this assumption does not result in a large difference for the water limited growth, but the actual estimated yield may differ from reality.
- The tree- parameters used in the model as the ε and the WUE are not empirically determined for E. camaldulensis, but were assumed to be the same for E. camaldulensis as for other eucalyptus species. With this assumption the potential growth as well as the ability of transpirating by the tree is assumed to be equal for the different eucalyptus species, although for the transpiration large differences are found between the quality of for example the stomatal conditions of the leaves. The impact of this assumption is shown in the sensitivity analysis. It can be seen that the impact on the actual yield estimation of the variation of the two parameters is not very large. For the estimation of the water limited yield the parameters are much more sensitive.

<u>Assumptions made with the input parameters used in the model for the estimation of the actual yield</u>

The soil profundity was assumed to be the same for the plantations of both sugarmills. It was mentioned that this is not the case in reality. The soils of the plantation of the sugarmill San Antonio are much more profund, a profundity of 200 cm was mentioned, where the soils of Victoria de Julio can be less profund then 100 cm. [6] This can result in a underestimation of the yield of the plantation of the sugarmill San Antonio of 12% (see section 5). In this study it was chosen to set the profundities of the plantations of both sugarmills on 100 cm because the exact profundity is doubtful.

<u>Assumptions that are made by ignoring some influences that exist on growth for both water limited and actual yield estimation:</u>

The model in general has some assumptions as well that may lead to differences between the estimated yield and the yield found in reality.

- In general the model takes the influence of the leaf surface and the leaf developing into account by incorporating them into the factor κ, the reduction for the canopy closure. This factor is based on estimations and is not calculated by the leaf area index or leaf development.
- The second influence that is related to the leaf development is the stomatal control. This control is as well not taken into account.
  The stomatal control regulates the amount of water that can be emitted and is influenced by climatic and crop characteristics. It is assumed that there will not be problems with the stomatal control, so the tree can always transpire. In reality this causes an overestimation of the yield.
- Related to this is the assumption that the canopy volume is constant over the year.
  The variation of growth-rate during the year is influenced by the status of the canopy as well. It is assumed that the canopy is closed after the second year of the first rotation. So it is assumed to be closed during the whole year. In reality the canopy is less developed and not closed during the dry summer. This assumption leads to an overestimation of the yield.
- The waterbalance that is used in the model uses only the transpiration as an output. The evaporation of the soil is left out the model (is only implicit taken into account). In reality the

water available for the tree will be lower, so a lower yield can be expected. As well it ignores the influence of interception. It assumes that the whole amount of the precipitation enters the soil, the part that is intercepted is ignored. Poore and Fries [21] reported an interception loss of different eucalyptus species of around 20%. In Appendix 12, it can be seen that the interception loss does not have a large effect on the actual yield estimation of the plantations of the sugarmill San Antonio. This can mainly be explained with the higher annual precipitation of San Antonio. The wet season is the part of the year when the crop grows most faster and on this part the interception will not or rarely have impact on the water input and so on the growth.

In general it is obvious that the water limited yield estimation made by the model leads to higher yields than in reality. The use of the RRF can give an estimation of the yield that will be obtained in reality, but has to be used with care.

- The most influential assumption of the model for the actual yield estimation is the assumption that the f_n and f_m can be incorporated by the use of the RRF. For the use of this RRF it is assumed that the plantations and therefore the chemical and physical characteristics of the soils and the management at the San Antonio sugarmill are equal to these of the Victoria de Julio sugarmill, except for the parameters already included. For the management the assumption can be made, in theory. In practise however the management seems to be different. The soils are also different especially with respect to the fertility. The soils at the Victoria de Julio site are much poorer than the soils of the plantations of San Antonio. By using the RRF obtained from data of Victoria de Julio an underestimation of the yield at the plantations of San Antonio is made. As well it should be noticed that the RRF and therefore the harvest data of Victoria de Julio react sensitive on the actual yield estimation for San Antonio.

It turned out to be not possible to give an general estimation of the variation in the estimation compared to reality.

6.2: Discussion of the environmental impact

<u>The nutrient depletion:</u>

- The trees that were analysed for the determination of the nutrient concentration are not coppiced yet. The trees after the first cropping will have a different nutrients status. Especially in the beginning the tree will relatively take up more nutrients than in the first years after planting. This effect is neglected in this study. It was assumed that the concentration will be the same for the whole lifetime of the plantation. Although, the uptake of nutrients because of coppicing will be more than the uptake without coppicing. It was not possible in this study to make an estimation of the impact of this assumption on the nutrient balance.
- The samples were all taken during the dry season. It can be expected that there are differences in nutrient concentration between dry and rainy season. The growth rate differs as well and therefore the nutrient uptake. During the wet season it is expected that more nutrients leave the soil by leaching or surface run-off, so the balance will be less negative during the dry season.

7: Conclusions and recommendations

7.1 The conclusions of the yield estimations

The model estimated the potential, water limited and actual yield for plantations of two sugarmills in Nicaragua, San Antonio and Victoria de Julio and estimated the actual yield of the plantations of the sugarmill San Antonio. The estimated potential yield was mainly determined by the radiation at that site and was higher for the plantations of Victoria de Julio than for San Antonio. The water limited yield was determined by the precipitation and as well by the soil characteristics the Wilting Point and the Field Capacity. The plantations of San Antonio are situated in an area with more precipitation than the plantations of Victoria de Julio. This influence was partly opposed by the higher ability of the soil of Victoria de Julio to retent the water (difference between FC and WP was higher for Victoria de Julio). This resulted in an estimated water limited yield that was higher for Victoria de Julio, still mainly determined by the higher yield during the wet season when the growth is mainly determined by the potential yield and therefore by the radiation. The plantations of San Antonio had a higher estimated growth rate during the dry season, when the water input was more limiting. The model did not take into account that the heavier soils of Victoria de Julio can be too dry during the dry months and can physically damage the tree roots.

The plantations of San Antonio are estimated to have a higher water limited yield over the whole lifetime of the plantations because of longer rotation length and a longer estimated lifetime of the plantation. Figure 7.1 shows the estimated potential and water limited yield of the plantations of both sugarmills.

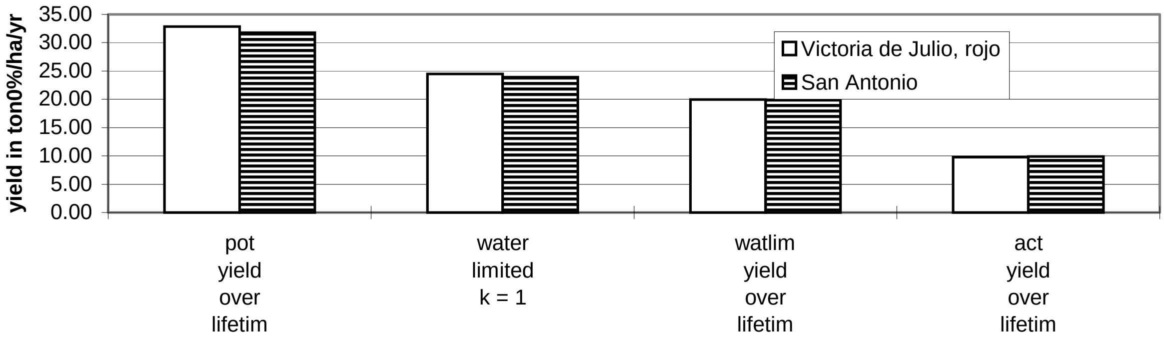

Figure 7.1: The estimated potential and water limited yield of the model for the plantations of both sugarmill

The actual yield of the plantations of San Antonio was estimated by the use of the Reality Reduction Factor RRF determined by the harvest results of the plantations of Victoria de Julio. In this way the estimated actual yield of San Antonio was correlated with the harvest results of Victoria de Julio. The estimated actual yield in this study was calculated as almost 10 $ton_{0\%}$/ha/yr over the whole lifetime of 26 years.
It was tried to validate the model with volume measurements of the plantations. Unfortunately these data were not available at the moment. For this reason it is not possible to draw conclusions on the reliability of the model and its results.

The water limited yield increases when the WUE or the ε increases. This effect is not occurred by the actual yield. The variation of ε is less sensitive for the actual yield because the ε is also used for the calculation of water limited yield of Victoria de Julio. The impact on the actual yield by the variation of the WUE is only very sensitive for lower WUE. The range given is this study can be found in the less sensitive part.

7.2: The conclusions of the environmental impact

Compared to the alternative fuel for electricity generation, fueloil, it can be concluded that the electricity generated from eucalyptus has less impact on the environment. The use of the fossil energy and the CO_2 and acidifying emission are much lower for the electricity generated by eucalyptus than by fueloil. The emission of dust is much higher for the electricity produced by eucalyptus, but this can be reduced by flue gas cleaning. The environmental impact of the production step were more difficult to assess. The only quantitatively determined impact was the nutrient depletion. Out of a simple nutrient balance it could be seen that the nutrient balance has a deficit; the nutrient output is higher than the input. This is very obvious, because the plantations are not fertilized. It was not possible to draw conclusion on the reduction of the fertility status at the end of the lifetime, because the effect on the actual yield or on the status of the plantation in the future was not determined. The nitrogen leaching was compared with the assessment of environmentally acceptable nitrogen losses for grassland in Holland and it could be concluded that the nitrogen losses in Nicaragua were far below these standards.
Because the balance used in this study was incomplete (see fig. 3.5 and 3.6) the results of this model have to be used with care. They could better only be used for indications of possible environmental impacts.

7.3: Recommendations

If the model will be used in the future as a management tool it is recommended to do more research on it. Especially the effect of rotation and the profundities can be studied in more detail. For this purpose measurements of the real harvest data after coppicing is recommended.

The model can be validated with real data from the energy plantations. When the model is validated it will be possible to estimate the error in the model, and optimise it.

It is also recommended to do research on the reliability of the model. In this study it was only possible to get some insight in the input parameters and their sensitivity to the model output, but it is recommended to study this in more detail.

It is recommended to use more different harvest results when the RRF is used. It could be seen from the sensitivity analysis that the RRF and therefore the harvest results of the plantation of Victoria de Julio has a large impact on the estimated actual yield of the plantations of San Antonio.

To be sure of possible impacts in the future it is recommended that the effect of the fertility of the soil is studied more in detail. The impact of returning the ash on the plantations as well the impact of the use of N-fixation crops in combination with the eucalyptus can be studied.

In this study the analyses on nutrient concentration in the soil and tree were done by one laboratory in Nicaragua. It is recommended to use more different laboratories for important samples, because it is possible to get large differences in the analyses of the different laboratories in Nicaragua.[34]

The environmental impacts of the energy plantations are not studied quantitatively. It is recommended to study the emissions due to pesticide, by obtaining more data of the amount and kind of pesticide used.

As well it is recommended to study the impact of the groundwater depletion in more detail. In literature it was found that the impact that eucalyptus plantations have on the groundwater depletion differ for different sites. It is recommended to monitor the groundwater depletion for some years at the eucalyptus plantations.

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Appendix 1: plantations of the sugarmill San Antonio

name	*year of planting*				
	ha	‘93	‘94	‘95	‘96
Mono Chingo	90.00				89.92
Esparta	171.29		105.30	65.29	0.70
Armenia	124.71		66.69	54.05	3.97
Poza Bruja	63.18	58.97	4.21		
La Danta	142.33	5.62	2.81	80.73	18.08
Borrel	14.04		14.04		
El Jordan	28.08	28.08			
Jesus-Maria	52.65	5.62		47.03	
El Mora	51.56	44.93		2.11	4.53
El Muerto	32.99	18.95	5.62	2.81	5.62
Manchester	46.33		37.91	8.42	
Wascalan	49.14			49.14	
La Campana	7.02		7.02		
Las Pampas	324.32			162.86	161.46
Provedencia	23.17	23.17			
Miravalle	91.96	14.04		77.92	
Toro Pinto	42.82		34.40		8.42
El Deseo	10.53		10.53		
La Cenicera	2.10				2.10
El Galillo	7.02			7.02	
El Pellisco	195.86				195.86
Zacatera	60.44				60.44
Norguega	14.04				14.04
Hoyada	79.66				79.66
Alaska	14.04				14.04
El Caerio	6.32				6.32
Cristo Rey	35.10				35.10
Dolmo	21.01				21.01
Total	1801.73	199.37	288.52	557.39	756.45

Appendix 2: Chemical and physical characteristics of the soils of the plantations of both sugarmills

Samples are taken in march 1998

Soilsamples San Antonio

	texture					chemical analysis											fysic analysis	
						%		ug/ml	(meq/100ml)							ppm	%	%
	texture	porosity	% clay	% loam	% sand	OM	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	Boro	WP	FC
Block 1-fr	loam	46,47	23,2	32,16	44,64	4,05	0,2	6,8	0,5	14,28	3,82	98,3	6,5	1,85	5,56	<0.10	6,6	26,14
Block 1-a	caly	33,00	59,2	19,44	21,36	1,9	0,1	7,84	0,2	26,7	10,88	43,5	4,83	1	2,9	<0.10	11,9	34,24
Block 2-fr	loam	45,64	15,2	36	48,8	4,64	0,23	9,07	1,6	13	3,83	117	23,41	3,75	5,62	<0.10	5,2	32,41
Block 2-a	caly	42,64	57,2	18	24,8	2,38	0,12	12	0,3	21,7	11,5	39,8	13,9	1	8,33	<0.10	11,2	35,23
Block 3-f	loam	46,11	23,2	32	44,8	4,17	0,21	6,94	0,53	11,5	4,62	112	23,66	1,9	25,6	<0.10	6,5	24,42
Block 3-a	caly	44,1	61,2	18	20,8	2,34	0,12	6,4	0,23	23	13,81	40,9	18,51	1	20,5	<0.10	12	36,21
Block 4-f	loam	39,7	27,2	28	44,8	2,3	0,12	3,32	38	9,65	3,8	81,9	13,96	3,72	4,65	<0.10	6,8	27,86
Block 4-a	caly	38,17	45,04	19,44	32,52	1,55	0,08	16,43	1,1	15,83	7,41	86,5	26,61	3,8	10,5	<0.10	10,8	32,7
Block 5-fare	sandy-loa	43,11	5,76	22	72,24	2,83	0,14	6,52	0,36	5,06	0,65	90,4	12,91	1	1	<0,1	4,39	28,2
Block 5 -f	sandy-loa	46,25	5,76	20	74,24	4,41	0,22	8,6	0,51	6,45	0,65	89,9	11,6	1	1	<0,1	4,63	27,57
Block 6- fa	loam	50,2	13,04	37,44	49,52	2,5	0,12	8,76	0,31	13	4,28	101	17,73	2	2,95	<0,1	5,93	27
Block 7-f	sandy-clay	41,2	21,04	23,44	55,52	3,02	0,15	29,52	1,05	9,7	2,88	102	14,78	2	7,88	0,71	5,2	29
Block 8	sandy-loa	38,87	7,2	20,36	72,44	2,08	0,01	12,4	0,35	7,23	0,96	120	12,42	2,9	<0,1	<0,1	4,21	12,18
Block 9	san-loam-	38,87	7,2	20,36	72,44	2,74	0,14	12,84	0,78	18	2,84	96,1	14,86	1	5,94	<0,1	9,42	31,52
the absolute	0.50	-	-	-	-	0.10	-	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	-	0.30	0.25

Soilsamples Victoria de Julio

	texture					chemical analysis							fysic analysis			
						%		ppm	(cmol+/kg)				%	%	g/ml	%
	texture	porosity	% clay	% loam	% sand	OM	N	P	K	Ca	Mg	Fe	WP	CC	densi	L P
Rojos			47,47- 66,74	24,52 - 32,50	8,75 - 23,2	1,16 - 1,91	0,06 - 0,10	7,85- 22,20	0,84 - 1,85	20,87 - 23,7	14,93 - 17,06		18,5	44	0,86	33
negros			64,13 - 81,75	9,88 - 15,85	7,5 - 19,23	1,61 - 2,08	0,08 - 0,1	4,36 - 20,6:	0,16 - 0,72	36,89 - 41,9	25,52 - 33,66		30	51	0,94	44

Appendix 3: The daily precipitation at the sites of the plantations of both sugarmills

Precipitation of San Antonio

mean daily precipitationdata based on 23 till 25 years at the area of the sugarmill San Antonio source: ISA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	t
Jan.	0	0,3	0,3	0,0	0,5	0,0	0,0	0,0	0,0	1,3	1,0	2,5	1,5	0,0	0,5	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
Febr.	0	0,0	0,0	0,0	0,0	0,0	0,5	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0				
Mar.	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	0,0	0,0	2,0	0,0	0,3	0,0	0,0	1,3	0,0	0,0	0,3	0,3	0,0	0,5	0,0	0,5	0,0	0,0	0,0	0,0	3,3	
Apr.	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,3	0,0	0,0	0,0	0,5	1,3	0,0	0,0	0,0	0,0	0,3	0,0	0,3	0,0	2,0	0,5	3,0	4,6	1,3		
May	1,5	0,3	1,3	8,4	2,8	3,3	4,6	4,3	4,1	3,0	0,5	3,8	0,8	1,8	4,3	2,8	4,1	7,1	8,4	6,9	6,4	7,6	13,2	17,5	19,1	26,4	19,3	10,2	29,7	26,7	20,6	
June	22,6	17,0	9,4	8,9	17,0	12,7	14,5	6,9	4,1	10,4	5,1	8,9	14,7	11,4	7,1	9,1	11,2	6,6	8,9	7,4	9,1	9,4	6,4	7,6	13,0	6,1	10,7	5,3	6,9	6,1		
July	5,8	5,6	2,0	10,9	10,9	10,4	5,6	5,3	5,8	3,6	6,6	3,3	6,1	4,1	4,3	2,8	11,4	6,9	5,8	8,1	6,4	7,1	13,0	7,6	3,8	2,3	9,7	9,1	14,5	4,1	7,6	
Aug.	6,4	7,4	10,2	12,2	5,6	4,1	5,3	6,4	9,4	5,6	7,1	8,4	10,7	3,8	6,1	8,6	5,1	10,4	6,4	8,6	13,0	16,5	8,6	10,2	8,4	9,1	11,7	19,6	7,1	6,9	15,5	
Sep.	15,7	13,7	12,7	16,3	16,5	12,4	8,4	14,7	7,6	21,6	9,4	24,6	21,6	11,9	11,2	18,0	22,1	23,4	21,3	15,7	7,9	16,5	8,4	14,5	16,0	13,0	21,8	20,6	15,5	10,9		
Oct.	12,2	15,2	15,2	17,8	16,0	15,2	13,0	13,0	8,1	18,0	6,1	18,3	8,1	6,6	10,4	13,0	18,0	7,4	8,1	8,6	8,4	5,6	6,4	11,2	10,7	8,1	3,6	2,5	6,1	7,4	12,4	
Nov.	8,9	8,4	4,3	5,6	3,6	3,0	2,8	2,3	0,8	5,3	3,3	3,3	2,8	2,3	1,3	3,8	3,3	11,4	1,3	4,8	5,1	2,3	1,3	0,5	0,0	0,0	0,0	0,3	0,8	0,3		
Dec.	0,3	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,3	2,3	1,3	0,0	

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daily precipitation around the sugarmill Victoria de Julio

Mean of monthly data

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jan.	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Febr.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0			
Mar.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Apr.	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	
May	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5
June	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	
July	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9
Aug.	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4
Sep.	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	
Oct.	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0
Nov.	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	
Dec.	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1

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Appendix 4: The daily radiation of the area around the plantations of both sugarmills

The daily radiation data are supplied by INETER, Managua. These data are mean data over 7 upto 16 years

Radiation Sandino airport in cal/m2 near sugarmill Victoria de Julio

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jan.	307	343	327	337	316	319	331	311	302	324	313	318	299	293	333	334	324	314	321	340	337	333	330	334	351	329	331	362	349	345	369
Febr.	354	332	347	326	372	361	353	330	367	380	351	368	380	382	393	397	295	383	415	400	408	398	393	423	408	382	382	396			
Mar.	394	407	439	429	419	405	406	421	413	421	411	422	437	411	413	393	419	414	423	412	440	434	449	445	439	435	429	412	424	424	425
Apr.	402	401	418	420	429	439	438	397	414	417	405	390	425	420	410	412	407	406	403	394	416	421	420	378	401	418	391	377	380	380	
May	374	412	407	403	418	425	445	397	412	378	357	359	356	410	398	395	390	407	383	396	401	397	365	359	381	357	315	325	355	346	333
June	301	341	346	364	361	350	361	348	338	324	382	359	339	367	387	331	322	337	331	367	376	388	341	324	354	344	321	333	330	300	
July	372	322	332	366	341	312	310	332	375	330	346	327	333	344	359	354	358	358	383	360	333	345	317	337	340	343	367	314	352	357	334
Aug.	392	353	326	365	389	364	341	368	328	362	373	369	368	373	383	363	340	388	377	349	401	370	381	392	390	363	356	333	374	382	353
Sep.	355	316	353	359	357	367	367	355	349	359	333	351	354	370	355	336	325	344	342	354	329	343	361	353	335	317	360	360	357	367	
Oct.	354	342	348	336	339	336	367	346	348	357	350	352	322	310	317	326	347	349	359	370	336	316	345	337	348	350	335	335	320	313	291
Nov.	300	326	302	319	356	333	332	319	304	311	309	298	309	325	303	313	294	293	296	306	298	312	302	340	320	319	350	315	312	320	
Dec.	327	314	311	300	290	311	324	295	284	301	306	314	309	253	284	287	303	304	301	307	291	330	321	311	304	314	297	281	311	296	258

radiation Chinandega in cal/cm2 near sugarmill San Antonio

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jan.	308	321	339	318	297	321	332	319	299	311	320	322	300	297	303	319	321	321	347	340	342	334	329	402	376	338	310	316	325	341	339
Febr.	345	343	353	368	368	359	363	336	356	343	371	358	354	366	382	382	343	361	375	362	365	378	394	386	393	363	379	376			
Mar.	393	385	378	408	401	379	386	385	380	386	382	420	386	398	385	391	409	410	405	395	388	381	395	392	399	402	397	379	381	398	404
Apr.	407	408	401	404	380	389	391	410	388	383	378	367	402	383	366	385	346	350	362	368	337	327	353	343	350	337	357	317	332	328	
May	350	346	324	348	338	330	352	350	338	352	341	339	355	358	376	331	341	345	364	364	340	360	328	297	308	276	299	295	312	280	302
June	287	302	329	310	346	317	306	319	309	328	354	317	316	320	317	364	344	362	340	323	341	338	326	333	361	345	354	375	308	349	
July	336	344	334	334	352	343	375	328	349	369	339	323	333	347	377	347	354	350	362	333	342	321	342	348	359	347	330	356	377	353	369
Aug.	341	329	326	355	404	366	332	348	338	332	318	351	418	368	356	378	347	403	345	347	315	328	343	366	343	290	300	315	346	340	348
Sep.	355	319	317	336	331	321	349	328	304	324	311	311	311	331	319	302	284	301	334	300	315	304	336	316	318	269	321	330	315	300	
Oct.	312	342	319	323	306	329	321	334	312	299	310	376	286	307	318	324	321	318	318	306	278	284	260	291	269	289	290	297	295	303	285
Nov.	293	264	258	233	268	314	279	290	262	283	270	311	306	269	306	305	308	306	270	290	254	283	275	295	287	279	305	266	273	278	
Dec.	294	258	304	264	261	302	259	294	305	285	304	297	288	282	307	303	279	312	305	279	303	290	280	293	307	272	296	309	286	282	298

Appendix 5: Technical details of the eucalyptus plantations of both sugarmills

technical details on the eucalyptus plantations of the two sugarmills: San Antonio and Victoria de Julio

	San Antonio			*Victoria de Julio*	
	'96/'97	'97/'98	>'99	'96/'98	>'99
Established eucalyptus plantation [1] [ha]	1796	2496	> 3500	3675	7354
Part of soils with wood owned by mill[1] [%]	72	n.a.	39	74	n.a.
Average eucalyptus yield [t_{dry}/ha.yr] [1]	-	-	12	5 - 11	n.a.
Harvest rotation (total lifetime) [year][2]	6 (26)			4-5 (20)	
Weed control [1]	by hand, machine and herbicide			by hand	
Largest distance from mill [km] [1]	55			15	
percentage of survivors at harvest time [2]	80 - 90 %			-	
Plant density [plants/ha] [1]	2200				
Genetic improvement [1]	only seed selection from local seed orchard				
"Subsoil breaking" [1]	applied				
Fertilisation [1]	not applied				
Irrigation [1]	not applied				
Pesticides use [1]	during establishment used against red ants				
herbicide use [2]	only in nursery, roundup				
cleaning of plantation [2]	by hand				
Harvest method [1]	chainsaw				
Use of leafs and small branches [1]	not harvested				
Air drying behaviour eucalyptus [1]	Drying of trunks: in 1 month from 45 to 25 - 18% m.c.				
Chipping of wood [1]	centrally at the power plant				

1 *Broek, R. van den and A. van Wijk,*[21]

2 *Silva, P and Colonel, R personal communication 1998*

Appendix 6: Harvest results of the plantations of the sugarmill Victoria de Julio

Table I: The obtained yield for the different soils at the sugarmill Victoria de Julio

		1st harvest	*2nd harvest*	
texture	site	ton $_{0\%}$/ha/yr.	ton $_{0\%}$/ha/yr.	increase
negro	125	5.4	8.0	18%
mixture	129	6.2	9.0	19%
rojo	85	7.1	10.5	23%
rojo	301	7.1	10.6	19%

Appendix 7: The analyses of the soil samples of the plantation of San Antonio

The soil analysis were done in the laboratory ‘Laquisa’ in León, Nicaragua. For the determination of the physical and chemical aspects of the soil, around five until ten samples representative for the plantation were taken from every soil type. The analysis were done from a mixture of these samples. For the chemical tree-analysis, three samples were analysed per age and the mean was calculated. For the analysis of the weightdistribution of the tree, five samples were taken from every year. Table I shows the method used for the chemical analysis of the soilsamples.

Table I: The method used for the chemical analysis of the soilsamples

name	*unit*	*method of extraction*	*determination*
pH	pH	1 : 2,5 in water	potentiometer
M.O	%	K2Cr2O7	blue volumetric of molibdene
P	ug/ml	2,5:25 Olsen modification	coulorimetry
K	meq/ml	2,5:25 Olsen modification	AAS
Ca	meq/ml	2,5:25 KCl 1 M	AAS
Mg	meq/ml	2,5:25 KCl 1 M	AAS
Fe	ug/ml	2,5:25 Olsen modification	AAS
Cu	ug/ml	2,5:25 Olsen modification	AAS
Zn	ug/ml	2,5:25 Olsen modification	AAS
Mn	ug/ml	2,5:25 Olsen modification	AAS
S (sulfur)	ug/ml	2,5:25 CaH4(PO)2 H2O	tubidimetry
B	ug/ml	2,5:25 CaH4(PO)2 H2O	coulorimetry
Mo	ppm		coulorimetry

Appendix 8: The estimated potential, water limited and actual yield of the plantations of both sugarmills

Table I: Estimated yield of the sugarmill San Antonio

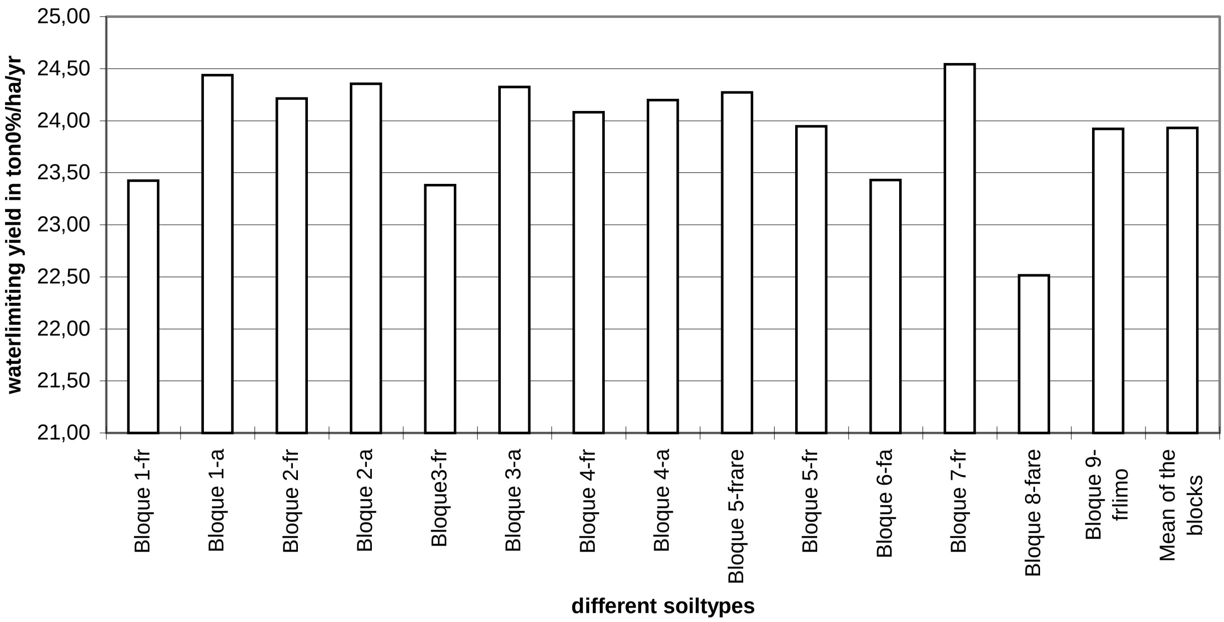
Yield	*mean*
Potential yield in $ton_{0\%}$/ha/yr	38.3
Water limited yield in $ton_{0\%}$/ha/yr	
$\kappa = 1$	23.9
first 6 years	14.4
next 5 years	21.5
mean over 26 years	19.9
Actual yield in $ton_{0\%}$/ha/yr	
RRF fist 6 years	0.50
RRF next 5 years	0.50
first 6 years	7.18
next 5 years	10.77
mean over 26 years	9.94

Table II: Estimated yield of the sugarmill Victoria de Julio. [#]

yield	*rojo*	*negro*	*mean*
potential yield in $ton_{0\%}$/ha/yr	40.8	40.8	40.8
water limited yield in $ton_{0\%}$/ha/yr			
$\kappa = 1$	24.5	24.1	24.3
first 5 years	14.2	14.0	14.1
next 4 years	21.4	21.1	21.2
mean over 21 years	17.0	16.7	16.9
actual yield in $ton_{0\%}$/ha/yr			
first 5 years	7.1	5.4	6.3
next 4 years	10.6	8.0	9.3
mean over 21 years	9.8	7.4	8.6
RRF			
first 5 years	0.50	0.39	0.45
next 4 years	0.50	0.38	0.44

[#] The actual yield used are obtained from harvested data

Appendix. 9 : The water limited yield distribution for different soil types of the plantations of the sugarmill San Antonio



Appendix 10: The results of the analyses of the tree samples

Table I: The total amount of nutrient in the tree parts after six years of growth, (in ton/ha) #

	stem	*leaves*	*branches*	*total*
N	88	46	21	155
P	30	4.6	4.18	38.78
K	113	46	30	189
Ca	925	62	63	1050
Mg	36	7.8	6	49.8

It was assumed that the amount after the first six years equals the amount after the next five years of growth before harvest

Table II: The nutrient concentration in different parts of the tree

part of the tree	*N (%)*	*P (%)*	*K (%)*	*Ca (%)*	*Mg (%)*
leaves mean	1,51	0,13	1,28	1,73	0,22
branches 1993	0,35	0,08	0,59	1,03	0,08
branches 1994	0,35	0,09	0,70	1,26	0,08
branches 1995	0,37	0,12	0,84	1,21	0,07
branches 1996	0,41	0,14	0,81	2,33	0,06
stem 1993	0,20	0,06	0,22	1,78	0,06
stem 1994	0,17	0,04	0,26	1,17	0,06
stem 1995	0,22	0,08	0,31	1,14	0,07
stem 1996	0,21	0,06	0,42	1,01	0,05

Appendix 11: The atmospheric deposition of nitrogen for NW Nicaragua

The mean max. and min deposition of N in kg/ha/yr. [22]

	mean max. in kg/ha/yr.	*mean min in kg/ha/yr.*
NO/NO2 etc. dry dep	0,20	0,13
HNO3 dry dep	0,63	0,12
HNO3 large scale wet dep	0,95	0,30
HNO3 conv. wet dep	0,52	0,06
total	2,30	0,61

Appendix 12: The sensitivity analysis of the model

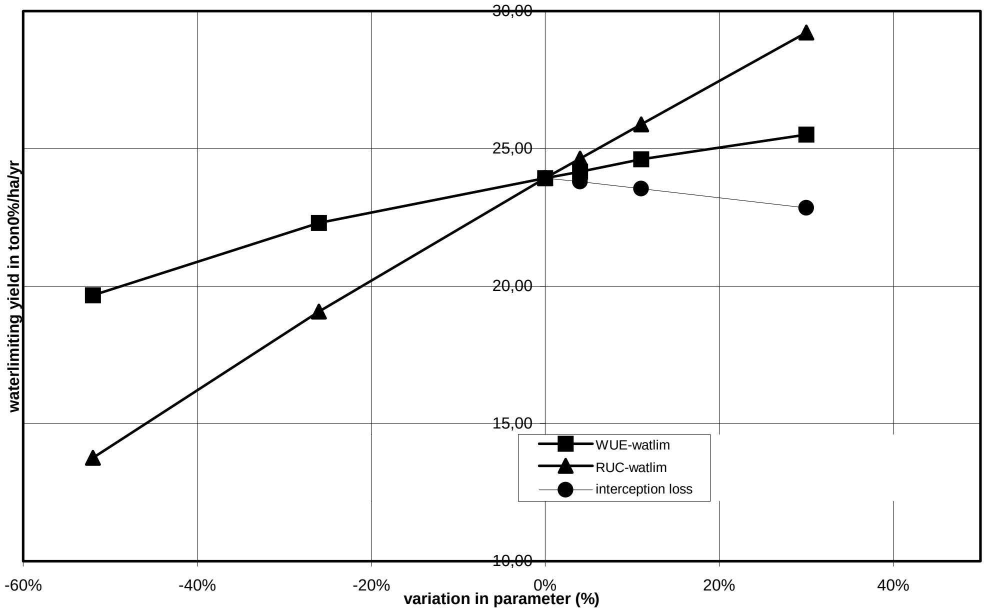


Figure 1: The sensitivity analysis of the parameters WUE, RUC and the interception loss on the water limited yield of the plantations of the sugarmill San Antonio

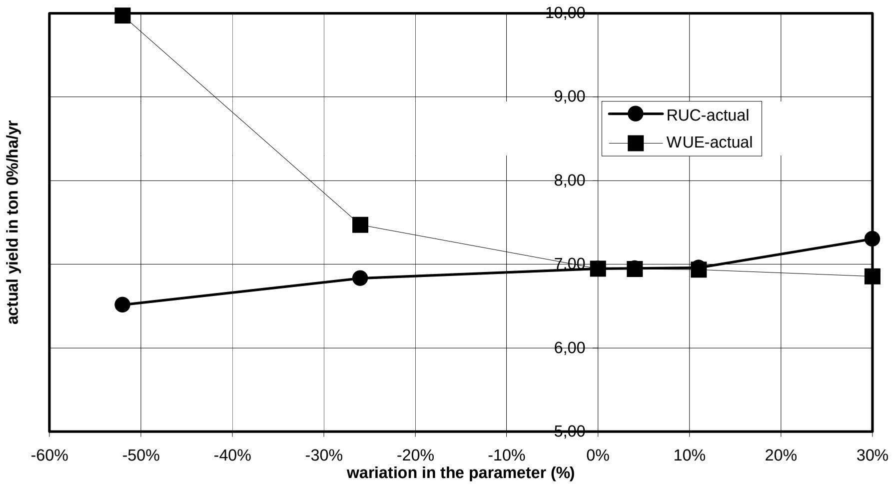


Figure 2: The sensitivity analysis of the parameters WUE and RUC on the actual yield of the plantations of the sugarmill San Antonio

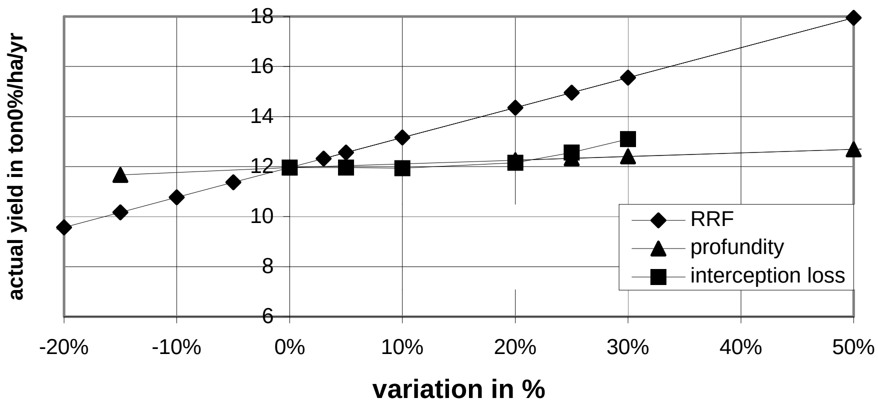


Figure 3: The sensitivity analysis of the effect of interception and variation in the RRF on the actual yield of San Antonio