Examensarbeten 2010:17

Institutionen för skogens ekologi och skötsel

Growth response of eucalyptus hybrid clone when planted in agroforestry systems

An approach to mitigate social land conflicts and sustain rural livelihood

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Sveriges Lantbruksuniversitet Skogligt magisterprogram/Jägmästarprogrammet
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Examinator: Anders Karlsson, SLU, Inst för skogens ekologi och skötsel Umeå 2010

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Abstract

Conflicts concerning land use associated with fast wood plantations (FWP) in the tropics put social strain on relations between the plantation companies and rural populations. To support rural livelihoods where FWPs are present introduction of agroforestry at plantations could be favourable. This study analyses the growth response of eucalyptus hybrid clone of *E. grandis* and *E. urophylla* grown in commercial spacing with agricultural crops integrated in an agroforestry system during the first year of the stand rotation period at Veracel FWP in Bahia, Brazil. Ten different treatments, with one control treatment of conventionally grown eucalyptus hybrid clone, were grown in a randomized block trial of four blocks. The crops were sown and fertilized according to general recommendations for each different crop. Tree height, diameter and volume per hectare were measured at age 16 months. The results were analysed with ANOVA and Scott-Knott test yielding three different volume growth responses at confidence level 0.05. The Scott-Knott grouped the means of stand volume to three significantly different groups. All but one treatment had a significantly higher volume production per ha than control plots. The highest volume occurred where beans and sunflower was grown with eucalyptus hybrid clone; 41.8 percent higher than conventionally grown eucalyptus hybrid clone after the first 16 months. Thus wood production at eucalyptus plantations would not suffer adverse effects, but rather positive effects, by implementation of this type of agroforestry.

Key words: Agroforestry ; Brazil; Eucalyptus; Fast growing plantation; FWP ; Land conflicts; Pulpwood

Sammanfattning

Konflikter gällande markanvändning i samband med snabbväxande trädplantager i tropikerna anstränger relationerna mellan skogsbolag och lokalbefolkningen på landsbygden. I avsikt att stödja landsbygdsutveckling i områden med stora plantager kan mångbruk vara gynnsamt. Denna studie analyserar tillväxtresponsen hos eukalyptus hybridklon av *E. grandis* och *E. urophylla*, planterad i produktionsförband, tillsammans med jordbruksgrödor i ett integrerat agroforestrysystem under det första året av trädens omloppstid på Veracels plantage i Bahia, Brasilien. Tio olika behandlingar, varav en var kontroll med konventionellt skött eukalyptus hybridklon planterades i ett slumpmässigt utlagt blockförsök med fyra block. Jordbruksgrödorna såddes och gödslades enligt generella rekommendationer för varje gröda. Trädens höjd, diameter och volym per hektar mättes vid 16 månaders ålder. Resultaten analyserades med ANOVA och Scott-Knott test med 5 procents konfidensintervall. Scott-Knott testet gav tre statistiskt signifikant olika grupper av volymproduktion per hektar där samtliga behandlingar utom en hade högre volymproduktion än kontrollbehandlingen. Den högsta volymen erhölls då bönor och solrosor odlades tillsammans med eukalyptus hybridklon; 41,8 procent högre volymproduktion än konventionellt odlad eukalyptus hybridklon efter de första 16 månaderna. Trädproduktionen på eukalyptusplantager vid implementering av denna typ av agroforestrysystem påverkas inte negativt utan snarare positivt.

Sökord: Agroforestry ; Brazil; Eucalyptus; Fast growing plantation; FWP ; Land conflicts; Pulpwood

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Introduction

Tree plantations are increasing their claim of land over the world. The land area covered by productive plantation forests increased from 43.6 million ha in 1990 to 140 million ha in 2005, i. e. 3 percent of the world's forested areas (Figure 1). Two thirds of tree plantations are found in temperate and boreal zones and one third in the tropical zone (Anon. 2006). The world's productive forest plantations, has the primary use to produce industrial wood products such as fibre, wood and charcoal (Anon 2009a). The productive plantations designated primarily for pulp and paper industries have increased by 40 percent between 1990-2005, with main emphasis in the tropics (Figure 2) (Anon 2009a). Fast Wood Plantations (FWP) is a term for productive tree plantations with short rotation time. Currently there are now approximately 10 million hectares of fast wood plantations worldwide and about one million hectares of land is converted to FWPs each year (Anon. 2005). New FWP establishments are mainly carried out on former agricultural land or pastures (Cossalter & Pye-Smith 2003). The dominating species planted in tropical regions are *Eucalyptus spp*, *Pinus spp*, *Populus spp* and *Acacia spp* (Bemmann et al. 2008).

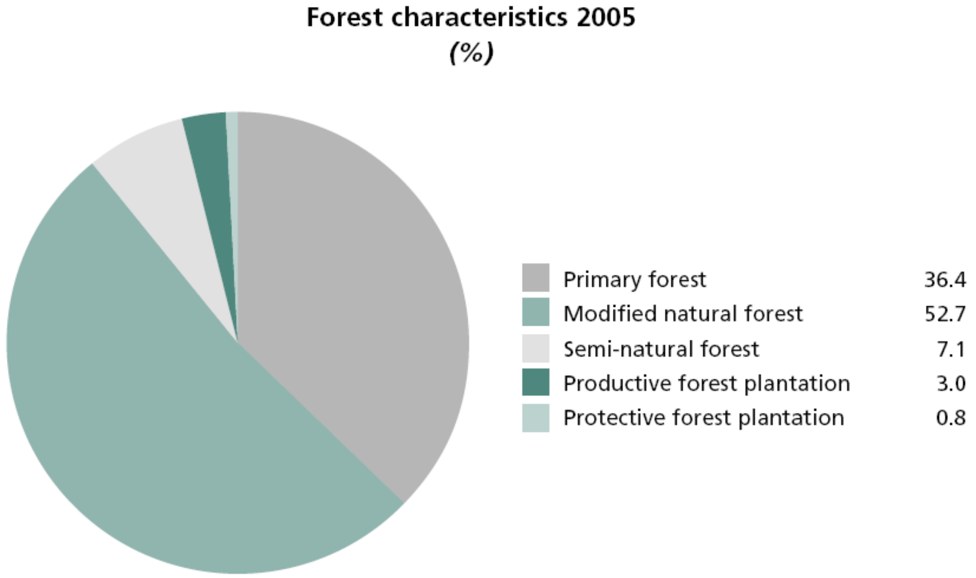

Figure 1. World's forest type distribution (Anon. 2006).

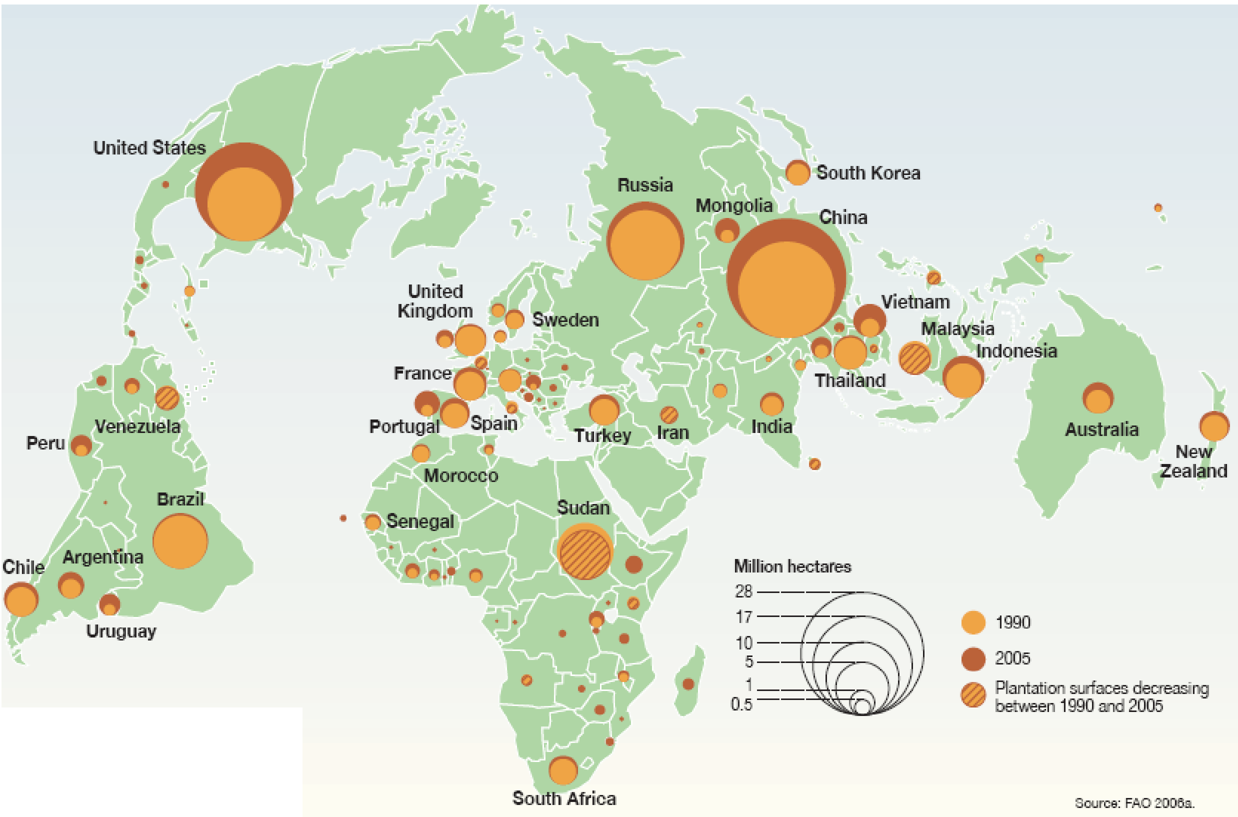

Figure 2. Productive forest plantations' global distribution (Anon. 2009a).

In the case of Brazil, interest for FWPs to produce pulpwood has been high, both from the government and foreign investors. Timber investment returns from Eucalyptus plantations in Brazil have an internal rate of return ranging from 13-23 percent, the best in the world due to excellent growth rates and high wood prices (Cubbage et al. 2007). From 2002 to 2008 the ownership structure of Brazil's forests has altered quite drastically. In 2002, the forest owned by individuals and companies was 57 million ha and had in 2008 increased to 198 million ha. This, whereas the public forest administered by the government decreased from 295 million ha in 2002 to 88 million ha in 2008 (Sunderlin et al. 2008).

A main aim has been to establish large scale cellulose plantations to supply the pulp mills with raw material. Thus plantations of rapidly grown trees are planted to obtain uniform diameter logs for the mills (Turnbull 1999).

In Brazil, about half of the country is covered by forest (Anon. 2005). The extent of natural forests is 743 million ha and plantation forests cover 5.4 million ha, of which about 55 percent are planted with Eucalyptus spp. In 2005, 138 million m^3 of industrial wood were harvested from plantations and the price for it was some 1.5 billion USD (Anon. 2006).

Demand

There is a rising demand for wood products, both due to global population increase and to an increase of per capita consumption of wood based products. The 6.2 billion global population of today will increase to 9.2 billion people by year 2050 according to the US Bureau of Census (Cossalter & Pye-Smith, 2003). Thereby, fast wood plantations are seen as a way to meet this rising demand (Fenning & Gershenzon 2002). Some of the most productive plantations, like Veracel eucalyptus plantation in Bahia state, Brazil, have a mean production of 43 m^3, ha^{-1}, yr^{-1} (Zélia Ferreira 2009, Personal communication).

Rural development

Another main reason why governments support establishments of FWPs is the possibilities of rural development (Anon. 2009a, Carrere & Lohmann 1996). In Brazil, since the 1970s, the expectations of development connected to FWP establishments have been high. Increased labour requirements, infrastructures such as roads, improved communications and prosperous welfare as economical development would lead to higher GDP per capita. The military government in the 1960s to the 1980s promoted occupation of the Amazon as a solution to population increase and access to natural resources (Carrere & Lohmann 1996, Pfaff 1999). Roads were built and subsidized credits were offered for development projects. The road network expanded significantly over the 1980s thus doubling the population from 1970-1991, and urban population more than tripled (Pfaff 1999).

Population increase and distribution is the most widely accepted explanation for deforestation (Pfaff 1999). Increased forest tenure would be foreseeable as more people require the same resources. Natural forests in the tropics are currently being converted into other land use at a high rate, mainly for agricultural and grazing purposes (Araujo et al. 2004). Of the two million hectares Atlantic rainforest, in Bahia in year 1945, only seven percent remains (Araujo et al. 2004).

Forest strain

When promoting FWPs the capacity to reduce strain on natural forests is often put forward as a major argument (Turnbull 1999). But if areas previously cleared for agriculture, shifting cultivation or pastures, are covered by FWPs, the local population who cleared the areas in the first place might carry out the same procedures in other areas of natural forests in order to sustain their livelihood. Pulp mills require large continuous areas to supply a pulp mill with raw material, 40,000 – 100,000 ha in production plus at times, large areas used for forest preservation. Thereby the people previously utilizing the land to support their rural livelihood are forced to seek land elsewhere or change profession (Cossalter & Pye-Smith, 2003). Farmers with poor education have few options with the latter and move to the slum of larger cities (Carrere & Lohmann 1996).

FWPs with the sole production of wood fibre, charcoal or other, seldom supply the wide range of forest products that local communities subtracts from natural forests, like resins, fruit and timber. Thus they will continue to seek these products in other natural forests, disregarding whether a FWP plantation is present (Cossalter & Pye-Smith, 2003).

Social conflicts and land use

As many forested areas were cleared for agricultural purposes in the first place, altering the land use from agriculture to wood production can have effects on rural livelihoods. When people for various reasons have lost their rights to use the land conflicts sometimes have arisen (Vergara-Camus 2009). FWPs in particular require large, continuous areas of land and may be owned by foreign multinational corporations. The beneficial effects of the restricted land use may be difficult to see for the local farmer. Discontent with the development may occur if the farmers interpret their livelihood to be threatened. This is however nothing unique for FWPs, the conflicts arose already with the agricultural revolution in the 1970's with less work force demand required in agriculture as a result of technical advances (Nair 2007). In addition to this is Brazil is a nation with large inequities in income. The 20 percent wealthiest Brazilians holds 64.2 percent of the country's income and the 40 percent poorest people only earn 5.7 percent of the income. Concerning land ownership, one percent of the land owners control 45 percent of the farm land in Brazil (Karriem 2009).

As a response to these inequities various and diverse rural, social organizations formed by indigenous people, dispossessed farmers and urban under class developed to protect peasantry livelihood in Argentina, Bolivia, Mexico, Peru, Brazil, Colombia, Ecuador and some places in North America as a response to the neoliberal agrarian policies of the Washington Consensus (Welch 2009). The Washington Consensus stipulated ten economic reforms to help South America struck by a financial crisis in 1989 (Williamson, 2004). The land use issue in South America is not constrained only to FWPs, similar conflicts are present concerning large scale, agribusiness models or bio energy production, which can dispossess farmers in similar ways (Karriem 2009).

The Agrarian land reform; II PNRA

Brazil's landless people are estimated to be between 3.3 and 6.1 million families while more than a quarter of the national territory of Brazil is estimated as unproductive farmland (Del Grossi & Da Silva 2001). The Agrarian reform, resettling landless farmers in Brazil to, by the state, expropriated, unused land, was drafted already in 1964 but was virtually abandoned by the military government of 1964-1984. President Luiz Inácio Lula da Silva has made the agrarian reform one of his priorities. In 2003 he launched the Second National Reform for Agrarian Reform (II PNRA) after several marches and demands from agrarian social organizations (Anon. 2004). During Lula da Silva's presidency 81,430 families per year have been resettled (Vergara-Camus 2009). Brazil's Landless Worker movement, *Movimento dos Trabalhadores Rurais Sem Terra* (MST) had in 2006, 1.1 million members fighting for landless people's access to land in Brazil (Del Grossi & Da Silva 2001). The fight for land in the countryside has become a way to move away from social marginalization (Vergana-Camus 2009).

In the land conflicts with FWP for pulpwood production, the social Non Governmental Organisations (NGO) appear to be most upset by the large continuous land required for the plantations and the way the land has landed in the hand of foreign multi national corporations. Food security, agrarian reform and better possibilities for small agribusinesses to thrive are things organisations like the MST are fighting for (Anon. 2009b). They are supported by environmental NGOs who claim adverse environmental effects associated with FWPs, like disturbance of water cycles, biodiversity reduction and soil deterioration (Carrere & Lohmann, 1996, Hance 2008). On April 7th 2009 the MST started an occupation of 'devolutas' land, lands without official land titles. The land was legally owned by the private company Veracel Celulose in southern Bahia state in Brazil, while the MST claimed that the company owned the land illegally (Anon. 2009c).

Social sustainability is a major issue for many large FWP companies, along with economic- and environmental sustainability. Incidents like the above can, apart for being unpleasant, generate high costs in form of bad publicity and loss of good will, vandalism, arson and legal prosecutions.

Agroforestry

In the perspective of the less than expected decrease of tenure and deforestation of natural forests and sustainability of rural livelihood, multiuse of the FWP land could possibly be favourable. Agroforestry is an age-old, well tried practice where agricultural or grazing crops are grown together with trees, in interacting combinations of temporal and spatial scales. The practice has been prevalent in various parts of the world for centuries, especially in conditions of subsistent farming (Nair 2007). In the 1970s new interest in the practice arose in the scientific community as a response to the Green revolution (Evenson & Gollin 2003) not sustaining agricultural production in marginal lands and remote areas, thus not benefiting small scale farmers. Land management issues like tropical deforestation, fuel wood shortages and soil degradation could also be addressed through agroforestry. A way to counteract these problems, agroforestry has been incorporated into forestry research and practices in many developing nations over the past three decades (Nair 2007).

Agroforestry systems differ widely over the globe in nature, complexity and objectives (Nair 1993). Depending on the objective and issues to be addressed, the resource system and management varies. The most common issues revolve rising population and resource scarcity and their effect on rural livelihood. The needs of people such as food, water, supplemental income etc must be considered when defining the objectives and management for the agroforestry system (Betters, 1988).
An agroforestry system's basic premise is that the total net benefit is greater where joint rather than singular production exist (Betters, 1988). Different crops and trees influence each other in different ways. Complementary production occurs when the crop production is increased in presence of the trees. Supplementary production occurs when trees and crops have negligible interaction. Competitive production occurs when the trees decreases crop production, like Eucalyptus reducing the production of vegetables. In finding the most optimal combination of crop versus tree density per area unit production economics concepts coupled with discounting, valuation and cost-benefit analysis can be used (Betters, 1988).

Many *Eucalyptus spp.* are fast growing species thus have short rotation cycles. This has made them suitable o be grown in monocultures optimized for fast wood production. The fast access to the valuable wood, in comparison to the lower economic value of agricultural crops, has also made it a popular agroforestry species (Ahmed 1989). A major motivation to practice agroforestry is the economic advantage of diversified income (Nair, 2007). There is however at least one trade off; as canopy closes it shades the crops, thus decreasing the crop production (Ahmed 1989).

FWPs and agroforestry

Large private pulp companies have high investment cost to cover and requirements of exact timber flows, strategic planning and rational management (Bertomeu et al. 2009). If agricultural crops could be grown in a controlled, rational fashion without adversely effecting the tree production, it could be used as a way to mitigate social strains and deforestation in areas with FWPs. For a Eucalyptus FWP the main objective is to supply the mill with required wood (Cossalter & Pye-Smith, 2003). Optimal tree rotation cycles and spacing can be viewed as fixed. This constrains the variation levels of crop production.

In order to explore the possibilities of using agroforestry as a tool to mitigate the social conflicts in Southern Bahia, Brazil, Veracel Cellulose has performed several block trials of eucalyptus hybrid clone of *E. grandis* and *E urophylla* in commercial spacing in agroforestry systems with various agricultural crops in lines between the tree rows. The different treatments consisted of corn, beans, sunflower, peanuts, ricinus, cassava and pumpkin which were planted directly after the tree planting. Two rotations of crops were harvested during the first year, except for cassava and ricinus as they need longer time to ripen. After the first year the tree canopy was considered closed and light access for the crops too scarce.

The crop production was about double to average production in Brazil, as the crop mass, ha^{-1} were about the same although number of plants/ha was about half (Carnielli Zamprogno 2009, personal communication). This can most likely be explained by use of fertilize in these trials. On basis of these trials it was assumed that the agricultural crops produced satisfyingly well together with the hybrid clone. The greater concern for Veracel is however the effects on wood production. This study is a follow up study of the agroforestry trials initiated by Veracel Celulose A. S., where tree performance, growth and production are analysed. The hybrid clone has similar growth properties to *E. grandis* (Carnielli Zamprogno 2009, personal communication). Therefore parallels are drawn to literature concerning *E. grandis* to explain results.

Objective

The objective was to analyse the growth response of the hybrid clone 1006 from *Eucalyptus grandis* and *Eucalyptus urophylla,* in commercial spacing grown together with two rotations of seven different agricultural crops and one rotation for two crops, within the first 6-9 months. The null hypothesis stated that the crop production would have no effect on the tree production.

Material and Method

Site description

The study was conducted at Veracel Celulose plantations, South Bahia, in the municipality of Eunápolis, Brazil (16º17'59"S; 39º28'42"W; altitude 168 m). The regional climate (Köppen) is of the *Af* type, hot and humid tropical, without dry seasons. Annual average temperature is 23.1ºC, minimum temperature of 17 ºC and average rainfall of 1250 mm year^{-1} (Bauch et al. 2006). The name of the trial site is Oiticica.

Previous to planting in June 2008, Oiticica was a pasture managed for cattle grazing. In the 1970s however, Atlantic rainforest covered the area (Migray 2009, personal communication) Infrastructure investments like the interstate highway and economic growth in the region lead to deforestation of the Atlantic rainforest in favour of pastures and agricultural land.

Soil properties

The soil in Oiticica is an Ultisol with most of the nutrients concentrated in the A horizon. It has medium fertility and consists of kaolinite, has a loamy sandy A horizon and increased clay content in the B horizon. The area is very flat with negligible inclination giving no general direction of surface runoff. A soil analysis was carried out previous planting by Veracel, (Table 1).

Table 1. Texture classes (in %) for A horizon, 1, and B horizon, 2, before fertilizing in 2008.

Texture class 1	**Clay 1**	**Coarse sand 1**	**Fine sand 1**	**Total sand 1**	**Silt 1**
Loamy sand (medium)	19	27	48	75	6
Texture class 2	**Clay 2**	**Coarse sand 2**	**Fine sand 2**	**Total sand 2**	**Silt 2**
Sandy clay loam (fine)	23	26	42	68	9

Site preparations for planting

The proceeding land use of Oiticica was cattle grazing, thus a new establishment of eucalyptus plants was carried out.

The new establishment was prepared by herbicide treatment before planting. Three litre per ha of glyphosphate were distributed all over the planting area 30 days prior to planting to reduce weed occurrence. Scarification to soil depth 60 centimetres was carried out by a riper, making the tree row distance four meters. Phosphorous was applied as fertilizer at 20 cm depth. It was made out of natural reactive phosphate, which contains 30 percent P_2O_5, 350 kg ha^{-1}. No liming was required as the soil had sufficient content of Calcium and Magnesium and the soil had pH level of 5.5 and *E. grandis* tolerate moderate salinity and alkalinity (Bellote et al. 2009).

Planting was preceded by a tractor elevating the soil into rows, in order to break capillary bonds in the soil to create better drainage for the plants. 84 kg ha^{-1} of fertilizer was added, at a 15 cm soil depth in the tree rows (picture 1). The fertilizer was composed by N 6 %, P 30 %, K 6 %, Cu 1 %, Mn 1 % and Zn 0.8 %. To ensure water availability for the plants, thus protecting them against drought, Hydrosorb gel was applied into the soil, underneath the plant, when planting (picture 2). The dose was 2 g $plant^{-1}$, geloid mixed with 0.6 litre H_2O giving 0.6 litre gel $plant^{-1}$. Cutlings of eucalyptus hybrid clone 1006 from *Eucalyptus grandis* and *Eucalyptus urophylla*, about 90 days old, from Veracel's nursery in Eunápolis, were planted manually (picture 3). Spacing between plants was the commercial spacing of 3 times 4 m, giving 833 trees per hectare. Spraying of the herbicide Fordor – Isoxaflutol to control grass was carried out after planting at a 1.3 m width along the tree rows, aiming only at the soil to control weeds.

Pictures 1, 2, 3. Scarification, planting, E. hybrid clone. Pictures of operation from another site at Veracel plantations.

Soil preparations for agricultural crops

Rows for crops were created motor-manually by a cultivator, making rows 10-15 cm deep. Fertilizer of NPK, concentration 06-30-06 percent was added into the rows in doses as general recommendations subscribe for each crop (Table 2 and Figure 3).

Table 2. Fertilizer dose for the different crops.

Culture	Seed amount, all plots total	g/plant	kg/culture
Corn	9600	5	48,0
Ricinus	1536	65	99,8
Peanut	30720	2	61,4
Cassava	1920	20	38,4
Beans	1280	15	19,2
Sunflower	11520	6	69,1
Pumpkin	384	260	99,8

Figure 3. Amount of fertilizer per hectare of the various treatments for the two repetitions, assuming that Cassava and Ricinus did not receive fertilizer when the other crops were sown again in the second repetition. For legend see Table 4.

Organic fertilizer: Húmus ativo (grupo Vida), fertilizer made of bark residues and activated sludge from Veracel pulp mill. Spots with yellow soil, due to presence of termites had Húmus ativo added to it as the sub soil brought to the surface is poor in organic matter thus require extra supply of nitrogen and micro nutrients. It was also added to all pumpkin plots as pumpkin has a high nitrogen demand (Migray 2009, personal communication).

Sowing agricultural crops:
Seeds for the agricultural crops were sown manually into the fertilized pits, distance in accordance to general recommendations specific for each crop (Table 3).

Table 3. Sowing spacing for agricultural crops.

Sunflower	Ricinus	Corn	Pumpkin	Cassava	Peanut	Beans
0,8 X 0,2 m	2 X 1 m	1 X 0,2 m	1 X 2 m	1 X 0,6 m	1 X 0,2 m	1 X 0,6 m

Trial design

The trial was laid out as a randomized block trial with seven crops in ten different crop, tree combination treatments of which one was control treatment with, by Veracel, standardized eucalyptus planting. Each treatment had four repetitions thus making 40 plots in total at an area of 2.4 ha (Table 4). The trial layout can be viewed in Figure 4 and Picture 4.

Table 4.Treatment combinations and number of plots.

Treat.	Crop	Consortium	Plots	Legend
1	Sunflower	-	4	S
2	Pumpkin	-	4	Pu
3	Ricinus	-	4	R
4	Corn	-	4	C
5	Beans	Sunflower	4	BS
6	Beans	Corn	4	BC
7	Cassava	-	4	Ca
8	Cassava	Peanut	4	CP
9	Ricinus	Peanut	4	RP
10	Eucalyptus	-	4	E

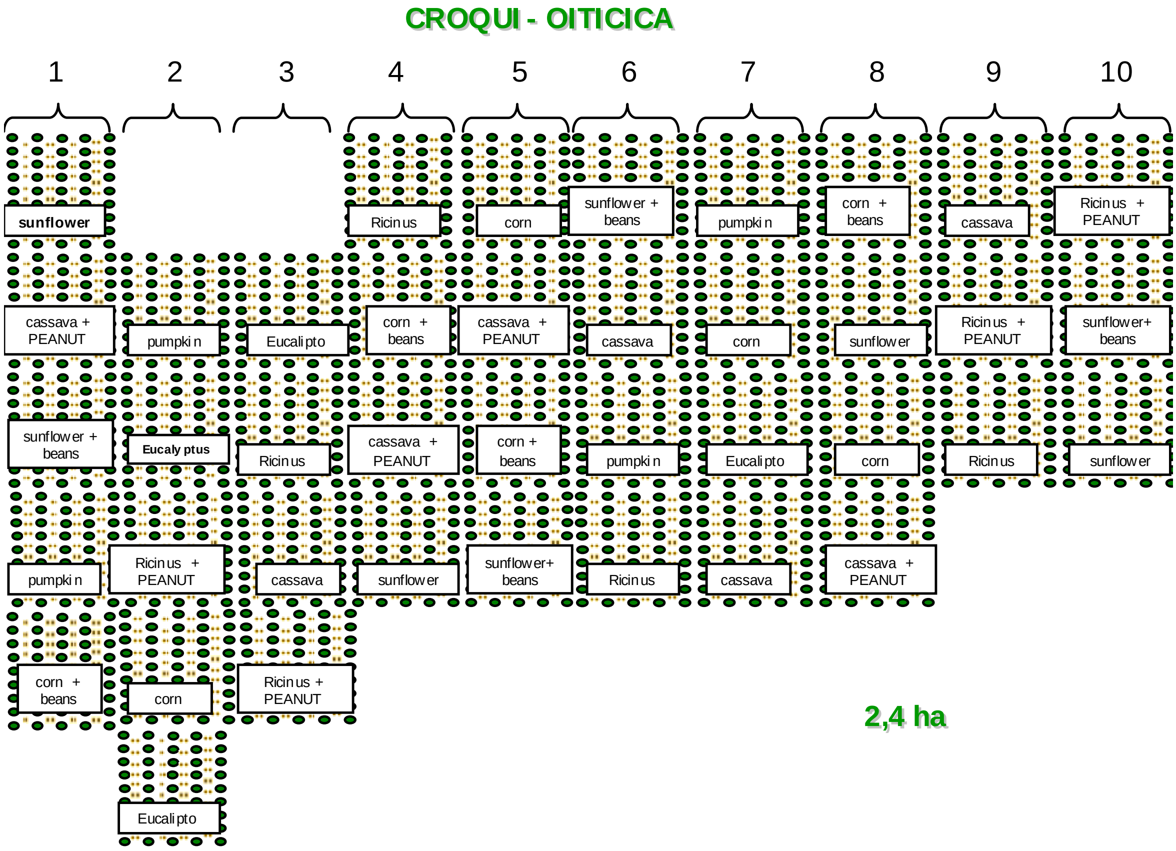

Figure 4. Trial layout of randomized blocks; four blocks with 10 treatments each.

Picture 4. Trial layout after planting of Eucalyptus and crops.

Crops treatment

The trial was irrigated by hand. The agricultural crops were harvested after 3 months, except for ricinus and cassava which were harvested after 9 months thus only making one rotation. The other crops were sown again, in exact repetition concerning species, spacing and fertilizer (pictures 5, 6 and 7), and then again harvested three months later. After the second crop harvest the canopy had closed and no further agricultural operations took place.

Picture 5, 6, 7. Planting of crops, 2nd rotation.

Eucalyptus treatment

Weeding of the eucalyptus was carried out three months after planting with a hoe, not by herbicide. The trees received their commercial standard second fertilization 6 months after planting, in December 2008. The dose was 300 kg ha^{-1} of ammonium sulphate and 0.5 percent boron, which was applied for each tree. The fertilizer was dug down in two holes on of each side of the tree, 10-15 cm deep.

Data collection

Measurements

At the time of inventory, the Oiticica stand was 16 months old (picture 8). Each plot was planted with five rows of *Eucalyptus* hybrid clone, spacing 3 X 4 m. Each plot was 9 trees long and five trees wide but to exclude border effects, only the three central lines were measured, as they then were surrounded by given agricultural crop. Thus, 27 trees made out each plot.

- The beginning and the end for each plot was carefully marked by pruning and painting the three first and last trees, making 6 trees per plot marked (picture 9).
- The actual area of each plot was measured by precision of 1 cm, including half border area from outer tree rows.
- Height of each tree was measured by 0.5 m precision with a Suunto clinometer, 15 m distance from tree.
- Circumference of each tree was measured at breast height (1.3 m) by 1 mm precision with a tape measure (picture 10).
- Abnormalities were noted by code, as base for diameter calculations of double stem.



Picture 8. Oiticica, 16 months old *E. hybrid clone*. Picture 9, 10. Plot marking and DBH measuring.

Analysis of data in Excel

Exact plot areas were calculated. Circumferences were converted to diameters according to Diameter = Circumference/Π. Diameters for trees forked below breast height diameter (dbh) were calculated by:

$D= \sqrt{(d_i^2 + d_j^2)}$

Height of double stems were calculated as the average by:

$H= (h_i + h_j)/2$

Volumes per tree were calculated by the volume formula for clone 1006:

$\text{Volume (1006)} = \exp^{(-10,0954+1,7907*\ln(dbh) + 1,306*\ln(h))}$

The formula has been obtained by multiple field measurements of clone 1006 (Zélia Ferreira 2009, personal communication). Volume per hectare was then obtained by dividing the total volume, unit m^3, of the plot by the plot area, unit m^2, and multiplied by 10^4.

Mean values for variables; height, diameter, volume per tree and volume per ha were calculated for each of the 40 plots and put into a joint table. The joint table was analysed with ANOVA using Sisvar software for Scott-Knott test with 0.05 confidence interval.
The data was considered normally distributed according to Anderson Darling test at 0.05 confidence level. The model used for analysis of data was expressed as:

$$EF = \mu + T_i + B_j + E_{ij} \qquad (1)$$

Where EF is the expected factor, μ is the grand mean, T_i is the treatment, B_j is the block and E_{ij} is the error term.

The Scott-Knott test is similar to Tukey's test and allows multiple comparisons between great numbers of treatments and unambiguous, discrete groups of means (de Aquino 1999). The Scott-Knott test partition the original group of treatments into multiple non-overlapping groups by maximizing the sum of squares between groups. The values obtained are tested by the statistic chi square test and each group formed can be partitioned again if the new groups are significantly different. Grouping is stopped when obtained groups are not statistically different in the constituent treatments. The treatments within the same group are considered equal (Scott & Knott 1974).

Results

The different treatments gave quite different results in all measured categories, mean height, mean diameter and mean volume per ha. In all categories of mean values the trees in the agroforestry treatments had higher production than the trees in the control plots. Three different significance classes occurred for the treatments mean values of volume per hectare.

Of the total 648 trees, 7 were dead or missing, giving a survival rate of 99 percent. There were 53 trees forked under dbh, no trend amongst treatments.

The results of the measured values analysed by ANOVA yielded clear results. With a confidence level of 0.05, there was no statistical difference between the four blocks but significant differences amongst the treatments (Table 5).

Table 5. Table of results from ANOVA at 0.05 level of the 4 blocks and 10 treatments.

ANOVA variance of	**Analysed data**	**Fc**	**Pr>Fc**
Height	Block	1.458	0.2480
	Treatment	4.254	0.0016
Diameter	Block	0.408	0.7845
	Treatment	4.163	0.0019
Volume / ha	Block	2.077	0.1267
	Treatment	9.542	0.0000

Height

The mean values of eucalyptus height ranged from 9.9 m for eucalyptus control plots to 11.5 m in the beans and sunflower combination. The Scott-Knott test gave three significantly different classes (figure 5).

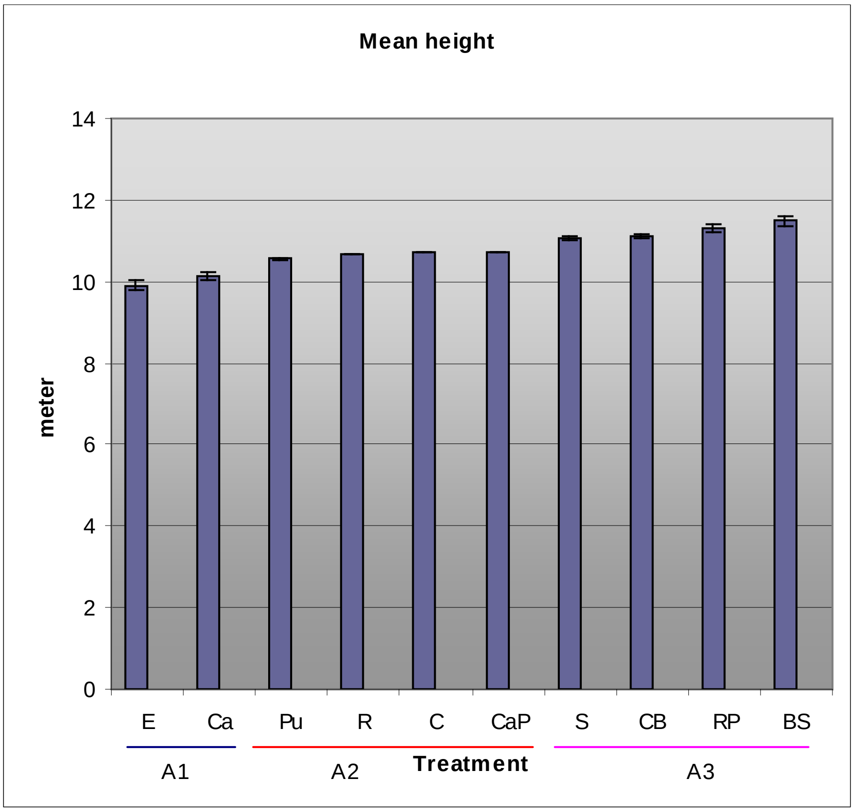

Figure 5. Mean height for each treatment. Coloured lines show which significance class values belong to. The standard deviation of the means of each treatment is shown by the top bars. For legend see Table 4.

Diameter

The lowest mean values of diameter for eucaluptus was 8.97 cm for the eucalyptus controls and maximum was 10.16 cm in plots with Ricinus and Peanuts. Mean values of diameter only discretizised into two significantly different groups, but with eucalyptus control plots and cassava remaining in the lowest group (figure 6).

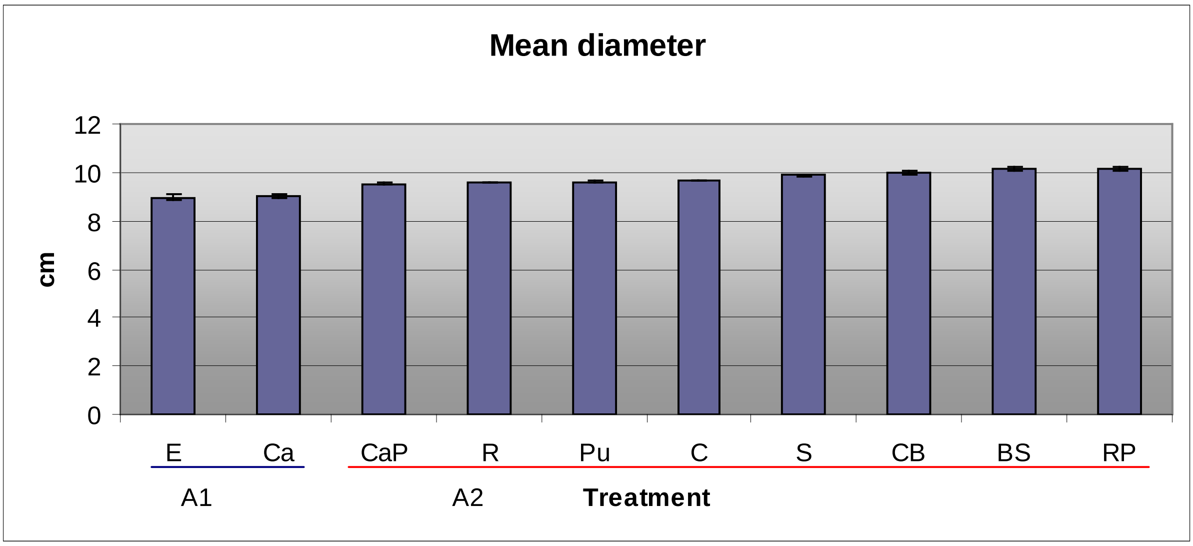

Figure 6. Mean diameter for each treatment. Coloured lines show which significance class values belong to. The standard deviation of the means of each treatment is shown by the top bars. For legend see Table 4.

Volume

The mean volume per hectare was grouped into three significantly different levels by the Skott-Knott test (figure 7). Control plots of Eucalyptus had the lowest mean value from all four blocks, at 24.03 m^3/ha and the treatment with beans & sunflower had the highest mean value at 34.07 m^3/ha. The Eucalyptus control plot and Eucalyptus & Cassava remained at the lowest production while Corn & Beans, Ricinus & Peanut and Beans & Sunflower had the highest volume per hectare. Wood production per hectare was 41.8 percent higher in the highest treatment, bean & sunflower, compared to the control plot of Eucalyptus at the time of measurement (Figure 7).

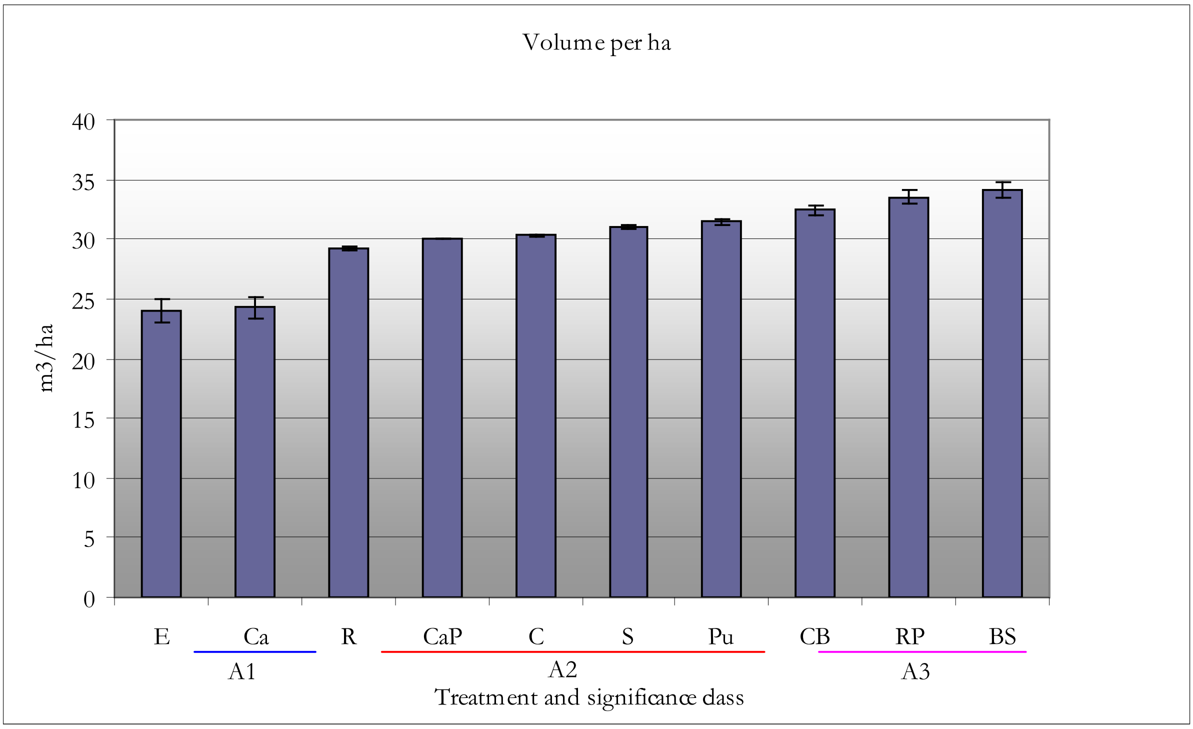

Figure 7. Volume per hectare. Coloured lines show which significance class values belong to. The standard deviation of the means of each treatment is shown by the top bars. For legend see Table 4.

Discussion

The trees in integrated crop treatments produced better than in the control plots of commercially conventional treated eucalyptus. Thereby there are no reasons concerning tree production against this type of agroforestry where agricultural crops and eucalyptus are grown together during the first year after planting. The increased production of a plantation can only be seen as positive for a eucalyptus plantation which has high productivity as a goal. Obtaining the 40 percent higher volume growth with beans and sunflower compared to eucalyptus control plots, while maintaining commercial spacing, one would expect to be of interest for plantation companies allocating substantial resources for genetically improvements of plant material and improved silvicultural techniques for higher production. The results can however not be extrapolated for the entire rotation period.

The eucalyptus trees had a different production for different crops making three significantly different groups of average volume per ha. Different crops have different properties such as nutrient and water demand, capacity for nitrogen fixation etc, which possibly can influence the tree production.

The treatments which ended up yielding the highest wood production were *E.* hybrid clone 1006, together with Beans & Corn, Ricinus & Peanuts and Beans & Sunflower. Both beans and peanuts are nitrogen fixating species (Bandyopadhyay et al. 2007) and could thus have supplied higher, continuous nutrient availability than in other treatments.

Further studies are needed to investigate nutrient uptake by tree roots and crops, the effects of fertilizer, water access and effects of nitrogen fixating crops in this type of agroforestry system.

An apparent cause of higher volume production would be the increased nutrient access for the tree roots in the agroforestry plots as the crops received extra fertilizer and the control plots did not. The control plots were fertilized as commercial practice with the initial fertilizer when planting and then again after six months, when the nutrient demand of *E. grandis* is the highest (Camoron et al. 2009). The *E. grandis* root system does however develop quickly in the top soil layers and has shown to be competitive with other tree species (Freitas Coelho et al. 2007). Within three months after planting the lateral root extension can be 2.5 m from the planting row, with most fine roots in the surface layers (Arnaud et al. 2002). This implicates that the plants could access the nutrients from the crops fertilizer in the course of the first six months. The control plots did not have the same access of extra nutrients as they were treated by current commercial, silvicultural regimes at Veracel. The correlation is however not clear as treatment that received most fertilize, the pumpkin, was found in the intermediate growth group and not in the group of highest volume per ha.

Another factor of interest is that the crops were irrigated by hand in cases of inadequate rainfall. Unfortunately, no exact records of the irrigations are at hand. The trees root systems in the top layers in the agroforestry stand could have profited from the extra access of water compared to the control plots which did not receive irrigation. The water access in combination with extra access of nutrients such as phosphorous could possibly have increased the allocation of above ground biomass production (Graciano et al. 2006).

As both the crop and tree production were overall high, possible allellopathic interactions between trees and crops appear of marginal concern for this type of system and exceeded the scope of this study. Further research is needed to seek optimization strategies of crops grown including light demand, nutrient demand, nitrogen fixating properties, allellopathic relationships, pests and pathogens, production costs, market demand etc. Social acceptance by rural population for this type of scheme will also need to be addressed.

Implementing this type of agroforestry to commercial eucalyptus plantation would have a positive effect on wood volume production. The choice of crops affects the wood production but only in various degrees of increased growth.

Potential use of findings

Plantation activities
To reduce social friction with local communities the FWP could let newly planted land to local farmers to grow agricultural crops between the tree rows. An alternative would be to lease the land after planting to the farmers thus generating an income for the FWP to mitigate the high investment costs of planting.
The soil could be prepared and rationally worked due to the forest operations thus facilitating agricultural practices for the farmers. The already present infrastructures as maintained roads could also further facilitate the practices. As eucalyptus hybrid clone is a fast growing, competitive species the canopy at Veracel Celulose plantation is considered closed after a year. Assuming the agriculture production to be unsuitable after canopy closure, the area available for agroforestry would thereby shift on a yearly basis.

Out growing schemes
Many FWP companies face restrictions of land access by the government of the state they are operating in. The large continuous areas required to supply a large mill can by the government be viewed as a too large area for a single enterprise to acquisition (do Nascimento. 2001). Especially in cases if the FWP wishes to increase its capacity and require more land. A solution to this dilemma is for the FWP company to buy the wood required from local land owners. The condition for that solution is of course that the land owners grow the trees required. One way of ensuring this would be for the FWP company to supply planting material, technology and a market to sell the timber while the land owner’s input would be land and labour. Small hold farmers in the tropics rural areas struggle with markets characterized by high risk and high transaction costs to produce and sell their products. Product diversification as producing trees as well as food crops could have a positive impact on small-scale cash-limited farmers. In such cases, integrated agroforestry systems could improve rural livelihoods (Nair. 2007).

As previously mentioned in this paper, the possibility to grow food is of major importance for many farmers. Out growing schemes could be made more attractive to farmers with the possibility to proceed with some food production as well as tree plantation with this type of agroforestry system.

This would be a very intensive form of land use. But as overall agricultural activities also have adverse effects on the environment, more than FWPs (Cossalter & Pye-Smith. 2003). Thus the extra environmental strain associated to this type of multi use could be argued as acceptable as it most likely would not exceed environmental pressure of common agricultural practices. The current land use has the main objective to produce of wood fibre for export or the domestic market. With this type of semi-industrial, rational agroforesty the second objective would be food production for local populations, however not leaving out possibilities of commercial production. Multi use of plantations could help to increase quality of rural livelihood and increase food production.

Conclusions

The production of eucalyptus hybrid clone of *E. grandis and E. urophylla* increased significantly in plots with agricultural crops compared to control plots of single eucalyptus, except with cassava. The hybrid clone together with Beans & Corn, Ricinus & Peanuts and Beans & Sunflower were the three treatments yielding the highest wood production increase during the first 16 months of the rotation cycle. The results prove absence of adverse effects on eucalypt production rate during the agroforestry phase when proper fertilization is carried out. Wood production would thus not decrease with this type of agroforestry system, it is increased. This implicates that there are no tree production limiting reasons against using this type of agroforestry as a method to mitigate social land conflicts, develop rural livelihoods and increase food production.

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