New Forests
DOI 10.1007/s11056-007-9077-0

Production of bioenergy on small farms: a two-year agroforestry experiment using *Eucalyptus urophylla* intercropped with rice and beans in Minas Gerais, Brazil

Produção de bioenergía em pequenas propriedades: um experimento de dois anos utilizando *Eucalyptus urophylla* consorciado com arroz e feijão em Minas Gerais, Brasil

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Received: 12 July 2007 / Accepted: 16 November 2007

Abstract Agroforestry systems using *Eucalyptus* for biomass production are important alternatives for small farms in the southeast of Brazil because they integrate timber and food production while reducing the environmental impact of large plantations. In this article, I studied the intercropping of *Eucalyptus urophylla* with rice and beans for two years to compare yields using intercropping versus monocultures. During the first year, in both seasons (dry and rainy), no differences were found in the productivity between the intercropped and monoculture systems of *E. urophylla*, rice and beans. In the second year, *E. urophylla* in monoculture had lower productivity compared to *E. urophylla* intercropped with agricultural crops. On the other hand, both agriculture crops showed a reduction in the productivity in the intercropping with *E. urophylla* when compared to monoculture. At least in the first two years, forest biomass production was higher for intercropping systems of *E. urophylla* with beans and rice compared to monocultural systems.

Resumo Sistemas agroflorestais utilizando *Eucalyptus* para a produção de biomassa florestal podem ser considerados como uma alternativa de produção para pequenos produtores no sudeste do Brasil, porque além de integrar a produção de biomassa com a produção de alimentos, reduz o impacto ambiental das plantações em grande escala. Neste trabalho os rendimentos do consorcio de *Eucalyptus urophylla* com arroz e feijão foram avaliados e comparados com os rendimentos de seus respectivos monocultivos, durante dois anos. No primeiro ano, não foram encontradas diferenças significativas entre os sistemas agroflorestais e os monocultivos de *E. urophylla*, arroz e feijão em ambas estações (seca e chuvosa). No segundo ano, *E. urophylla* em monocultivo apresentou uma produtividade mais baixa quando comparada com o *E. urophylla* consorciado com culturas agrícolas. Por outro lado, as culturas agrícolas consorciadas com *E. urophylla*

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apresentaram uma redução na produtividade quando comparados com seus respectivos monocultivos. O modelo do índice de equivalencia de area (IEA) confirmou as vantagens dos sistemas agroflorestais sobre os monocultivos tanto para *E. urophylla* como para arroz e feijão, ao menos nos dois primeiros anos, quando o principal objetivo é a produção de biomassa florestal.

Keywords Agriculture crops · Land equivalent ratio · Agroforestry systems · Monoculture · Intercropping · Forest partnership

Palavras-chave culturas agrícolas · indice de equivalencia de area · sistemas agroflorestais · monocultura · consorcio · parceria florestal

Introduction

Brazil is ranked seventh in the world in area of forest plantations after China, India, Russia, United States, Japan, and Indonesia (ABRAF 2006). *Eucalyptus* is the main planted hardwood species (10–15 million ha; Neilson 2000), and the productivity of managed forests has increased from 12 m^3 ha^{-1} $year^{-1}$ in the 1960s, to 20–60 m^3 ha^{-1} $year^{-1}$ due to genetic improvement and silvicultural techniques (Mora 1986; Santana et al. 2000; Stape et al. 2001). These rates are 5–15 x higher than those corresponding to the most important temperate species used for forest plantations elsewhere in the world (Roy et al. 2001). Faster forest growth rates are generally associated with depletion of onsite resources which, in turn, brings up questions related to both ecological impacts of plantations and wood production sustainability (Singh and Kohly 1992; Lima 1993; Ceccon and Martínez-Ramos 1999).

In Brazil, the genus *Eucalyptus* is considered the most important wood as an energy source for the steel industry (Magalhães 1993) and the state of Minas Gerais accounts for 90% of the total charcoal consumption in the country (Larson et al. 1994). *Eucalyptus urophylla* is one of the most planted species in Brazil, mainly due to its fast growing rate and potential value for charcoal production among others (Scanavaca and García 2003).

Large-scale *Eucalyptus* plantations are often owned by steel companies (Couto and Betters 1995). However, these plantations discouraged due to more lucrative land-use alternatives and because of objections to the establishment of plantation monocultures by environmental groups and the government. This situation is very critical in southeastern Brazil, where Minas Gerais is located. Therefore, some companies have pursued a different strategy by going into a partnership with local farmers to planting trees in order to assure the long term availability of wood. Farmers provide the land and the workforce in these most of partnership programs, while the forest company provides *Eucalyptus* seedlings, fertilizers and technical assistance. The companies buy some or all of the first-cut harvest at a pre-agreed price at the end of the plantation cycle (around 7 years), which includes repayment for the initial inputs and services (circa 21%). The farmer may then sell the remaining timber to other companies if they offer a better price (Ceccon 1999).

Besides providing wood supplies for the industry, small plantations contribute to the reduction of the environmental impacts of large plantations, the reason being that small plantations have fewer negative environmental impacts than large plantations because they are scattered within a landscape matrix of many other vegetation types. There is mistrust, however, by some local farmers who are concerned that *Eucalyptus* plantations would divert land away from the food production (Assis et al. 1986). Under this scenario, agroforestry was recognized as a potential alternative, which would integrate biomass production for the steel industry and food production for local consumption and sale. Most farmers who were engaged in forest partnerships were convinced that agroforestry systems using *Eucalyptus* species could provide an excellent economic opportunity (Sungsumarn 1993; Couto and Betters 1995; Ceccon 1999). However, accurate biological, technical and economic information on the intercropping of agricultural crops and *Eucalyptus* species is necessary in order for *Eucalyptus* agroforestry to be socially acceptable.

Most of the research in Brazil involving *Eucalyptus* agroforestry is aimed at tree production and is focused on agricultural cropping during the first year of the forest plantation (Schreiner and Balloni 1986; Almeida 1990; Ferreira Neto 1993). A different approach by the Pains Florestal Steel Company (part of the GERDAU Group), involved the initiation of an agroforestry research program with the objective of exploring a variety of models for intercropping *Eucalyptus* with agriculture crops (e.g., Couto et al. 1996; Passos 1996; Ceccon et al. 1999; Ceccon 2005). The main goal of these studies was to evaluate agricultural productivity and to determine until what age *Eucalyptus* plantations could maintain compatibility with field crops, while, at the same time, assessing all the potential benefits of the *Eucalyptus* biomass production in the agroforestry systems.

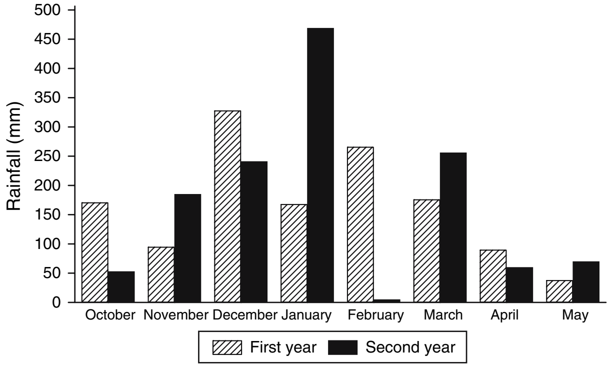
This study presents the results of a two-year field experiment that evaluates the productivity of *E. urophylla* intercropped with rice (*Oryza sativa* L.) and beans (*Phaseolus vulgaris* L.). Hypotheses tested were that intercropping could increase *E. urophylla* yield at least during the two-year tree lifespan and that the total productivity of agroforestry systems would be higher than the productivity of trees and crops under monoculture systems.

Materials and methods

Study area

The experiment was carried out at the Dona Rosa Research Center in Agroforestry Systems in Claudio, near Divinopolis City (20°08′21″ S and 44°53′17″ W) in Minas Gerais state, Brazil. The climate corresponds to that of a montane tropical forest (Cwa) according to Köppen (average 23°C). The annual rainfall was of 1,300 mm, occurring mainly between October and March (Fig. 1). The average altitude is 670 m and the landscape profile of the region is 6% flat, 64% undulating, and 30% mountainous (Biblioteca Municipal de Divinópolis 1992) while the area where the experiment was carried out is mostly flat (<10% slope). The soils in the region are mainly oxisols (Bedê and Barezzani 1991) and

Fig. 1 Total monthly rainfall (mm) in the first and second year when agriculture crops were planted (source Ceccon, 2005)



the natural vegetation is known as “cerrado” (savanna-like; Biblioteca Municipal de Divinópolis 1992).

Study design

Eucalyptus urophylla *establishment and management*

During the first two weeks of December (summer), seedlings of *E. urophylla* were planted on 20 plots (30 m × 16 m, 480 m^2 each plot). Eight plots were intercropped with rice, eight plots with beans and four were planted alone (monoculture). The spacing among seedlings was 5 m × 2 m (1,000 trees ha^{-1}; Fig. 2). Approximately 4.2 tons ha^{-1} of calcareous dolomite was initially spread with a tractor after plowing operations. The fertilizer that was incorporated into the *E. urophylla* mid-row bands was 200 kg ha^{-1} of NPK 5:26:5. After the harvesting the first plantation of rice and beans, a second fertilization of 150 kg ha^{-1} of NPK 14:00:28 was added to both side bands of the *E. urophylla* plantation. During the second year of the plantation and before the plantation of agricultural plots, one-third of the lower green crown of the trees was pruned to minimize the effects of shade on the crops. To evaluate the response of *E. urophylla* to different treatments, the height and DBH of the 24 central trees (150 m^2) of each plot was measured. The first evaluation was made when the trees were 4-months-old, the second at 8-months-old and the third at 16-months-old. The following formula was used in order to determine the volume of *E. urophylla* per hectare:

$$V\ \mathrm{ha}^{-1} = \pi \times D^2 \times H \times 1000/4$$

where: V = volume (m^3), D = stem diameter (m), H = height (m).

Agricultural crop cultivation during the first year

Rice and beans were planted at the same time as the forest plantation. Each crop of eight plots was planted in the alley (5 m between rows) of the *E. urophylla* plantations and four plots (for each crop) were planted alone. Each plot occupied an area of 450 m^2 (25 × 18 m). In the intercropped systems, both crops occupied 9 lines between *E. urophylla* rows (Fig. 2). In the monoculture system, the same spacing between the lines was used in order to compare the same production resulting from the monoculture and the intercropped system. However, in the monoculture crops, between each group consisting of nine crop lines, there was a spacing equivalent to the area normally occupied by the *E. urophylla* (1.0 m) in the intercropped system which was not planted with crops. We called this “effective productivity” in order to compare it with the same productivity of crops in the intercropped systems (Fig. 2). In the intercropped system, *E. urophylla* occupied 20% of the plantation area, while agriculture crops occupied 80%. Hence, it is important to point out that the usual production of monoculture crops is 20% higher than the “effective productivity.” The spacing between bean plants was of 20 cm and between lines 0.5 m, with three seeds planted per hole. Around 75 seeds rice were sown at each linear meter and the spacing between the lines was of 0.5 m. When both crops were intercropped with *E. urophylla*, the first line of crops was placed at a distance of 0.5 m from the tree line.

Fertilization of the agricultural crops soil was applied according to the results of a previous soil analysis which characterized its nutrient profile; in the bean plantations,

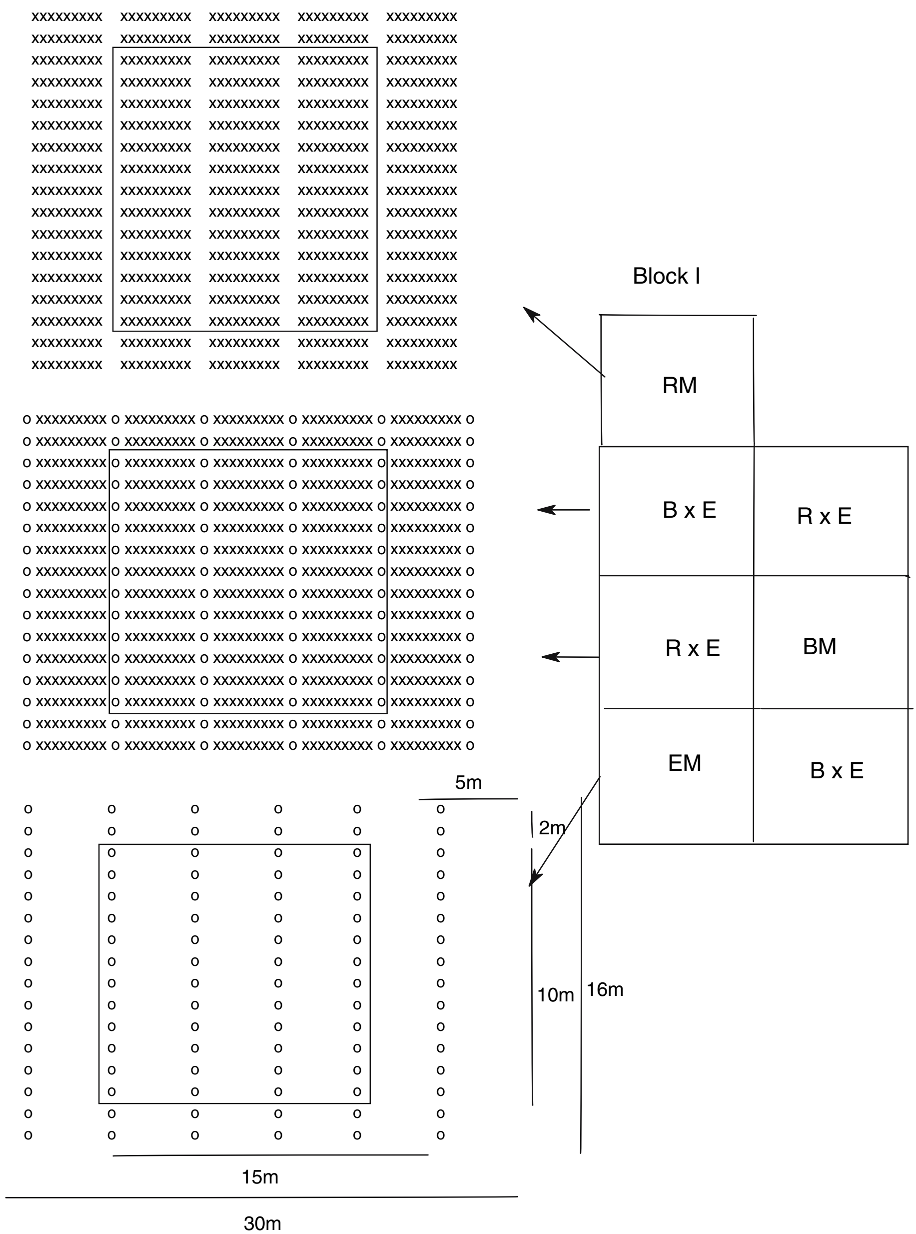


Fig. 2 Agroforestry experiment design. The plots of *E. urophylla* with crops (R × E, B × E), the crops in monoculture (RM, BM) and the *E. urophylla* in monoculture (EM) are shown with detail, including the block I randomly assigned and the useful area (square inside each plot)

750 kg ha^{-1} of gypsum, 180 kg ha^{-1} of MAP (monoammonium phosphate), 100 kg ha^{-1} of ammonium sulfate, and 100 kg ha^{-1} of chlorate of sodium were spread by hand in each plot. After 20 days, 10 kg ha^{-1} of borax, 20 kg ha^{-1} of zinc sulfate, and 70 kg ha^{-1} of urea were applied by hand to both side bands of the bean lines. To prevent insect and

fungus attacks, pesticides were applied. In the rice plantation, 750 kg ha^{-1} of gypsum, 140 kg ha^{-1} of MAP, 100 kg ha^{-1} of chlorate of sodium and 20 kg ha^{-1} of zinc sulfate was spread by hand in each plot. Two months later, 80 kg ha^{-1} of ammonium sulfate was applied by hand in both side bands of the rice lines. No pesticide treatment was necessary and only one clearing of the field for weeds in both crops was carried out.

For Brazilian small farmers planting beans in the dry season is the standard practice; therefore, beans were planted in March (dry season, Fig. 1) establishing identical treatments as in the rainy season, including identical management and sanitary care. The hand-applied fertilizers were 120 kg ha^{-1} of MAP, 60 kg ha^{-1} of ammonium sulfate, and 6 kg ha^{-1} of potassium chlorate.

To assure some production in the case of a possible absence of rain during the four months of rice growth, the plantation plant plantation was established using blocks at different times (one month between the first and fourth block).

Harvesting of crops was conducted manually in the central 150 m^2 of each plot area. Each plot yield was measured by weight (approximately 10% of humidity) and the productivity per hectare was calculated.

Agricultural crops cultivation during the second year

When the second year of the cultivation of rice and beans began, *E. urophylla* trees were one-year-old. The plots used were the same as in the previous year. Also the varieties and fertilizations practices of rice and beans were the same as those of the previous year. However in the second year, calcareous dolomite was not applied. Crop rotation was carried out in such a way that the plots cultivated with rice the previous year were cultivated with beans and vice versa because, as suggested by de Oliveira et al. (2000), crop rotation helps reduce carryover of most disease pathogens, including rust, bacterial blights, most root rots, and anthracnose. Bean seeds were treated with fungicide before plantation. Organophosphorus insecticide was applied to the rice plantation, to prevent termite attacks (very common in the region). Similarly to the first year, the rice plantation was established by blocks at different times with a difference of one month between the plantations of the first and fourth block.

The land equivalent ratio (LER)

To evaluate intercropping among different crops in relation to monoculture of the same crops, LER was used (Willey and Osiru 1972). The model determines the number of hectares needed for the productivity of monocultures which are equivalent to 1 ha of intercropping productivity. For example, a LER >1 means that intercropping is advantageous because more land would be required to obtain crop and tree yield by sowing each species separately.

In this study, in order to calculate the LER since monoculture and intercropping plantations area for the crops presented the same size, the productivity of the monoculture crop was increased by 20% (area that would be occupied by the crops in a normal monoculture crop system). The formula used is the following (beans as an example):

$$\mathrm{LER} = \mathrm{LERB} + \mathrm{LERE} = (\mathrm{BPI}/\mathrm{BPM}) + (\mathrm{EPI}/\mathrm{EPM})$$

LER = land equivalent ratio, LERB = land equivalent ratio of beans area, LERE = land equivalent ratio of *E. urophylla* area, BPI = beans productivity on intercropping, BPM =

beans productivity on monoculture, EPI = *E. urophylla* productivity on intercropping, EPM = *E. urophylla* productivity on monoculture.

Statistical analysis

Eucalyptus urophylla, beans and rice yields were analyzed separately for each year. The response variables for each system were timber volume (m^3 ha^{-1}) for *Eucalyptus* and productivity (kg ha^{-1}) for rice and beans. The statistical design was unbalanced ANOVA (random blocks) with four replicates for *Eucalyptus* alone and 8 replicates for *E. urophylla* associated with rice and eight replicates for *E. urophylla* associated with beans. Tukey tests were used for the post hoc comparison of means. The computer program used was STATISTICA 5.0.

Results

Main effects of associated crops on *Eucalyptus urophylla* timber volume

In the first 4 months there was no significant difference in *E. urophylla* volume of timber between the monoculture and the intercropping with rice and beans (Fig. 3). However, after eight months, significant differences ($P < 0.05$) among all systems were found (Fig. 3). *Eucalyptus urophylla* intercropped with beans showed a significantly higher timber volume compared to the *E. urophylla* intercropped with rice and the *E. urophylla* monoculture, while the volume of *E. urophylla* intercropped with rice was significantly higher than the *E. urophylla* planted alone ($P < 0.05$).

After 16 months, significant differences ($P < 0.05$) also were evident among systems (Fig. 3). However, *E. urophylla* intercropped with rice was the treatment that presented a significantly higher timber volume compared to the *E. urophylla* intercropped with beans and the *E. urophylla* monoculture, while the volume of *E. urophylla* intercropped with beans was significantly higher than the *E. urophylla* planted alone ($P < 0.05$). In both periods of growth, the *E. urophylla* monoculture showed a significantly lower timber volume.

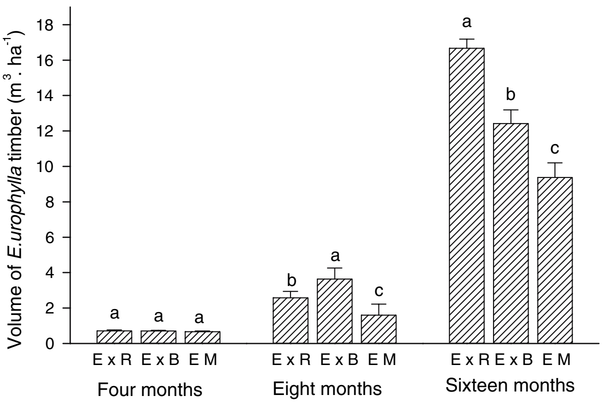


Fig. 3 Total timber volume (m^3 ha^{-1}) of *E. urophylla* at 4, 8 and 16 months intercropped with beans (E × B) and rice (E × R) and in monoculture (EM). Vertical lines are standard errors. *Note*: for each variable, means are significantly different between treatments when followed by different letters ($P < 0.05$)

Main effects of *Eucalyptus urophylla* on average beans yield

Rainy season

There were no significant differences in productivity among systems (intercropping with *E. urophylla* or in monoculture) in the first year of the bean plantations (Fig. 4). Productivity of all treatments was higher in the second year than in the first year. However, the productivity of beans in monoculture was significantly (P (0.05) higher than that intercropped with *E. urophylla* (Fig. 4).

Dry season

No significant differences among systems in the first year were found. In the second year, even when the rainfall during the dry season was higher than during the first year (386 and 304 mm respectively), bean monoculture showed a significantly (P (0.05) higher productivity than the one intercropped with *E. urophylla* trees (Fig. 5).

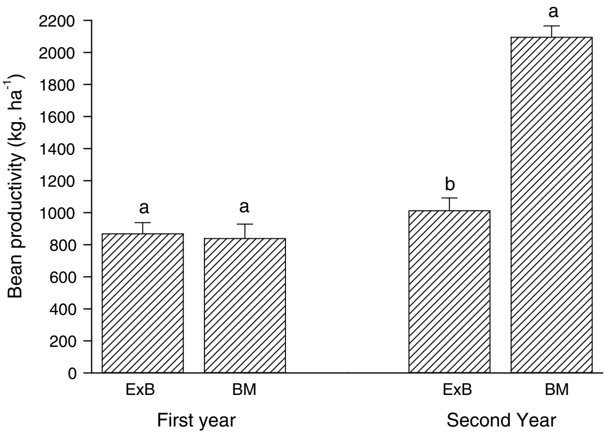


Fig. 4 Total effective productivity of beans (kg ha^{-1}) intercropped with *E. urophylla* (E × B) and in monoculture (BM) over the two years. Vertical lines are standard errors. *Note*: for each variable, means are significantly different between treatments when followed by different letters ($P < 0.05$)

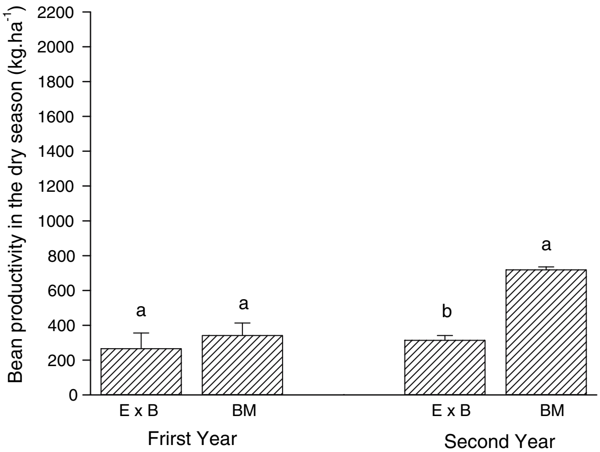


Fig. 5 Total effective productivity in the dry season of beans (kg ha^{-1}) intercropped with *E. urophylla* (E × B) and in monoculture (BM) over two years. Vertical lines are standard errors. *Note*: for each variable, means are significantly different between treatments when followed by different letters ($P < 0.05$)

Main effects of Eucalyptus urophylla *on average rice yield*

For the first harvest of the rice plantations there were no significant differences among the systems (intercropping with *E. urophylla* or monoculture; Fig. 6). However, during this year termite attacks reduced the productivity slightly. In the second year, the productivity was very low (Fig. 6) and these were only significant differences among blocks (not among treatments), because they were planted at different times: Block IV (916 kg ha^{-1} productivity) was planted one month before the last block II (84 kg ha^{-1} productivity). The F value among blocks was 12.859 ($P < 0.01$). During rainiest five months, the precipitation was higher in the second year than in the first year (1,136 and 1,036 mm), however in February, precipitation in the first year was 266 mm and only 5 mm in the second year (Fig. 1), hence, the productivity of the first year was much higher when compared to that obtained in the second year.

The land equivalent ratio model (LER)

Values of the LER of the studied systems for the two years are shown in Table 1. The values of the LER higher than one show that all intercropped systems were feasible. However, in the second year, the total LER of the intercropped systems was slightly lower (6.21) than in the first year (6.93). The first year had a higher LER with the bean systems in both seasons, while for the rice system, the first year had a lower LER than the second year. In the first year of the experiment, *E. urophylla* intercropped with beans (dry season) had the highest LER. In general, besides the lower productivity of rice, the intercropping of *E. urophylla* with rice was the most productive system in the second year. For example, to produce the same amount of timber and rice obtained in one hectare of intercropping system in the second year, it would be necessary to plant 1.78 ha of *E. urophylla* and 0.50 ha of rice monocultures. In total, 2.28 ha would be needed for both systems planted separately (more than double the area). Even in the system with the lowest LER (*eucalyptus* × beans in the dry season), in order to produce the same amount of timber and beans obtained in one hectare of intercropping system, 1.32 ha would be needed of *E. urophylla* monoculture and 0.44 ha of beans monoculture. In total, 1.76 ha would be needed for both planted in monoculture, nearly double the land used in the intercropped area.

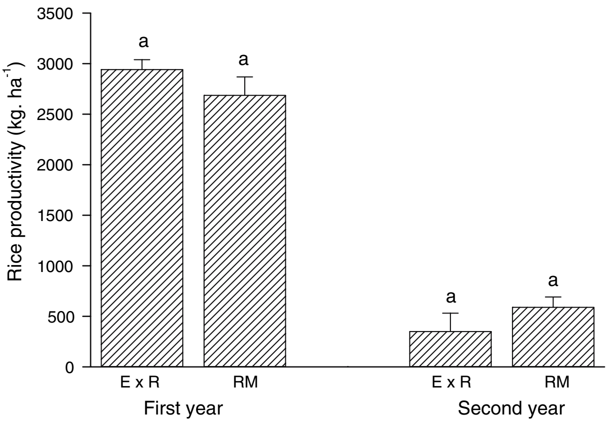


Fig. 6 Total effective productivity of rice (kg ha^{-1}) intercropped with *E. urophylla* (E × R) and in monoculture (RM) over the two years. Vertical lines are standard errors. *Note*: for each variable, means are significantly different between treatments when followed by different letters ($P < 0.05$)

Table 1 Land equivalent ratio of intercropped systems, using as a base the cylindrical volume (m^3 ha^{-1}) of *E. urophylla* at four (after the first rainy crop harvest) and 16 months (after the second rainy crop harvest) and the productivity (kg ha^{-1}) of rice and beans, over the two years

System	*E. urophylla* EPI/EPM	Beans BPI/BPM	Rice RPI/RPM	Total
First year				
Eucalyptus × Beans (rainy season)	1.04	0.86	–	1.90
Eucalyptus × Beans (dry season)	2.25	0.78	–	3.02
Eucalyptus × Rice	1.10	–	0.91	2.01
Total				6.93
Second year				
Eucalyptus × Beans (rainy season)	1.32	0.40	–	1.72
Eucalyptus × Beans (dry season)	1.32	0.44	–	1.76
Eucalyptus × Rice	1.78	–	0.50	2.28
Total				6.21

Discussion

In the first four months of this study, there were no significant effects of the intercropping on the *E. urophylla* growth. Ceccon (2005) also found no significant effects with the crops in a similar experiment with *Eucalyptus camaldulensis* in the same region. In addition, Schlonvöigt and Beer (2001) in Costa Rica found no significant effects on initial growth of *Eucalyptus deglupta* when associated with maize.

Only after eight months was there a positive impact of intercropping on *E. urophylla* timber volume; the strongest effect was on the system that received two fertilizations which was *E. urophylla* and beans planted in the rainy and dry season. Sixteen months later, the effect of intercropping on *E. urophylla* volume was also markedly positive. In Guatemala, Leiva (1994) found similar results in the height of *Eucalyptus globulus* when intercropped with maize and beans after one year. Whereas in Brazil, Pinto et al. (2005) found that *Eucalyptus grandis* trees benefited from the association with sugarcane. However, in this study, the timber volume was the highest, when *E. urophylla* was intercropped with rice. In a similar experiment, in this same region, the intercropping of *E. camaldulensis* with rice in the second year, also obtained the best yield (Ceccon 2005). Besides the fact that, after sixteen months all intercropping plots received four fertilizations to the crops, it seems that the rice fertilization in the second year strongly improved the *E. urophylla* yield. For comparison, in the same region, the yield of *E. urophylla* with rice was much higher than another monoculture experiment with the same species, but with almost double the time (30 months; 15.3405 m^3 ha^{-1}; Lopes da Silva et al. 2006).

Productivity of agriculture crops intercropped with *E. urophylla* was not affected in the first year. In Minas Gerais, Stape and Martini (1992) and Ceccon (2005) also found positive results when intercropping *E. camaldulensis* with agriculture crops in the first year of the plantation under well-fertilized soils. The maximum height reached by E. *urophylla* at the age of 4 months in this study was 2.32 m; it is possible that their root systems were small and did not have any below ground effect on the crops. However, Nissen et al. (1999) found belowground competition between 9-months-old *Eucalyptus torelliana* and close cabbage rows and determined that this competition was for moisture, but not for nutrients. The difference is that in this study, rain was not scarce throughout the period of crop cultivation which possibly minimized potential belowground competition (Figs. 1, 4, 6).

In the second year, however, intercropping with *E. urophylla* affected the bean (rainy and dry season) and rice productivity. In a similar experiment with *E. camaldulensis*, however, there were no significant second-year effects of trees on the crop yield (Ceccon 2005). The most important difference between both experiments was that *E. urophylla* had denser lower crowns than *E. camaldulensis.* In this study, the *E urophylla* trees grew to approximately 5 m tall and had a much higher average volume than in *E. camaldulensis* experiment (Ceccon 2005). In the Minas Gerais state, it is well-known that *E. urophylla* has a higher productivity when compared with the *E. camaldulensis*, a more rustic species known to be well-adapted to drier regions (Pereira et al. 2002). In addition, previous studies with *Eucalyptus* genus found that stem diameter measurements explained 93% of the variation in the leaf area and that there is a strong relationship between stem diameter and transpiration (Vertessy et al. 1995). In the second year of this study, it is possible that soil water availability for *E. urophylla* was considerably lower compared to the *E. camaldulensis* experiment. At same time, Cohen et al. (1997) studying the underground water used by *Eucalyptus*, found a dense root mat in the forest floor, a high density of fine and medium-sized roots in the first 20 cm of the upper soil, and a marked decrease in root density in deep soil layers. Therefore, due to high growth rates of *E. urophylla*, these fine roots may be competing for water with the crops, which their roots also occupying the first 20 cm of the same upper soil.

It seems that in this study, pruning was not able to reduce the effect of belowground water competition, a result that is compatible with Ong et al. (1991) who found that a reduction of 40% in millet productivity when intercropped with *L. leucocephala* pruned to 0.7 m before millet sowing. Also, Pinkard et al. (1999) found that changes in leaf area and foliage distribution did not affect the cumulative net biomass production following 50% pruning of *E. nitens.*

Another possible reason for the reduction in crop productivity is the allelopathic effect of *E. urophylla.* Recently, there has been increased criticism of *Eucalyptus* planting related to allelopathy caused by its litter. Studies have documented the allelopathic properties of *Eucalyptus* genus (Lisanework and Michelsen 1993; Espinosa-Garcia 1996). Allelopathy, however, has not yet been confirmed in all species of the genus, particularly for *E. urophylla*.

As the alleys used for the cultivation of the crops (the widest, 5 m) had a north-south orientation (not recommended for agroforestry experiments), due to undesirable land inclination (around 10%), the shading of *E. urophylla* could have exerted some effect on the crops. However, beans and rice are C_3 plants and photosynthesis becomes light saturated at relatively low irradiances. Therefore the reduced flux of photosynthetically active radiation (PAR) resulting from partial shading may have little effect on carbon assimilation (Stirling et al. 1990). Results from this study suggest that shade did not affect the crop yield.

The general productivity of the rice experiment was very low in the second year, mostly due to low precipitation during the rice fruition phase (only 5 mm in February; Fig. 1). Under this kind of stress, it is known that physiological activity is reduced (Paleg and Aspinall 1981; Boyer 1982), and may therefore, have reduced rice productivity. The blocks that were planted first were less affected by this exceptional water stress.

However, except for the rice in the second year, the productivity of the intercropped systems was generally much higher than the average Brazilian monoculture productivity (602 and 1,573 kg ha^{-1} for bean and rice respectively, IBGE 2001), and were similar to results reported in another study with the same technology in the same region (Ceccon 2005). The measured difference in productivity between the Brazilian average and the experimental average in this study, may be explained by the fact that nearly all crop plantations in Brazil are planted on small farms with low levels of technology, i.e., with minimal fertilization and soil conservation (da Veiga 1996).

In relation to the LER of both years, intercropping was markedly advantageous for all intercropping systems. Despite the fact that the intercropping/monoculture ratio for the crops was low in the second year; the same ratio for the *E. urophylla* was very high (especially when intercropped with rice in the second year). Therefore, the component that most profited from the intercropping was the *E. urophylla*. LER in a similar experiment with *E. camaldulensis* was higher in both years compared to the *E. urophylla* experiment, but the volume of timber of *E. urophylla* in the intercropping system was around 31.5% higher on average than in the *E. camaldulensis* experiment (Ceccon 2005).

The above results provide sound evidence to conclude that, at least in the first two years, when the tree biomass is the priority, the intercropping of *E. urophylla* with rice and beans in well-fertilized soils on small scale is highly productive. Also, at least in the first two years, the intercropping provides food sources in addition to wood yield. According to results elsewhere, including those by Ceccon et al. (1999) and Ceccon (2005) with *E. camaldulensis*, the use of agroforestry systems in the *Eucalyptus* plantations oriented towards small farm partnership programs is likely to become an important element for the biomass production.

Acknowledgements I gratefully acknowledge PAINS Florestal S. A. (Brazil) for financial support and Deuselis João Firme, Julio Bedê and Luciano Rodrigues for their valuable suggestions provided during this study. We also thank Adinésio for assistance in the field and to Dr. Octavio Miramontes, Dr. Todd S. Fredericksen and Angie Kitson-Harris for English revision and suggestions to the manuscript.

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