CHAPTER

4

Integration of Crops, Livestock, and Forestry: A System of Production for the Brazilian Cerrados

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Abstract

Some of the most promising and at the same time some of the most challenging areas of future food production are found in the savannas of South America. Integrating cropping, livestock, and forestry in these regions can increase the eco-efficiency of agricultural production. This chapter presents a case study of an integrated crop, livestock, and forestry system in Brazil. The study area is in Goiás State in the Cerrado region, a vast savanna covering almost one quarter of Brazil's land area. About half of the area suited to agriculture in the Cerrado is under cultivated pasture, but much of this is degraded as a result of overgrazing. The systems studied in this report include different arrangements to test productivity, profitability and sustainability of eucalyptus, crops, and pastures. Findings demonstrated that integrated crop, livestock, and forestry systems are economically and technically feasible in the Cerrados. In addition to producing food of high biological value (meat and milk), cultivated pasture provides other important environmental benefits, including long-term ground cover, carbon fixation, increases in soil organic matter content; and reduction in the emission of greenhouse gases.

Background and System Description

Demand for food is expected to continue to increase for at least the next 40 years (Godfray et al., 2010), and food production will need to increase by 70 to 100% by 2050 (World Bank, 2008). However, this has to be done in the face of growing competition for land, water, and energy, and without harming the environment. The objective must therefore be sustainable intensification of agricultural production (The Royal Society, 2009).

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Brazil is one of the countries with the highest potential of farmland expansion to meet the growing demand for food and biofuel (Brown, 2004), especially in the Cerrado region. The Cerrado is characterized by a savanna-like native vegetation of low trees, scrub brush, and grasses. It covers approximately 204 million hectares (Mha), or 23% of Brazil's land area (Bustamante et al., 2006). About 62% of this area (127 Mha) is suitable for agriculture (Lilienfein and Wilcke, 2003). Cultivated pastures in the Cerrado region cover about 66 Mha (Sano et al., 2006). An estimated 50 Mha are subjected to a process of degradation by excessive grazing (Silva et al., 2004; Klink et al., 2008).

The Cerrado biome is the second largest vegetation formation after the Amazon, and also the world's richest in biodiversity (Mistri, 2000). The climate is characterized by two well-defined seasons: dry winters and rainy summers. Average temperature of the coldest month is about 18 °C. The dry season extends from April to September; the relative humidity is low, enabling the occurrence of fires. Even in the rainy season from October to March, drought spells often occur, varying from 1 to 2 weeks and sometimes causing considerable losses to agricultural production. Latosols predominate, with good soil physical characteristics (high water infiltration, moderate water retention, and easy mechanization). The majority of the soils are acid, with high aluminum saturation, strong phosphorus retention, and poor nutrient contents. Those characteristics inhibited the development of the Cerrado for agriculture until modern times.

The Cerrado became the leading edge of the expansion of the agricultural frontier in Brazil in the 1970s. Before that, only a small portion of dusky red latosols, and structured "terra roxa" were considered suitable for agriculture—a little more than 5% of the total. However, from 1975 a federal government development program known as "Polocentro" allocated resources to develop technologies for profitable and productive agriculture in the Cerrado soils (Bittar, 2011).

Traditionally, beef cattle production is a major source of income for many farmers in the Cerrado region (Klink and Moreira, 2002; Diniz-Filho et al., 2009). However, poor herd management, overgrazing, and lack of adequate nutrient replacement to the soil has led to declining productivity and reduced profitability of the system (Landers, 2007).

There have been many challenges to developing sustainable agricultural systems in the Cerrados, chief among them the soil constraints. Natural low soil fertility and aluminum toxicity limit root development and mineral nutrition. Further, limited root systems turn plants more susceptible to short drought periods during the summer wet season. Liming and organic matter incorporation were key input to alleviate aluminum saturation, raise water retention capacity, stabilize soil aggregates, and increase soil macro biota activity. Research also advanced in developing new varieties adapted to these environmental characteristics. These varieties typically possess deep root systems, have high tolerance to aluminum toxicity, respond well to fertilization, are adapted to mechanization; besides having high resistance to insect pests, diseases, and hydric stress.

In recent years the increasing demand for ethanol biofuel resulted in leasing land for sugarcane production being more profitable than raising beef cattle or even growing crops such as soybean and maize (Koh, 2007; Koh and Ghazoul, 2008). Although profitable in the short term this monoculture brings with it risks such as increasing incidence of pests and disease, degradation of soil and natural resources, and declining yields. It also exposes farmers to dependence on a single income source: the ethanol processing plant.

With those technological advancements, the region became the principal growing agricultural pole. Today Cerrado agriculture broadly employs modern technologies, and system productivity continues to climb.

Agriculture and livestock production in the Cerrado region generates 42% of the agribusiness share of GDP in Brazil. Currently agribusiness contributes about 30% of the country's GDP, employs around 40% of the economically active population, and accounts for a large portion of the country's balance of trade surplus. One third of the country's grain production (soybeans, maize, sorghum, rice, wheat, coffee, etc.), half of the meat and most of the cotton output come from the Cerrados. A big share of that production is for export.

Nonetheless, managing agriculture in the Cerrado biome is an ongoing learning process. When the stabilizing effects of diversity were replaced by simple systems such as monoculture, destabilizing factors showed their destructive potential. Intensive cultivation without crop rotation resulted in low yields, due mainly to destabilization of soil physical quality, and pest and disease infestations.

According to Cunha (2008), soil degradation is the main ambient threat to sustainability of agriculture in the Cerrado region. A large portion of the soils is compacted and susceptible to erosion when facing strong rainfall. Under these conditions, traditional techniques such as contour planting may be inadequate.

This challenge led to the adoption of no till systems, which increased soil cover and brought additional environmental benefits. In the early 1990s, the area under no till in the Brazilian Cerrado represented just 9% of the total; by the 1995/96 cropping season that percentage rose to 33%. In the same period, the total no till area in Brazil grew 3.5 times, but in the Cerrados it increased 17 times (Marouelli, 2003).

In spite of huge advances in productivity of agriculture and our understanding of the environmental risks, Brazil has a long way to go to transform the Cerrados into a biome that will sustainably support crop, animal, and forest production, with acceptable levels of profit to producers and safe, economic food supplies for urban consumers. Research on eco-efficient systems will drive that transformation.

The Ministry of Agriculture, Livestock and Food Supply is promoting low carbon agriculture as a means of reducing agricultural emissions of greenhouse gases, especially carbon dioxide (CO_2). Besides offering financial support for farmers, the government promotes agricultural research through the Brazilian Agricultural Research Corporation (Embrapa), and provides professional training to facilitate the diffusion of modern practices such as no till, use of biological nitrogen fixation, and technologies to revive degraded pastures.

It is also promoting the Crop–Livestock–Forestry Integration System (CLFIS). CLFIS combines cropping, livestock, and forestry activities through approaches such as crop rotation, succession, double cropping, and intercropping, searching for synergistic effects among the components of the agroecosystems. One approach is to grow commercial crops such as soybeans, maize, or beans between rows of forest trees for the first 2 or 3 years after the trees have been planted. Thereafter, the area is planted with forages for livestock, in association with maize or sorghum. Once the pasture is established between the tree rows, it is grazed by livestock until the trees are ready for harvest. This diversification of economic activities minimizes the impact of climate or market changes on farm income.

Integration of the system components minimizes use of agrochemicals, reduces the opening of new areas for crop or livestock production, and reduces environmental impacts, increasing biodiversity, reducing soil erosion, and improving soil structure and fertility, particularly in combination with conservation agriculture practices such as zero-tillage (Vilrla et al., 2003; Landers, 2007).

Integrated crop, livestock, and forestry systems show particular promise in increasing the eco-efficiency of agricultural production (Wilkins, 2008), i.e., maximizing production while minimizing inputs such as land, water, nutrients, and energy (Keating et al., 2010).

Integrating Crops, Livestock, and Forestry through CLFIS

Overview

CLFIS is focused in the so called "green agriculture". This system combines cropping, livestock, and forestry activities to promote the recovery of degraded pastures. Each farm will have a varied production system, such as grains, fibers, meat, and milk and agro-energy. It also aims to improve soil fertility with the use of adequate cropping systems and techniques to optimize and intensify its use. Therefore, it allows the diversification of economic activities on farm, and minimizes income risks due to climate and/or market changes. The system consists in growing forest species simultaneously with commercial crops like soybeans, maize, or beans added for the first 2 or 3 years. After crop harvest, the area is planted with forages for livestock, associated with maize or sorghum. After grain harvesting, the pasture is already established between the tree rows, enabling grazing, until wood is harvested.

Integration of different system components minimizes use of agrochemicals, reduces the opening of new areas for crop-livestock, and prevents environmental liabilities. It enables increases in biodiversity, and allows a better control of erosion through soil coverage. Integration, together with soil conservation practices such as no till, is an economic and sustainable alternative to raise yields in degraded areas. Other attributes of CLFIS are related to environmental compliance of the farm, maintenance and/or recovery of permanent preservation areas, and of 'legal reserves' (percentage of a forested property that needs to be set aside). The introduction of new technologies is aimed at eco-efficiency—minimizing environmental impact while improving production and profitability.

A major challenge facing CLFIS is its dissemination and incorporation into the production chain and extension of benefits at the national level. It is necessary to invest in training, as well as to publish results for widespread knowledge dissemination.

CLFIS should be: (1) technically efficient, using adequate management and inputs, and taking into account local conditions of the farms; (2) economically viable with a better use of land and other natural resources; (3) diversified; (4) socially acceptable, i.e., adaptable to any farm size, providing more consistent and higher income and improved agricultural competitiveness; and (5) environmentally fit through the use of soil conservation practices, and better land use.

Enhancing eco-efficiency

Intensification of production should not be synonymous for indiscriminate use of inputs; it should mean rational and efficient use of technologies to maximize profits, using natural resources rationally. For a certain level of production, resources (land, water, inputs) should be used with a minimal impact on the environment without sacrificing the bio-economic productive potential of the cropping-livestock activity. The efficient use of nutrients, agrochemicals, and energy along with the reduction of greenhouse gas (GHG) emission are key factors to enhance eco-efficiency of the system.

A feasible alternative to effectively implement the CLFIS can be a partnership between grain producers and ranchers. Farmers who use sorghum and maize intercropped with *Brachiaria* spp. to obtain crop residues for no till soil preparation could harvest that forage collected in the off season. To minimize capital costs in the purchase of animals, those farmers could establish partnerships with ranchers. Harvested grain residues could be used as feed supplement during the dry season, either in grazing or in confinement, besides using the forage obtained in the intercropping system.

A common problem of intercropping forages and grains is competition for water and nutrients. Losses in crop yield and failures in pasture establishment may occur. There are alternatives to minimize that competition, such as delayed sowing of the pasture component and use of low doses of herbicides, as well as plant arrangement, to minimize the competition of the forage with the grain crop (Kluthcouski et al., 2003).

Farms adopting the CLFIS may benefit from a better stability of forage production to feed the herd year around. During the wet season, pastures are more productive due to the higher soil fertility developed during the crop phase. During the dry season, crop residues and harvest byproducts, as well as the newly green established pastures are in adequate amounts and of good quality to provide weight gains. Weight loss is very common in the dry season on most farms of the Cerrado region.

Good soil and ecosystems management practices are potentially capable of mitigating greenhouse anthropogenic gas emissions. In this sense the Cerrado region is capable of playing an important role in the carbon cycle equilibrium (see also Chapter 11 of this volume).

A Case Study of CLFIS

Study area and experimental design

Faced with this scenario, farmers are seeking alternative production systems that maximize the economic productivity of their land while minimizing risks. One such alternative is integrated crop, livestock, and forest production. This section presents a case study that evaluates and compares three different spatial arrangements of crops, livestock, and forestry.

The study was located at Boa Vereda Farm, Cachoeira Dourada County, in the south of the State of Goiás (latitude 18°29'30", longitude 49°28'30") and average altitude of 459 m. The climate is typical of the tropical savanna type (Aw, according to Köppen classification), with well-defined wet and dry seasons. Annual average temperature is 24 °C, with an average annual rainfall of 1,340 mm, distributed from October to March. Soils are classified as dark red latosol, highly weathered, with low natural fertility.

Much of Boa Vereda Farm consists of degraded pastures with low carrying capacity that are used to raise beef cattle. Income from livestock sales has been insufficient to invest in reclaiming the pastures.

CLFIS demonstration plots were established on 17 ha in the 2008/09 cropping season and a further 27 ha in the 2009/2010 cropping season. The land was cultivated twice using a disc harrow to incorporate lime and was then leveled, again using a disk harrow. Fertilizer was applied according to recommendations based on soil analyses. Weeds were controlled using herbicide and hoeing between tree rows up to the 12th month after planting. Pests were controlled using integrated pest management.

In the establishment year (year 0), eucalyptus was planted in rows, and soybean was planted in the plots between the tree stands. In the following year (year 1), plots were sown with a maize/brachiaria grass intercrop, in accordance with the Santa Fé System (Kluthcouski et al., 2003). Cattle were introduced to the pasture 70 days after the maize was harvested. At this time (18 months after the plots were established) the eucalyptus was about 6 m tall with trunks 10 cm in diameter at chest height, allowing the entry of cattle without risk of damage to the trees. From this point on the pasture was used for animal husbandry, particularly fattening beef cattle, until the eucalyptus was cut, which in this study was modeled as being between the fourth and the sixth year after planting.

Three different planting arrangements were tested. Scenario 1 consisted of three rows of eucalyptus (stands), with 3 m between rows and 3 m between plants; the stands were spaced 14 m apart to allow for crops and pasture to be established between them. Thus, 62.5% of the land under scenario 1 was allocated to crop/pasture and 37.5% to forest, with a tree density of 500 trees/ha. Scenario 2 consisted of four rows of eucalyptus spaced 3 m between rows and 3 m between trees, with 22 m between stands, giving 68% of the land allocated to crop/livestock and 32% forest and a tree density of 430 trees/ha. Scenario 3 consisted of single rows of eucalyptus, with 1.5 m between trees within the row and 14 m between rows, giving 89% of the area allocated to crops/livestock and 11% to forest, with 476 trees/ha.

The soybean cultivar used was BRS-GO 8360; maize cultivars were BRS 1030 and BRS 1035; and for the pasture *Brachiaria brizantha* cultivar

'Marandu' was used. Six clones of the *Eucalyptus urograndis* were used. Eucalyptus yield was estimated based on tree development in November 2010.

The crossbred cattle used in the trial weighed an average of 242 kg when introduced to the plots. Supplementary concentrate feed was provided at a rate of 250 g/head per day in the dry season and 350 g/head per day in the wet season. Average carrying capacity was estimated at 2.1 animals/ha. With adequate management and fertilization, this stocking rate was assumed to be maintained until the eucalyptus was cut and the system reestablished.

Prices for calves were set 10% higher than the price paid for adult animals, because the market pays more for young animals.

The cost for pasture maintenance was based on the price paid locally for pasture rental (R$10.00/head per month; approximately US$18.40, February 2010 exchange rate). Other livestock production costs were purchase of supplementary feed and R$3.00/head per month for vaccines, labor, and veterinary supplies.

Production costs were calculated up to harvest, including freight from the farm to the store.

The opportunity cost for land was set at the value of ten 60 kg bags of soybean per hectare (US$168.48/ha), equal to the price paid by ethanol processing plants to lease land for sugarcane production.

Data on farm operations and prices were collected in 2008/2009 and 2009/2010 cropping seasons from farmers and companies associated with agriculture. Net present value (NPV), internal rate of return (IRR), and equivalent uniform annual net value (NUV) were calculated using an interest rate of 5.75%, the rate applied by banks run by the federal government.

Results and conclusions

Production costs for scenario 1 are shown in Tables 1, 2, and 3, while Table 4 shows the yields achieved in all three scenarios.

Table 1. Production costs in the establishment year (year 0) for one hectare of eucalyptus intercropped with soybean (scenario 1).[a]

Specification	Unit	Amount	Value (US$)		OEC
			Unit value	Total	(%)
Soybean					
Inputs					
Lime (cif)	t	1.25	37.50	46.88	4.47
Fertilizer NPK(02-20-20)+(0.3 B+0.5 Zn)	t	0.25	527.17	131.79	12.56
Seeds BRS-GO 8360	kg	31	1.03	32.27	3.08
Inoculants	liter	0.25	4.18	1.05	0.10
Seed treatment	liter	0.06	206.52	12.91	1.23
Formicide	g	6.3	0.54	3.40	0.32
Preemergence herbicide	kg	0.02	592.17	13.32	1.27
Preemergence herbicide	liter	0.5	25.22	12.61	1.20
Postemergence herbicide	liter	0.25	32.61	8.15	0.78
Mineral oil – 3 applications	liter	1.88	3.26	6.11	0.58
Fungicide – 3 applications	liter	0.56	86.41	48.61	4.63
Insecticide	liter	0.16	29.35	4.59	0.44
Insecticide – 2 applications	liter	1.88	6.25	11.72	1.12
Subtotal inputs soybean				333.40	31.78

(Continued)

Table 1. (Continued.)

Specification	Unit	Amount	Value (US$)		OEC
			Unit value	Total	(%)
Labor					
Lime distribution	ha	0.63	13.32	8.32	0.79
Lime incorp. (heavy disc harrow × 2)	ha	0.63	95.65	59.78	5.70
Soil preparation (leveling × 2)	ha	0.63	71.74	44.84	4.27
Formicide application	day	0.16	21.74	3.40	0.32
Sowing	ha	0.63	27.17	16.98	1.62
Preemergence herbicide application	ha	0.63	4.18	2.62	0.25
Postemergence herbicide application	ha	0.63	4.18	2.62	0.25
Fungicide application (× 3)	ha	0.63	12.55	7.85	0.75
Insecticide application (× 3)	ha	0.63	12.55	7.85	0.75
Harvest (6% of income)	%	6	302.16	18.13	1.73
Freight (farm to storage house)	bag	33	0.33	10.76	1.03
Subtotal labor soybean				183.14	17.46
Soybean cost				516.54	49.24
Eucalyptus – establishment					
Inputs					
Lime	t	0.75	37.50	28.13	2.68
Fertilizer – NPK(06-30-06)+(0.3 B+0.5 Zn)	kg	75.0	0.41	30.57	2.91
Fertilizer – single super phosphate (SSP)	kg	100	0.23	23.37	2.23
Seedlings	thousand	0.50	206.52	103.26	9.84
Seedlings (replanting)	thousand	0.05	206.52	10.33	0.98
Formicide	g	3.8	0.54	2.04	0.19
Preemergence herbicide	g	15	0.54	8.15	0.78
Subtotal inputs eucalyptus				205.84	19.62
Labor					
Liming	ha	0.38	13.32	4.99	0.48
Lime incorp. (heavy disc harrow × 2)	ha	0.38	95.65	35.87	3.42
Soil preparation (leveling × 2)	ha	0.38	71.74	26.90	2.56
Formicide application	day	0.09	21.74	2.04	0.19
Pit preparation	ha	0.38	79.35	29.76	2.84
Planting	ha	0.38	32.61	12.23	1.17
Fertilizer application – NPK	ha	0.38	43.48	16.30	1.55
Fertilizer application – SSP	ha	0.38	76.09	28.53	2.72
Preemergence herbicide application	ha	0.38	4.18	1.57	0.15
Subtotal labor eucalyptus				158.19	15.08
Eucalyptus cost				364.04	34.70
Land opportunity cost				168.48	16.06
Total operational cost				1049.05	100.00

a. Scenario 1 consists of three rows of eucalyptus (stands), with 3 m between rows and 3 m between plants; the stands were spaced 14 m apart to allow for crops and pasture to be established between them.

Table 2. Production cost (year 1) of one hectare of eucalyptus intercropped with maize and brachiaria grass (scenario 1).[a]

Specification	Unit	Amount	Value (US$)		OEC
			Unit value	Total	(%)
Maize and brachiaria					
Inputs					
Fertilizer – NPK(02-20-20)+(0.3 B+0.5 Zn)	t	0.19	527.17	98.85	15.62
Urea	t	0.13	516.30	64.54	10.20
Maize seed	kg	11	5.16	58.08	9.18
Brachiaria brizantha seed	kg	6.3	2.99	18.68	2.95
Preemergence herbicide	liter	0.06	28.26	1.77	0.28
Postemergence herbicide	liter	1.88	4.35	8.15	1.29
Mineral oil	liter	0.31	3.26	1.02	0.16
Insecticide	liter	0.38	38.04	14.27	2.26
Subtotal inputs				265.35	41.94
Labor					
Incorporation (heavy disc harrow × 1)	ha	0.63	47.83	29.89	4.72
Soil preparation (leveling × 1)	ha	0.63	35.87	22.42	3.54
Brachiaria sowing	ha	0.63	13.32	8.32	1.32
Maize sowing	ha	0.63	27.17	16.98	2.68
Topdressing	ha	0.63	13.32	8.32	1.32
Postemergence herbicide application	ha	0.63	4.18	2.62	0.41
Insecticide application (× 1)	ha	0.63	4.18	2.62	0.41
Harvest	%	5	277.06	13.85	2.19
Freight	bag	67	0.33	21.85	3.45
Subtotal labor				126.87	20.05
Maize cost				392.22	62.00
Eucalyptus – maintenance					
Inputs					
Fertilizer – single super phosphate (SSP)	kg	100.0	0.23	23.37	3.69
Fertilizer – boric acid	kg	10.0	1.30	13.04	2.06
Formicide	kg	0.015	543.48	8.15	1.29
Herbicide	liter	1.0	5.43	5.43	0.86
Subtotal inputs				50.00	7.90
Labor					
Fertilizer application	ha	0.38	43.48	16.30	2.58
Herbicide application	ha	0.38	4.18	1.57	0.25
Formicide application	day	0.19	21.74	4.08	0.64
Subtotal labor				21.95	3.47
Eucalyptus cost				71.95	11.37
Land opportunity cost				168.48	26.63
Total operational cost				632.65	100.00

a. Scenario 1 consists of three rows of eucalyptus (stands), with 3 m between rows and 3 m between plants; the stands were spaced 14 m apart to allow for crops and pasture to be established between them.

Table 3. Production cost (year 2) of one hectare of eucalyptus intercropped with pasture grazed by cattle (scenario 1).[a]

Specification	Unit	Amount	Value (US$)		OEC
			Unit	Total	(%)
Livestock					
Animal purchase	head	3	306.52	919.57	57.90
Vaccine + labor + medicine	head	3	19.57	58.70	3.70
Feeding (dry season)	head	3	24.46	73.37	4.62
Feeding (wet season)	head	3	34.24	102.72	6.47
Pasture maintenance (leasing value)	head	3	65.22	195.65	12.32
Livestock cost				1350.00	85.00
Eucalyptus – maintenance					
Inputs					
Fertilizer – boric acid	kg	10.0	2.40	24.00	0.51
Formicide	kg	0.015	543.48	8.15	1.51
Subtotal inputs				32.15	2.02
Labor					
Fertilizer application	ha	0.38	80.00	30.00	0.48
Formicide application	day	0.35	21.74	7.61	1.89
Subtotal labor				37.61	2.37
Eucalyptus cost				69.76	4.39
Land opportunity cost				168.48	10.61
Total operational cost				1588.24	100.00

a. Scenario 1 consists of three rows of eucalyptus (stands), with 3 m between rows and 3 m between plants; the stands were spaced 14 m apart to allow for crops and pasture to be established between them.

Table 4. Prices and yields of soybean, maize, livestock, and eucalyptus used to calculate economic performance of integrated crop, livestock, and forestry system in Cachoeira Dourada County, Goiás, Brazil.[a]

Product	Unit	Price	Yield (unit/ha)		
		(US$/unit)	Scenario 1	Scenario 2	Scenario 3
Soybean	60 kg bag	16.85	33	34	47
Maize	60 kg bag	7.61	67	70	95
Livestock	kg live wt.	1.40	540	570	690
Eucalyptus	cubic meter	24.46	28	24	26

a. Scenario 1 consisted of three rows of eucalyptus (stands), with 3 m between rows and 3 m between plants; the stands were spaced 14 m apart to allow for crops and pasture to be established between them. Scenario 2 consisted of four rows of eucalyptus spaced 3 m between rows and 3 m between trees, with 22 m between stands. Scenario 3 consisted of single rows of eucalyptus, with 1.5 m between trees within the row and 14 m between rows.

Table 5 shows cash flow for scenario 1, including the value of lumber for energy from the trees cut in the sixth year. In years 1 and 2 the annual cash flow balance was negative: costs exceeded income due to the high cost of establishing the eucalyptus. From year 3 onwards cash flow was positive as a result of income from the cattle and low maintenance costs for the eucalyptus.

Scenario 3, with one row of eucalyptus with 14 m between rows and 1.5 m between trees,

Table 5. Cash flow for integrated crop, livestock, and forestry production in Cachoeira Dourada County, Goiás, Brazil, under scenario 1.[a]

Year	Costs (US$)[b]	Income (US$)	Net income (US$)
0	1049.05	555.98	-493.07
1	632.65	509.78	-122.87
2	1588.24	1672.83	84.59
3	1588.24	1672.83	84.59
4	1588.24	1672.83	84.59
5	1588.24	1672.83	84.59
6	1588.24	5781.52	4193.28

a. Scenario 1 consisted of three rows of eucalyptus (stands), with 3 m between rows and 3 m between plants; the stands were spaced 14 m apart to allow for crops and pasture to be established between them.
b. February 2010 prices and exchange rate.

gave the best economic performance (Table 6), with the highest NUV being achieved if the trees were harvested in year 5. In scenarios 1 and 2 NUV was highest when the trees were harvested in year 6.

These findings are in keeping with reports of similar studies elsewhere in Brazil (Dube et al., 2002; Yamada and Gholz, 2002), and demonstrate that integrated crop, livestock, and forestry systems are economically and technically feasible in the Cerrado. The system is flexible enough to be adapted to meet local environmental, social, and economic circumstances, and offers the prospect of sustainable, eco-efficient agricultural production.

Much of the Cerrado is underutilized or degraded, and integrated crop, livestock, and forestry production offers an opportunity for raising productivity without harming the environment. In addition to producing food of high biological value (meat and milk), cultivated pasture provides other important environmental benefits, including long-term ground cover, which reduces erosion and promotes water infiltration; carbon fixation; increases in the soil organic matter content; and reduction in the emission of greenhouse gases.

Table 6. Net present value (NPV), internal rate of return (IRR), and equivalent uniform annual net value (NUV) for integrated crop, livestock, and forestry production in Cachoeira Dourada County, Goiás, Brazil, as affected by the age at which eucalyptus was harvested.

	NPV (US$)	IRR (%)	NUV (US$)
Scenario 1[a]			
Year 4	1,710.04	53	502.01
Year 5	2,131.67	48	516.42
Year 6	2,495.40	44	519.49
Scenario 2[b]			
Year 4	1,498.58	52	439.93
Year 5	1,882.57	48	456.07
Year 6	2,215.49	44	461.22
Scenario 3[c]			
Year 4	1,911.47	75	561.14
Year 5	2,337.33	66	566.24
Year 6	2,707.26	60	563.60

a. Scenario 1 consisted of three rows of eucalyptus (stands), with 3 m between rows and 3 m between plants; the stands were spaced 14 m apart to allow for crops and pasture to be established between them.
b. Scenario 2 consisted of four rows of eucalyptus spaced 3 m between rows and 3 m between trees, with 22 m between stands.
c. Scenario 3 consisted of single rows of eucalyptus, with 1.5 m between trees within the row and 14 m between rows.

In the search to produce more food and energy within the constraints of available water, land and other inputs, eco-efficient, climate-smart systems like integrated crop, livestock, and forestry systems have a vital role to play.

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