Emergy Analysis for Brazilian Cotton Agriculture

BLATT, E. F. [a*], ALMEIDA, C.M.V.B. [a]

a. Universidade Paulista, São Paulo

**Corresponding author, edu.blatt@hotmail.com*

Abstract

The aim of this paper is applying environment accounting in Emergy to analysis the Brazilian cotton agricultural production system. To determine which cotton agricultural production items, have more relevance. This study takes into consideration the diversity of Brazilian cotton production characteristics per region, the calculation data are the weighted mean per production per productive area. The results of this paper are compared into with two Brazilian and one North American Articles and the Emergy Sustainability Index results at all studied cotton production systems shown results <1 that characterize cotton agriculture as a short term value for sustainability classification. Demanding high amount of fertilizers and pesticides. Those are purchased inputs into the production system.

Keywords: emergy; environmental accounting; cotton agricultural systems, environmental sustainability metrics in cotton agriculture.

1 - Introduction

Cotton (*Gossypium hirsutum*) is a product of socioeconomic importance for Brazil. Besides being the most important natural source of fibers, it guarantees Brazil a privileged place in the international scene, as one of the five largest producers in the world, along with China, India, the United States and Pakistan. In addition, among the largest producers, the country has the highest average productivity per hectare, slightly ahead of China and far beyond the US, second and third place in terms of production by area. From the 1990s, the culture migrated to the Cerrado region (Brazilian Savannah) and today occupies an area of more than one million hectares, mainly concentrated in the states of Mato Grosso, Bahia and Goiás. (ABRAPA 2011)

Using Emergy analysis to determine the most influents items at Brazilian cotton agricultural production. Emergy is the solar energy available and used directly or indirectly to obtain a product or service, including contributions from nature and economy. Take into consideration that Brazil is fifth largest country and the cotton production is spread into this territory, with at each production areas with their own production, productivity, and weather characteristics. To overcome these issues the input data results are the weight mean by area production participation.

1.1 - Bibliographic Review

Studies on sustainability and agriculture required a tool that can assess and quantifying interactions between the environment and the economy. The environmental accounting in Emergy allowed this evaluation. Developed by ODUM (1996), Emergy Environmental Accounting, simultaneously accounts for the contributions of nature (renewable and non-renewable natural resources) and the economy (financial resources) into a common metric. It is necessary to have full knowledge of the flows of mass and energy, because through them understood the relation with the environment. Emergy accounting present indicators inherent to the tool to evaluate the efficiency of used resources, yield, environmental loading, and sustainability (ODUM, 1996). They are: (EYR, Emergy yield ratio), (EIR, emergy investment ratio), (EER, emergy exchange ratio), (ELR, environmental loading ratio) and (ESI, environmental sustainability index). Information at the method's chapter.

Studies of Brazilian agriculture that used Emergy analysis:

BONILLA (2010) Studied the production of giant bamboo and the results showed a great variation in indicators, mainly at first three years due to the value of the financial resources used in soil preparation and planting.

GIANNETTI et al. (2010) Studied the coffee production at Brazilian savanna (Coromandel, Minas Gerais) With the use of accounting in emergy measure the contributions of environmental flows, economic resources and human labor used in the stages of planting, coffee harvesting.

At the studies that directly analyzed the cotton agriculture production:

TAKAHASHI et, al. 2010. aim of this paper was to make an Emergy assessment of oleaginous crops cultivated in Brazil, available to produce biodiesel, to determine which crop is the most sustainable. The Emergy table for cotton and the non- renewable resources that most impact the system are the limestone (11.81%) and soil loss (19.95%).

BRANDT-WILLIAMS, 2002 The Folio 4 compendium presents Emergy assessments for 23 agricultural commodities in Florida, USA, from published commodity assessments FLUCK et.al. (1992), and the statistical analysis of commercial production in Florida from 1974 to 1992. The Emergy table for cotton the renewable resources that most impact the system is Evapotranspiration (6.58% when don´t included service and 6.25% when included service); the non-renewable resources that most impact the system is Net topsoil loss (44.78% when don´t included service and 42.48% when included service); the economic resources that most impact the system are Nitrogen (fertilizer) (33.89% when don´t included service and 32.15% when included service) and Service (5,12%).

VENDRAMETTO, 2011 Emphasizes respect the agricultural aptitude of each locality, such as soil with good drainage and nutritional quality. Encourage product residues such as straw to retrofit the system to avoid loss of energy. The Emergy table for cotton at this study was considered the service included and the renewable resources that most impact the system is Chemical rain energy (16.11%; the non-renewable resources that most impact the system is Net topsoil loss (0.40%); the economic resources that most impact the system are Nitrogen (fertilizer) (44.85%) and Labor (21.88%).

2 – Materials and Method

2.1 Emergy environmental accounting

The Emergy flows represent three categories of resources: (R) as renewable resources, (N) as non-renewable resources and the purchased inputs provided by the economy, (F). All three categories are fundamental for the emergy accounting and for the understanding of the system interactions with the environment. R and N flows are provided by the environment and are economically free.

While renewable resources can be replaced at least at the same rate as they are consumed, the non-renewable resources are depleted faster than their ability of recuperation. The purchased inputs, F, are provided by the market and are related to flows supplied by the economy. The emergy employed to obtain the product, Y (defined as T = R + N + F), may include products, services and also emissions that are released to the environment. In order to establish the emergy flows, every mass, energy or monetary input has to be inventoried and multiplied by its correspondent transformity or emergy/unit value. The identification of the flows by the emergy environmental accounting enables the calculation of emergy indices.

The emergy yield ratio (EYR = U_{cotton}/F), EYR is the ratio of the outputs (U_{cotton} = R+N+F) divided by the purchased inputs (F) to the process that are fed back from outside the system. The emergy investment ratio (EIR = F/(N+R)), EIR is defined as the ratio of purchased inputs (F) divided by the local unpaid resources (R + N). EIR indicates the matching of emergy inflows to production, which is equivalent to balance potential limiting factors. The index of emergy loading ratio ((N+F)/R), ELR is the ratio of purchased and non-renewable inputs divided by the renewable inputs. The emergy sustainability index (ESI = EYR/ELR), ESI aggregates the measure of emergy yield ratio and the emergy loading ratio. The objective function for sustainability is to obtain the highest yield ratio at the lowest environmental loading.

Results and discussion

To obtain the production numbers those reflect the characteristics of Brazilian cotton agriculture is necessary to take into consideration the diversity of Brazilian weather, geographic position, and water availability. The author obtained these numbers of each Brazilian cotton producer state and weighted each one by their respective production participation.

Table 1: Weighted Mean of Brazilian Cotton Harvest indicators - Season 2015/2016

Brazilian Cotton Harvest 15/16							
	YIELD	Production	Participation	Weighted Mean			
Region/FU	**3,924**	**3,754.2**	**100**	Elevation	Solar Radiation	Wind Power	Rain Precipitation
	(kg/ha)	(mil ton)	%	**525** meters	**1.41E+13** J / ha.yr	**5.06E+08** J / ha.yr	**755** mm^3 / mm^2
North	**3,848**	**30.4**					
TO	3,848	30.4	0.81%	639	1.48E+13	8.48E+08	685
Northeast	**3,832**	**1,059.2**					
MA	4,034	83.9	2.23%	551	1.48E+13	3.81E+08	685
PI	3,636	24.0	0.64%	406	1.47E+13	7.23E+08	507
CE	750	0.3	0.01%	439	1.73E+13	5.56E+08	581
RN	4,000	1.2	0.03%	129	1.86E+13	1.20E+09	282
PB	1,000	0.2	0.01%	302	2.15E+13	1.52E+09	387
PE	1,000	0.1	0.00%	380	2.69E+13	1.77E+09	455
AL	0	0.0	0.00%	378	1.36E+13	8.21E+08	464
BA	3,830	949.5	25.29%	628	2.13E+13	1.15E+09	1065
Midwest	**3,975**	**2,575.9**					
MT	3,943	2,314.1	61.64%	450	1.07E+13	1.71E+08	646
MS	4,502	137.3	3.66%	607	1.73E+13	8.67E+08	724
GO	4,069	124.5	3.32%	822	1.56E+13	8.72E+08	724
Southeast	**3,689**	**86.7**					
MG	3,726	70.8	1.89%	874	1.86E+13	8.57E+08	569
SP	3,533	15.9	0.42%	633	1.84E+13	2.42E+09	437
South	**2,222**	**2.0**					
PR	2,222	2.0	0.05%	276	1.93E+13	1.48E+09	488

The biggest cotton producer is Mato Grosso (MT) $2.31x10^3$ ton per year that represents 61.64% of entire Brazilian Cotton production, its yield isn't the best in Brazil with 3,943 kg/ha losing to Mato Grosso do Sul (MS) with 4,502 kg/ha; Goias (GO) with 4,069 kg/ha and Rio Grande do Norte (RN) with 4,000 kg/ha. Goias and Mato Grosso do Sul have almost the same characteristics (Elevation, Solar

Radiation, Wind Power and Rain Precipitation of Mato Grosso, but Rio Grande do Norte has lowest rain precipitation with 282 mm^2/mm^3 and besides this with a higher productivity than Mato Grosso. Another note that worthy to mention is Bahia the second Brazilian cotton producer with the highest rain precipitation at cotton producers areas with 1,065 mm^2/mm^3. With these diversities of characteristics shows the challenger to develop cotton variation that is able to adapt into the reality of each Brazilian producer region.

Table 2: Plantation and Harvest seasons per localization

Region/FU	22/09 to 21/12			21/12 to 20/03			20/03 to 21/06			21/06 to 22/09		
	Spring			Summer			Autumn			Winter		
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep
North												
TO			P	P	P				H	H		
Northeast												
MA			P	P	P				H	H	H	H
PI			P	P	P				H	H	H	H
CE				P	P	P			H	H	H	
RN	H			P	P	P			H	H	H	H
PB	H				P	P	P	P	H	H	H	H
PE	H	H			P	P	P	P	P	H	H	H
AL	H						P	P	P			H
BA		P	P	P	P			H	H	H	H	H
Midwest												
MT			P	P					H	H	H	H
MS		P	P	P			H	H	H	H	H	
GO		P	P	P					H	H	H	
Southeast												
MG		P	P	P			H	H	H	H	H	
SP	P	P	P		H	H	H	H	H	H		
South												
PR	P	P	P			H	H	H				

Source: (CRESESB 2016) - P = Plantation / H = Harvest

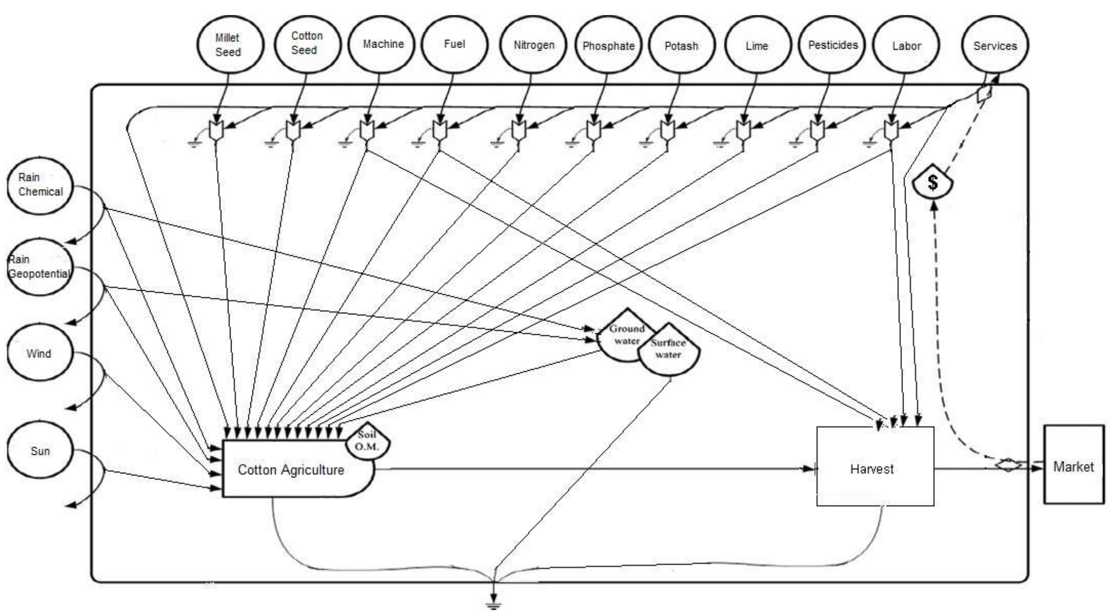

Figure 1: Energy system diagram of cotton production system.

Table 3 shows the cotton plantation system operates within a renewable input at rain chemical with 33.69% when don´t take into consideration the participation of service the participation changes to 10.78%. Cotton plantation has 1,300 kg of soil loss per year hectare a non-renewable resource, even with high soil loss mainly if compared with another crops like soybean or corn, the influence of soil loss is 1.28% when don´t take into consideration the service, it is change to 0.41% take into consideration the service. The majors purchased inputs are Nitrogen 26.87%, Phosphate 11.04% fertilizers purchased inputs to correct the acid and latosol soil of Brazilian savannah and labor with 7.46% all these numbers are without service. If we include service that has an impact alone of 65.03% these numbers changes to Nitrogen 8.60%, Phosphate 3.53% and Labor 2.39%. The Em$ value equal the Item's Emergy divided by the Service's UEV will obtain the equivalent value in US$ at the 2011 currency.

Table 3: Emergy evaluation of cotton crop in Brazil

Note	Item	Unit	Data (units / ha yr)	Unit Solar EMERGY (seJ/unit)	Solar EMERGY (E13 seJ/yr) 1E+13	Em$ Value US$ (2011)/yr	%
RENEWABLE RESOURCES							
01	Sun	J	1.10E+13	1.00E+00	1.10E+00	1.96E+00	0.19%
02	Wind	J	5.06E+08	4.23E+03	2.14E-01	3.82E-01	0.04%
03	Rain Geopotential	J	3.89E+08	2.96E+04	1.15E+00	2.05E+00	0.20%
04	Rain chemical	J	3.73E+10	5.14E+04	1.92E+02	3.42E+02	33.69%
NONRENEWABLE STORAGES							
05	Net Topsoil Loss	J	5.88E+08	1.24E+05	7.29E+00	1.30E+01	1.28%
	Sum of free inputs (sun, rain omitted)				1.99E+02	3.55E+02	
PURCHASED INPUTS							
Operational inputs							
06	Millet Seeds	J	2.14E+08	1.13E+05	2.42E+00	4.32E+00	0.43%
07	Cotton Seeds	J	2.64E+08	3.72E+05	9.81E+00	1.75E+01	1.72%
08	Machine	*	*	*	9.52E+00	1.70E+01	1.67%
09	Fuel	J	2.99E+09	1.11E+05	3.32E+01	5.93E+01	5.83%
10	Nitrogen	g	2.31E+05	6.62E+09	1.53E+02	2.73E+02	26.87%
11	Phosphate	g	6.72E+04	9.35E+09	6.28E+01	1.12E+02	11.04%
12	Potash	g	2.03E+05	9.32E+08	1.89E+01	3.38E+01	3.32%
13	Lime	g	1.39E+05	1.68E+09	2.34E+01	4.18E+01	4.11%
14	Pesticides	g	5.90E+03	2.49E+10	1.47E+01	2.62E+01	2.58%
15	Labor	Person	1.54E-02	2.75E+16	4.25E+01	7.58E+01	7.46%
	Sum of purchased inputs				3.70E+02	6.61E+02	
	Emergy without services				5.69E+02		100.00%
16	Services	US$(2011)	2.16E+03	5.60E+12	1.21E+03	2.16E+03	
	Total Emergy with services				1.78E+03		
TRANSFORMITIES, Calculated							
17	Total Yield without services	g	3.92E+06	1.45E+09	seJ/g		
		J	6.67E+10	8.53E+04	seJ/J		
18	Total Yield with services	g	3.92E+06	4.53E+09	seJ/g		
		J	6.67E+10	2.67E+05	seJ/J		
INDICES, calculated							

Note	Name of Index		Formula	Without Service	With Service
19	Emergy Yield Ratio (EYR)	EYR	U_{cotton} / F	1.54	1.13
20	Emergy Investment Ratio (EIR)	EIR	F / (N+R)	1.86	7.94
21	Environmental Loading Ratio (ELR)	ELR	(N+F) / R	1.97	8.28
22	Environmental Sustainability Index	ESI	EYR / ELR	0.7814	0.1361

Table 4: Compare the results with index results of the cited literatures.

	EYR	EIR	ELR	ESI	%R	%N	%F	Total Emergy	UEV (seJ/g)	UEV (seJ/J)
Blatt WS	1.126	7.936	8.275	0.1361	10.78	0.41	88.81	1.78E+16	4.53E+09	2.67E+05
Blatt WOS	1.538	1.859	1.968	0.7814	33.69	1.28	65.03	5.69E+15	1.45E+09	8.53E+04
Vendrametto WS	1.200	5.060	5.210	0.2300	16.10	0.40	83.50	1.82E+16		2.84E+08
Takahashi WS	1.580	1.710	4.900	0.3224	16.96	19.95	63.09	1.39E+16		1.56E+06
Folio 4 WS	1.950	1.052	15.007	0.1300	6.25	42.48	51.27	2.40E+16	2.31E+10	1.36E+06
Folio 4 WOS	2.056	0.947	14.187	0.1449	6.58	44.78	48.64	2.28E+16		

WS = with service; WOS = without service

EYR (Emergy Yield Ratio) [EYR = (R+N+F)/F]

This index measures the relationship between the emergy value of the evaluated system and the paid resources employed [(R + N + F) / F], that is, the influence of economic resources on the evaluated system. The EYR is applicable when analyzing agricultural systems, in which the purchased resources are used to concentrate natural energies to produce yields, in the case of agriculture. Renewable inputs such as sun, rain and wind are low quality energies that are "scattered" in the agricultural field (MARTIN et al., 2006). Intensive agricultural production systems have similar values: Florida USA (EYR = 3,33) (FOLIO 4), for Savannah cotton (EYR = 1,8 (VENDRAMETTO) and Brazilian cotton (EYR = 1,80) (TAKAHASHI et al., 2010).

EIR (Emergy Investment Ratio) [EIR=F/(R+N)]

The ratio of paid by unpaid resources (F / R + N). Cotton uses high amounts of paid inputs (such as fertilizers and pesticides) which results in a high EIR value.

ELR (Emergy Loading Ratio) [ELR=(N+F)/R]

This indicator measures the environmental stress of the evaluated system, that is, the use of nonrenewable resources and paid for free renewables. This relationship is directly related to the fraction of renewable resources, and is considered a measure of ecosystem stress due to production (BROWN & ULGIATI, 1998). This index influences the environmental sustainability (ESI) of the evaluated system. High ELR values indicate distance from the system to the state of environmental equilibrium, and high dependence on the outside or a high degree of support coming from outside the system.

According to TILEY & SWANK (2003), ELR is an index to measure the intensity of land use. The cultivation of cotton is a system that has a high environmental impact resulting in less use of renewable resources and large amount of resources paid. According to BROWN & ULGIATI (1997) ELR values lower than 2 represent less impact, values between 2 and 10 have moderate impact and greater than 10 have great impact. Intensive agricultural production systems such as the study of Brazilian cotton (ELR = 4.90) (TAKAHASHI and ORTEGA, 2010).

ESI (Emergy Sustainability Index)

Per BROWN & ULGIATI (2002), the expected values for sustainability classification of systems in the short, medium, and long terms are: Short term: ESI <1; Medium term: 1 <ESI <5; Long-term: ESI> 5. This measure assumes that the real function for sustainability is to obtain the highest productivity index, while minimizing the environmental burden (BROWN & ULGIATI, 1998).

The ESI results at all studied cotton production systems shown results <1 that characterize cotton agriculture as a short term value for sustainability classification.

Conclusions

Use the environment accounting in Emergy to evaluate the sustainability of Brazilian cotton agriculture system showed as a valuable tool to identify the environmental flows (renewable, non-renewable and purchased inputs).

Emergy table for cotton and the renewable resources that most impact the system is rain chemical (33,69%). The non-renewable resources that most impact the system are the net top soil loss (1,28%) and Financial inputs resources those have significant influence are Nitrogen (26,87%) and Phosphate (11,04%). The Brazilian states of Mato Grosso and Bahia are placed at Brazilian Savannah (Cerrado) and represent the 86.93% of cotton production. To provide the best production results the savannah soil must be correct to supply NPK fertilized demanded by cotton culture

The Emergy assessment of Brazilian cotton agriculture indicates that the cotton produced with conventional farming methods cannot yet be considered sustainable it demands high amount of fertilizers and pesticides. This intensity is demonstrated through by the Emergy Loading Ratio (ELR) index and the lower Environment Sustainability Index (ESI).

Acknowledgements

The author is grateful to CAPPES - PROSUP scholarship for the financial support.

References

BICE**,** D., Using Stella models to explore the dynamics of Earth systems: experimenting with Earth's climate system using a simple computer model, **Journal of Geoscience Education.**, v. 49, p. 170-181, 2001.

BONILLA, S.H.; GUARNETTI, R.L.; ALMEIDA, C.M.V.B.; GIANNETTI, B.F. Sustainability assessment of a giant bamboo plantation in Brazil: exploring the influence of labour, time and space. **Journal of Cleaner Production**, v.18, p.83-91, 2010

Brandt-Williams S. 1999. Evaluation of Watershed Control of Two Central Florida Lakes: Newnans Lake and Lake Weir. Ph.D. Dissertation, Environmental Engineering Sciences, Univ. of Florida, Gainesville.

BRANDT-WILLIAMS, S.L. **Folio #4: Emergy of Florida Agriculture. Handbook of Emergy Evaluation**: A compendium of data of emergy computation issued in a series of folios. Center of Environmental Policy, Univ. of Florida, Ganesville. , sep. 2002.

Brown, M.T. and J. Arding. 1991. **Transformities Working Paper**. Center for Wetlands, Univ. of Florida, Gainesville.

BROWN, M. T.; ULGIATI, S. Energy quality, emergy, and transformity: H.T. Odum's contributions to quantifying and understanding systems. **Ecological Modelling**, v. 178, n. 1–2, p. 201–213, out. 2004.

CARVALHO, M. da C. S.; FERREIRA, G. B.; STAUT, L. A. Nutrição, calagem e adubação. In: FREIRE, E. C. (ed.). **O algodão no Cerrado do Brasil**. Brasília: ABRAPA, 2011. p. 581-647.

CONAB. Metodologia de Cálculo de Custo de Produção da CONAB – Disponível em: www.conab.gov.br/conabweb/download/safra/custosproducaometodologia.pdf\ Acessado em 13/12/2016.

CRESESB – Centro de Referência para Energia Solar e Eólica. BRITO, S. DE S. Atlas Solarimétrico do Brasil. Centro de Referência para Energia Solar e Eólica Sérgio de Salvo Brito. Disponível em: www.cresesb.cepel.br .Acessado em 01/10/2016.

EMBRAPA, 2016 - http://www.agricultura.gov.br/politica-agricola/zoneamento-agricola/portarias-segmentadas-por-uf

Fluck, R. C., B. S. Panesar, and C. D. Baird. 1992b. Florida Agricultural Energy Consumption Model. Final Report to the Florida Energy Extension Service, Inst. of Food and Agricultural Sciences, Univ. of Florida, Gainesville.

GIANNETTI, B.F.; OGURA, Y.; BONILLA, S.H.; ALMEIDA, C.M.V.B.; Emergy accounting of a coffee production farm in the Brazilian savannah, **Anais da 6th Biennial Emergy Research Conference**. January 14-16th 2010. University of Florida, Gainesville, Florida, USA, 2010

Odum, H.T., M.T. Brown, and S. L. Brandt-Williams. 2000. **Folio #1: Introduction and global budget. Handbook of Emergy Evaluation**: A compendium of data for emergy computation issued in a series of folios. Center for Environmental Policy, Univ. of Florida, Gainesville.

SEVERINO, L. S. Cultivo do algodão irrigado. **Embrapa Algodão. Sistema de Produção**, 3, ISSN 1678-8710. Julho 2014. Disponível em: https://www.spo.cnptia.embrapa.br/conteudo?p_p_id=conteudoportlet_WAR_sistemasdeproducaolf6_1ga1ceportlet&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_count=1&p_r_p_-76293187_sistemaProducaoId=7717&p_r_p_-996514994_topicoId=7982

A CADEIA DO ALGODÃO BRASILEIRO: DESAFIOS E ESTRATÉGIAS Associação Brasileira dos Produtores de Algodão - **ABRAPA Biênio 2011/2012**. Visitado em 10 03 2017 14:30. Site: http://www.abrapa.com.br/BibliotecaInstitucional/Publica%C3%A7%C3%B5es/Livros/Livro%20A%20Cadeia%20do%20Algodao%20-%20Abrapa.pdf

GALLOPÍN, G. C. Environmental and Sustainability Indicators and the Concept of Situational Indicators. A System Approach. **Environmental Modelling & Assessment**, v.1, p.101-117, 1996.

MARTIN, J.F.; DIEMONT, S.A.W.;POWELL,E.;STATON,M.;LEVY-TACHER,S. Emergy evaluation of the performance and sustainability of three agricultural systems with different scales and management. **Agriculture, Ecosystems and Environment**, v.115, p.128-140, 2006.

TAKAHASHI, F.; ORTEGA, E. Assessing the sustainability of Brazilian oleaginous crops – possible raw material to produce biodiesel. **Energy Policy**, v.38, p.2446-2454, 2010.