Boletim de Pesquisa 95
e Desenvolvimento
ISSN 1678-1961
Dezembro, 2015

Emergy Evaluation of Tillage Systems in Maize Production in the Agreste of Sergipe State

Embrapa

ISSN 1678-1961

Dezembro, 2015

Empresa Brasileira de Pesquisa Agropecuária
Embrapa Tabuleiros Costeiros
Ministério da Agricultura, Pecuária e Abastecimento

Boletim de Pesquisa e Desenvolvimento 95

Emergy Evaluation of Tillage Systems in Maize Production in the Agreste of Sergipe State

Inácio de Barros
Edson Patto Pacheco
Hélio Wilson Lemos de Carvalho

Embrapa Tabuleiros Costeiros
Aracaju, SE
2015

Embrapa Tabuleiros Costeiros
Av. Beira Mar, 3250
49025-040 Aracaju, SE
Fone: (79) 4009-1344
Fax: (79) 4009-1399
www.cpatc.embrapa.br
www.embrapa.com.br/fale-conosco

Supervisão editorial: *Raquel Fernandes de Araújo Rodrigues*
Normalização bibliográfica: *Josete Cunha Melo*
Editoração eletrônica: *Raquel Fernandes de Araújo Rodrigues*
Foto da capa: *Inácio Barros*

1ª Edição (2015)
On-line (2015)

Dados Internacionais de Catalogação na Publicação (CIP)
Embrapa Tabuleiros Costeiros

Barros, Inácio
Emergy evaluation of tillage systems in maize production in the agreste of Sergipe state / Inácio Barros, Edson Patto Pacheco, Hélio Wilson Lemos de Carvalho. – Aracaju : Embrapa Tabuleiros Costeiros, 2015.

37 p. Il. (Research Development Bulletin / Embrapa Coastal Tableland, ISSN1678-1961; 95).

1. Soil. 2. *Zea mays*. 3. Convencional tillage. 4. Enviromental indicators. I. Pacheco, Edson Patto. II. Carvalho, Hélio Wilson Lemos de. III. Title. IV. Serie.

CDD 632.78 (21. ed.)

Sumário

Avaliação Emergética de Sistemas de Preparo do Solo na Produçao de Milho no Agreste Sergipano

Inácio de Barros[1]
Edson Patto Pacheco[2]
Hélio Wilson Lemos de Carvalho[3]

Resumo

A produção de milho no Agreste do Estado de Sergipe tem passado por uma transformação em direção a sistemas de cultivo com o uso de agroquímicos, híbridos geneticamente modificados e preparo intensivo do solo. Isto devido a uma combinação de fatores tais como genótipos selecionados, proximidade de mercados consumidores, uma infraestrutura relativamente boa para o escoamento da produção e um período chuvoso que coincide com a entressafra das principais regiões produtoras. Todavia, o uso intensivo de grade pesada pode acelerar o processo de degradação do solo na região. O objetivo do presente trabalho foi avaliar o desempenho ambiental de diferentes sistemas de preparo do solo na produção de milho no Agreste de Sergipe por meio da contabilidade de emergia. Indicadores ambientais mostraram que o plantio direto melhorou o desempenho ambiental quando comparado com o cultivo convencional e o cultivo mínimo.

Palavras-chave: semeadura direta, preparo convencional, cultivo mínimo, preservação ambiental, indicadores ambientais.

---

[1] Engenheiro-agrônomo, doutor em Ciências Agrárias, pesquisador da Embrapa Tabuleiros Costeiros, Aracaju, SE

[2] Engenheiro-agrônomo, doutor em Ciências do Solo, pesquisador da Embrapa Tabuleiros Costeiros, Aracaju, SE

[3] Engenheiro-agrônomo, mestre em agronomia, pesquisador da Embrapa Tabuleiros Costeiros, Aracaju, SE

Emergy Evaluation of Tillage Systems in Maize Production in the Agreste of Sergipe State

Abstract

Maize production in the Agreste part of Sergipe State in Brazil is undergoing a shift towards farming system with use of chemical inputs, high yielding GMO hybrids and intensive tillage for seedbed preparation. This can be attributed to a combination of factors like improved genotypes, closeness to consuming market, relative good infrastructure to production outlet and a rainy period that falls during the off-season of main producing areas. However, the intensive tillage being extensively used may accelerate the soil degradation process in the region. The goal of this study was to assess the environmental performance of different tillage systems in maize production in the Agreste of Sergipe through emergy accounting. Environmental indicators showed that no-till improves environmental performance when compared to reduced and conventional tillage.

Key words: no-till, conventional tillage, reduced tillage, environment conservation or environmental indicators.

Introduction

Even though subsistence agriculture is the main kind of farming system in Brazilian Semiarid Tropics (SAT), maize production in the so called Agreste part of the region is undergoing a shift towards systems with use of chemical inputs, machinery and high yielding GMO hybrids. This changing in the technological profile is being driven by a combinations of factors like adapted genotypes; closeness to consuming market (poultry farming); relative good infrastructure for production outlet, and rainy period during the off-season of traditional producing areas (BARROS et al., 2013). Such changes, specially the intensive tillage, may speed-up soil degradation and threaten the sustainable agricultural development of the region, since long-term studies have shown that continuous intensive plowing is undesirable as it leads to unsustainability, particularly in the SAT (JAT et al., 2012).

Possibly, the most suitable option to overcome soil degradation and promote sustainable farming in Semiarid Tropics is conservation tillage, which is the collective umbrella term given to no-tillage, direct-drilling, minimum tillage and/or ridge-tillage, to denote that the specific practice has a conservation goal of some nature (BAKER et al., 2002; JAT et al., 2012). It is been presented as a solution for many agricultural issues in the tropics (HEBBLETHWAITE et al., 1996; STEINER et al., 1998; FOWLER; ROCKSTRÖM, 2001; HOBBS, 2007; HOBBS et al., 2008; FOLEY et al., 2011) and aims to address questions concerning agricultural sustainability through soil management with minimum disturbance, therefore protecting it against the processes that lead to degradation - erosion, compaction, aggregate breakdown, loss in organic matter, leaching of nutrients among others (JAT et al., 2012; SERRAJ SIDDIQUE, 2012).

Despite all advantages, the adoption of conservation tillage in SAT is still low. According to Silva et al. (2011), there are difficulties for farmers to adopt no-till because the low production of crop residue that, combined with high temperatures, accelerates its decomposition, decreasing soil cover quickly after harvest (SILVA NETO, 2003; NUNES, 2006; BOT; BENITES, 2005). Also, early studies have concluded that no-till would be not a suitable management for SAT, because severe yield depressions on several crops have been documented (NYE; GREENLAND, 1964; CHARREAU; NICOU, 1971; BUANEC, 1972, BUANEC, 1974; NICOU, 1974; LAL, 1995).

Nevertheless, recent research findings have shown that even in semi-arid areas no-till can be an appropriate management to improve soil fertility and crop yields (MRABET, 2000; MRABET et al., 2001a, b; BESSAM; MRABET, 2003; SILVA et al., 2011; SILVA, 2002; NUNES, 2006; HOOGMOED, 1999). It would appear that there is a need to identify situations where availability of even moderate amount of residues can be combined with conservation tillage to enhance soil quality and efficient use of rainwater in rainfed agriculture (GUTO et al., 2011).

Emergy accounting for agricultural performance evaluation

As agriculture operates exactly at the interface between nature and the human economy, it depends on a combination of economic as well as natural inputs. Consequently, both economic and environmental contributions need to be accounted in equivalent terms when comparing resource uses in agricultural systems (CAMPBELL, 1998). However, conventional performance evaluation of agricultural production systems relies mostly on economic information, or on multi-criteria analysis that lacks an equitable basis for the different assets involved, economic, environmental, or social.

Since assessments of systems’ performance based solely on economic analysis clearly underrate environmental contributions to the system (MARTIN et al., 2006), optimal use of natural resources cannot be achieved as it results from an inappropriate accounts and an undervaluation of environmental relative to economic inputs (ULGIATI et al., 1994). Therefore, methods that quantify ‘‘non-marketed’’ resource value by avoiding reliance on human preferences may provide an informative standard against which derived monetary valuation can be compared.

Emergy synthesis is a form of energy analysis in which the large-scale environmental support to the human economy is quantified by computing the values of natural and economic resources on a common basis (ODUM, 1988). It is a ‘donor-side’ evaluation approach, because it accounts for all environmental work and natural capital previously involved in generating a resource, product or service and, in so doing, the emergy method sets out to provide a scientific basis for wealth (LEFROY; RYDBERG, 2003). Therefore, emergy synthesis is a promising tool to evaluate resource uses, production, and performance of agricultural systems.

Emergy is defined as the energy of one kind required directly or indirectly to create a product or service (ODUM, 1996; ODUM et al., 2000). Since each input (whether economic or environmental) to a process is itself a product of energy transformations, emergy is often referred to as energy memory, with units referenced to a standard energy source, typically solar energy (seJ) (COHEN et al., 2006). The ratio of emergy in a product to the remaining available energy (exergy) is called transformity (ODUM, 1988; COHEN et al., 2006) or energy transformation ratio (ODUM, 1984).

Transformity is a measure of energy quality, because the available energy after each transformation has properties that distinguish it from heat and the fundamental assumption of emergy analysis is that the contribution of a resource is proportional to the available energy of one kind required to produce the resource (BROWN; HERENDEEN, 1996). The theoretical background on emergy approach can be found in Odum (1996), Odum (1998b), Brown; Ulgiati (1999), Odum et al. (2000), Brown; Ulgiati (2001); Brown; Ulgiati (2004b) and Odum; Odum (2008).

The capacity to value economic inputs, renewable and non-renewable resources and environmental services on a common basis represents a potential advantage of emergy evaluation over conventional economic and energy analysis (LEFROY; RYDBERG, 2003).

Environmental accounting based on emergy synthesis has been increasingly used to evaluate the sustainability of agricultural systems worldwide, offering a solid base for environmental decision making related to agricultural policy and management (ULGIATI et al., 1994; BASTIANONI et al., 2001; RYDBERG;JANSEN, 2002; RODRIGUES et al., 2002; HONG-FANG et al., 2003; LEFROY; RYDBERG, 2003; MARTIN et al., 2006; AGOSTINHO et al., 2008; BARROS et al., 2009; ZHANG et al., 2012; FERRARO et al., 2015). These studies however, have usually aimed to compare very contrasting agricultural systems (conventional intensive farming against low-input traditional indigenous systems, etc.), often with different crops in each analyzed system, and where large differences are expected. However, emergy accounting can also be instrumental to evaluate how changes in specific management practices within a cropping system affect the environmental performance of the system as a whole.

The goal of the present study is to compare three different tillage systems for maize production in the “Agreste” part of the State of Sergipe with regard to: resource use, productivity, environmental impact and overall sustainability based upon the emergy approach.

Methodology

Study site and tillage systems

An experiment was carried out during the period of 2011 to 2013 aiming at evaluating the performance of different tillage systems for maize production in the “Agreste” part of the State of Sergipe. Popularly, the Agreste is a kind of climate region, the transition between humid region (Atlantic coast) and semi-arid region. The experiment was set up in the research station of Embrapa Coastal

Tablelands in the municipality of Frei Paulo, State of Sergipe (10º 55′ S; 37º 53′ W and 272 m.a.s.l). According to Emdagro (2008), the mean annual temperature is 24.5ºC and the average precipitation is 580 mm per year, with more than 71% of rainfall concentrated during the period of March to August (mean 2006-2014, direct measurements in the research station). Following Köpenn-Geiger climate classification system (KÖPEN, 1936; PEEL et al., 2007) the region falls in semiarid or steppe climate class (BSh).

Three tillage systems were been tested as follow: 1) Conventional tillage – Disk plowing (20 cm depth) followed by disk harrowing; 2) Reduced tillage – Chisel plowing (20 cm depth) followed by disk harrowing and 3) No-till.

Seeding was carried out on May, 18th; June, 28th and June, 12th respectively for 2011, 2012 and 2013 and GM maize hybrid with both glyphosate resistance and Bt events have been used. During seeding, 20 kg of N and 43.7 kg of P per ha (in the form of Monoammonium Phosphate - MAP) have been band applied as starter. No K supply was needed. When plants reached 4 – 5 leaves, a further 180 $kg.ha^{-1}$ of N were sidedress applied.

Weed dissection was performed with Glyphosate (1.5 kg a.i. per ha) three weeks prior to seeding in no-till and Atrazine (1.92 kg a.i. per ha) was used for weed control in conventional and reduced tillage just after seeding.

Experimental design was Complete Blocks with 3 replications. Each plot had 77 m^2 (3.5 x 22 m) but only the 48 m^2 (2.4 x 20 m) in the center of the plot have been considered for statistical analysis.

Harvests occurred on October, 28th; November, 26th and November, 11th for 2011, 2012 and 2013 respectively and the measured grain yields have been standardized for 13% commercial benchmark humidity level

For further details concerning experimental set-up and yield performances, please refer to Barros et al. (2015a, b).

Emergy accounting

After defining the objective of the study and the product to be analyzed, an emergy accounting requires the following steps according to Rotolo et al (2015):

a) A diagram, drawn in energy systems language, showing components, interactions, driving forces, economic and product flows.

b) A detailed inventory of the flows contributing to the process. These are usually grouped as Local renewable resources (R), Local non-renewable resources (N), Imported or purchased products, labor and services (F) and inputs expressed in their raw units.

c) Construction of a table, to summarize inventory flows, transformities, and emergy values. The table includes all kinds of input and output flows from the inventory.

d) Calculation of Total Emergy ($U = R + N + F$), and emergy-based performance and sustainability indicators. These include:

i) Transformity: The ratio between the total emergy used (Y in seJ) and energy content (in J) of the exported products.

ii) Mass emergy: The ratio between the total emergy used (Y in seJ) and the mass (in g) of the exported products (ODUM, 1998b);

iii) Fraction renewable (FR): The percentage represented by the renewable resources (R) in the total emergy used (Y). Fraction renewable = $100.R.Y^{-1}$.

iv) Environmental loading ratio (ELR): reports on the ratio of non-renewable resources ($N + P$) to renewable flows (R) and is an estimation of the environmental impact of the system. As ELR increases, stress on environmental services is expected due to convergence of sources that intensify existing flow patterns (COHEN et al., 2006). $ELR = (N + P).R^{-1}$.

v) Emergy investment ratio (EIR): describes the ratio of purchased inputs (P) to total endogenous flows (N + R), and quantifies outside investment to match flows of locally available emergy, therefore evaluating if a process is a good user of the invested emergy while compared to other alternatives for the use of the same resources (BROWN; ULGIATI, 2004a). $EIR = P.(N + R)^{-1}$.

vi) Emergy yield ratio (EYR): computes the return-on-investment of environmental work. It is a measure of the ability of a process to exploit and make local resources available by investing in outside resources, which can be read as a potential additional contribution to the main economy, gained through the investment on inputs. $EYR = Y.P^{-1}$.

vii) Emergy exchange ratio (EER): measures the advantage of one partner over the other in the trading of a product or service by money, providing a measure of who “wins” or who “loses” environmental work in economic trade (BROWN; ULGIATI, 2001). $EER = Y.(sales \bullet EMR)^{-1}$, being EMR (emergy-money ratio) the ratio of gross domestic product (GDP) to total emergy use.

viii) Emergy sustainability index (ESI): is the ratio of the EYR to ELR. Sustainability (as ESI) increases with returns on investment and decreases with environmental load. This measure assumes that the objective function for sustainability is to obtain the highest yield ratio while minimizing environmental pressure (BROWN; ULGIATI, 1999).

For a deeper understanding on emergy approach for environmental performance assessment, readers are invited to consult Odum (1996), Ulgiati and Brown (1998) and Brown and Ulgiati (2004a, b).

Results and Discussion

Emergy accounting diagram, analysis and performance indices

A diagram representing the flows of free environmental inputs, energy, materials and services used as basis for the assessment of emergy accounting of the tillage systems studied is showed in Figure 1. Quantitative flows of all main natural resources and economic inputs as well as the emergy analysis weighing the flows by their respective transformity factors are detailed in Table 1, while the emergy performance indices are presented in Table 2. The calculations of raw data in Table 1 are presented in Appendix 1.

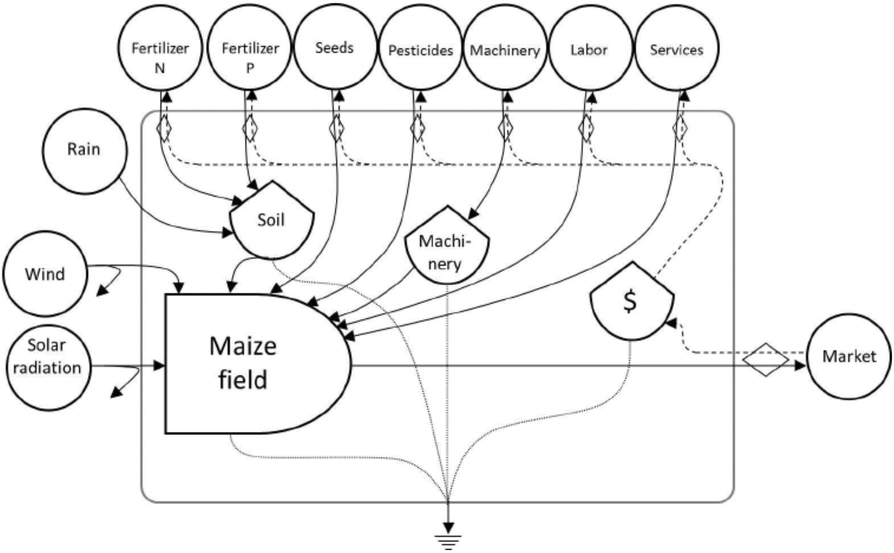

Figure 1. Generic maize production system diagram, showing the flows of renewable, non- renewable and economic resouces(solid lines) as wll as the flow of money (dashed lines) driving the production process.
Source: Odum (1998b) and Brow (2004).

Table 1. Emergy table of maize production following three different tillage systems in the Agreste of Sergipe.

Nº	Item	Raw unit	Raw amounts (units.ha^{-1}.year^{-1})			Emergy/ unit (seJ/unit)	Ref[b]	Emergy (E+13 sej.ha^{-1}.year^{-1})		
			CT[a]	RT[a]	NT[a]			CT	RT	NT
Local renewable resource *(R)*										
1	Solar radiation	J	5.23E+13	5.23E+13	5.23E+13	1	[1]	5.23	5.23	5.23
2	Wind Kinetic Energy	J	1.76E+11	1.76E+11	1.76E+11	2.51E+03	[2]	44.23	44.23	44.23
3	Rain geopotential	J	3.28E+08	3.28E+08	3.28E+08	4.70E+04	[3]	1.54	1.54	1.54
4	Rain chemical	J	2.72E+10	2.72E+10	2.72E+10	3.05E+04	[2]	82.87	82.87	82.87
Local non-renewable source (N)										
5	Top soil loss	J	1.32E+08	8.25E+07	6.89E+07	1.24E+05	[4]	0.98	0.61	0.51
Feedback from market *(F)*										
6	Fuel & Lubricants	J	4.77E+09	3.61E+09	2.48E+09	1.81E+05	[5]	86.39	65.28	44.82
7	Seeds	g	2.65E+04	2.65E+04	2.65E+04	1.98E+09	[6]	5.26	5.26	5.26
8	Nitrogen Fertilizer (N)	g	2.00E+05	2.00E+05	2.00E+05	2.41E+10	[7]	154.60	154.60	154.60
9	Phosphate Fertilizer (P_2O_5)	g	1.00E+05	1.00E+05	1.00E+05	5,67E+09	[7]	56.70	56.70	56.70
10	Herbicide: Atrazine	g	2.00E+03	2.00E+03	......	1.92E+10	[8]	3.84	3.84	......
11	Herbicide: Glyphosate	g	......	......	1.44E+03	4.32E+10	[8]	......	......	6.22
12	Agricultural machinery	g	9.59E+03	4.32E+03	3.39E+03	3.78E+09	[9]	3.63	1.63	1.28
13	Transport bags	US$	8.03E+01	8.03E+01	8.03E+01	3.70E+12	[10]	29.71	29.71	29.71
14	Labor	J	5.01E+07	4.62E+07	4.23E+07	1.10E+07	[2]	55.14	50.82	46.51
15	Services	US$	2.19E+01	1.71E+01	1.25E+01	3.70E+12	[10]	8.09	6.34	4.63

Continua...

Tabela 1. Continuação.

Nº	Item	Raw unit	Raw amounts (units.ha^{-1}.year^{-1})			Emergy/ unit (seJ/unit)	Ref^{b}	Emergy (E+13 sej.ha^{-1}.year^{-1})		
			CT^{a}	RT^{a}	NT^{a}			CT	RT	NT
Total emergy								487.21	457.66	433.11
Output *(Y)*										
16a	Grain Mass	g	8.24E+06	8.04E+06	8.26E+06					
16b	Grain Energy	J	1.44E+11	1.40E+11	1.44E+11					
	Grain Economic Value	US$	2.34E+03	2.28E+03	2.35E+03					

a/ CT: Conventional tillage; RT: Reduced tillage; NT: No-till.

b/ Transformity references: [1] by definition; [2] Odum (1996); [3] Odum et al. (2000); [4] Brown and Bardi (2001); [5] Brown et al. (2011); [6] ROTOLO et al. (2015a); [7] Brandt-Williams (2002); [8] after Helsel (1992), multiplied by crude oil transformity from Brown et al (2011 – [5]); [9] Bargigli and Ulgiatl (2003); [10] Demetrio (2011).

Table 2. Environmental performance indicators based on emergy indices for tillage systems in maize production in the Agreste of Sergipe.

Performance index		Formulae	CT[a]	RT[a]	NT[a]
R	Renewable resources	R	8.29E+14	8.29E+14	8.29E+14
N	Non-renewable resources	N	9.80E+12	6.10E+12	5.10E+12
F	Feedback from market	F	4.03E+15	3.74E+15	3.50E+15
Y	Yield	Y	4.87E+15	4.58E+15	4.33E+15
Tr	Transformity	$sej.j^{-1}$	3.39E+04	3.27E+04	3.01E+04
ME	Mass-emergy ratio	$sej.g^{-1}$	5.91E+08	5.69E+08	5.24E+08
FR	Fraction renewable	$R.Y^{-1}$	17.01%	18.11%	19.13%
ELR	Environmetal Loading Ratio	$(N+F).R^{-1}$	4.88	4.52	4.23
EIR	Emergy Investment Ratio	$F.(N+R)^{-1}$	4.81	4.48	4.19
EYR	Emergy Yield Ratio	$Y.F^{-1}$	1.21	1.22	1.24
	Empower Density	$sej.ha^{-1}.yr^{-1}$	4.87E+15	4.58E+15	4.33E+15
EER	Emergy Exchange Ratio	$Y.(PEV^{b}.EMR^{c})^{-1}$	0.671	0.645	0.595
ESI	Emergy Sustainability Index	$EYR.ELR^{-1}$	0.25	0.27	0.29

[a] CT: Conventional tillage; RT: Reduced tillage; NT: No-till.

[b] Production Economic Value.

[c] Emergy-to-money ratio.

Renewable flows

Renewable flows (sunlight, wind, rainfall geopotential and chemical energy) were expressed for the emergy accounting of maize production mainly as evapotranspiration, which is the largest flow and integrates all the sunlight derived flows. This is recommended in emergy analysis of agricultural systems in order to avoid double counting, because all the climatic derived energy flows are by-products of the same coupled process of sunlight energy dissipation (ODUM, 1996; LEFROY; RYDBERG, 2003; MARTIN et al., 2006).

In semiarid environments, potential evapotranspiration is larger than rainfall and pronounced water deficits are observed in most part of the year. Using Thornthwaite; Mather approach (THORNTHWAITE; MATHER, 1955) for estimating water balance, an average water deficit of 881 mm.year^{-1} and a reference evapotranspiration of 551.5 mm was estimated using locally collected data. Therefore, the contribution of renewable environmental resource to maize production in this semiarid region was in the amount of 82.87E+13 seJ.ha^{-1}.year^{-1}.

Non-renewable flows

Non-renewable resources used by the systems included important flows referred to as soil erosion, which varied from 0.51 up to 0.98E+13 sej.ha^{-1}.year^{-1}. No tillage systems reduced the flows of non-renewable sources by 48 and 16% in relation to conventional and reduced till respectively (Tables 1 and 2). Conservation tillage practices like no-till and reduced tillage are specifically designed to hinder soil degradation primarily by reducing soil erosion.

Conservation tillage has been highly effective in reducing the use of non-renewable resources in the form soil loss. While an average loss of soil of 31.5 g.m^{-2}.year^{-1} was measured in Conventional Tillage, in No-till the soil loss was 16.4 g.m^{-2}.year^{-1}. Despite this result, the values may be considered low when compared to some others emergy accountings of maize production. Martin et al. (2006) published emergy flows by soil erosion as high as 21.60E+13 seJ.ha^{-1}.year^{-1} in Kansas (USA);

Ulgiati (2001) found 40.10E+13 seJ.ha^{-1}.year^{-1} in Italy; FRAZESSE et al (2013) estimated 50.50E+13 seJ.ha^{-1}.year^{-1} in the South of Brazil and Rótolo et al. (2015) calculated 3.90E+13 seJ.ha^{-1}.year^{-1} in the Argentinean Pampas.

Purchased resource flows

The main differences among tillage systems were in the flows of imported resources from the marked that varied from 35.00E+14 seJ.ha^{-1}.year^{-1} in no-till system to 40.30E+14 seJ.ha^{-1}.year^{-1} in conventional tillage, reflecting the effects of reduced intensity in soil management. No-till reduced emergy imports in the form of fuel, machinery, labor and services while increased imports of emergy sources in the form of herbicides. Overall, emergy imports from the market were 12.5 and 5.7% higher in conventional and reduced till than in no-till, respectively (Table 2).

In spite of the differences, high yielding maize production in the Agreste of Sergipe may be considered highly dependent upon purchased resources. These represent about 82% of total emergy use. Of all imported resources, between 53 and 61% were invested in fertilizer, 1/4 as phosphate and 3/4 as nitrogen. The main impact that tillage systems have had on imported resources was observed in the use of fuels, that was reduced by half, from 86.39E+14 to 44.82E+13 seJ. ha^{-1}.year^{-1} or, from 22 to 13% of all imported emergy sources.

Maize yields

In average of the three years, the emergy allocated to maize production in Brazilian SAT varied from 433.11E+13 in no-till up to 487.21E+13 seJ.ha^{-1}.year^{-1} when conventional tillage was used for seedbed preparation, resulting in transformities for maize production between 3.01 and 3.39E+04 seJ.J^{-1} (Table 2).

Performance indices

No-till showed better environmental performance than reduced and conventional tillage for all evaluated indices (Table 2). Fraction renewable (FR) increased by 12.5% while environmental loading ratio (ELR) decreased by 13% only by changing from conventional to no-till, indicating that such change in seedbed preparation reduces the potential of environmental impact due to lower stress on environmental services (COHEN et al. 2006).

At the same time, no-till showed to be a better user of invested emergy than reduced and conventional tillage. Emergy investment ratio (EIR) was lower and the emergy yield ratio (EYR) was higher in this system than in the other two evaluated tillage methods (Table 2). This indicates that more free environmental resources are being incorporated into the system with less emergy being invested in purchased sources.

The results of emergy exchange ratio (EER) point out that, when selling the outputs, all three systems are getting more emergy from the market (in form of money) than giving emergy to this same market (in the form of maize grains), being therefore a “winner” in the trading process. And, among the three systems, no-till gets more emergy than reduced and conventional tillage. In average of all three years, 1.49 seJ is gotten (as money) for each seJ given (as maize grains) when conventional tillage is adopted. This proportion increases to 1.68 seJ. seJ^{-1} for no-till.

As consequence, emergy sustainability index (ESI) is higher in no-till than in conventional tillage, indicating that no tillage yields more emergy and adds more contributions to the main economy while reduces potential environmental loading.

Conclusions

This study showed that emergy synthesis can be instrumental to highlight improvements towards sustainability promoted by changes in very specific management practices, because it accounts for the spreading effects of this change in the whole system due to the holistic nature of this approach.

In relation to seedbed preparation, no-till is a management practice environmentally more efficient than conventional or reduced tillage while keeping the yielding capacity even in the Agreste part of Sergipe State.

According to emergy accounting, the main effects of no-till in relation to conventional tillage are related to reductions in the flows of non-renewable resources of soil losses and in the flows of purchased inputs like fuel, machinery, labor and services, while increasing flows of agrochemicals (herbicides). In synthesis, no-till improves sustainability of maize production in relation to conventional tillage in the Agreste of Sergipe State.

Acknowledgments

The authors thank the National Council for Scientific and Technological Development (CNPq) and State Funding Agency of Sergipe (FAPITEC - SE) for funding this research project.

References

AGOSTINHO, F.; DINIZ, G.; SICHE, R.; ORTEGA, E. The use of emergy assessment and the Geographical Information System in the diagnosis of small family farms in Brasil. **Ecological Modelling**, Amsterdan, NL, v. 210, p. 37-57, 2008.

BAKER, C. J.; SAXTON, K. E.; RITCHIE, W. R. **No-tillage seeding:** science and practice. 2nd. ed. Oxford, UK: CAB International, 2002. 258 p.

BARGIGLI, S.; ULGIATI, S. Emergy and life-cycle assessment of steel production. In: BIENNIAL EMERGY CONFERENCE, 2., 2003, Gainsville. **Proceedings**... Gainsville: Center for Environmental Policy, University of Florida, 2003. p. 141-156.

BARROS, I.; BLAZY, J. M.; RODRIGUES, G. S.; TOURNEBIZE, R.; CINNA J. P. Emergy evaluation and economic performance of banana cropping systems in Guadeloupe (French West Indies). **Agriculture, Ecosystems and Environment,** Amsterdan, NL, v. 129, p. 437-449, 2009.

BARROS, I. de; PACHECO, E. P.; CARVALHO, H. W. L. de; CINTRA, F. L. D.; SILVA, J. M. L. da; DANTAS, E. do N.; SOARES, T. F. S. N. **Desempenho da cultura do milho em diferentes sistemas de manejo do solo nas condições do agreste sergipano.** Aracaju, SE: Embrapa Tabuleiros Costeiros, 2015a. 22 p. (Embrapa Tabuleiros Costeiros. Boletim de Pesquisa e Desenvolvimento, 89).

BARROS, I. de; PACHECO, E. P.; CARVALHO, H. W. L. de; CINTRA, F. L. D.; SILVA, J. M. L. da; DANTAS, E. do N.; SOARES, T. F. S. N. **Perdas de solo e água em sistemas de cultivo de milho no agreste sergipano.** Aracaju, SE: Embrapa Tabuleiros Costeiros, 2015b. 24p. (Embrapa Tabuleiros Costeiros. Boletim de Pesquisa e Desenvolvimento, 90).

BARROS, I. de; PACHECO, E. P.; CINTRA, F. L. D.; CARVALHO, H. W. L. de; CRUZ, T. S. Perdas de solo e água em diferentes sistemas de cultivo de milho no Agreste sergipano: biênio 2011-2012. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 34., 2013, Florianópolis. **Ciência do solo:** para quê e para quem: anais. Florianópolis: Sociedade Brasileira de Ciência do Solo, 2013. 1CD-ROM.

BASTIANONI, S.; MARCHETTINI, N.; PANZIERI, M.; TIEZZI, E. Sustainability assessment of a farm in the Chianti area (Italy). **Journal of Cleaner Production,** Amsterdan, NL, v. 9, p. 365-373, 2001.

BESSAM, F.; MRABET, R. Long-term changes in particulate organic matter under no-tillage systems in a semi-arid soil of Morocco. In: INTERNATIONAL SOIL TILLAGE RESEARCH ORGANIZATION (ISTRO), 16., 2003, Toowoomba. **Proceedings...** Toowoomba, Australia, 2003. p. 144-149.

BOT, A.; BENITES, J. Creating drought-resistant soil. In: FAO. **The importance of soil organic matter:** key to drought-resistant soil and sustained food production. Rome: FAO - Land and Plant Nutrition Management Service, 2005. p. 35-40. (FAO. Soils Bulletin, 80).

BRANDT-WILLIAMS, S. L. **Handbook of emergy evaluation:** a compendium of data for emergy computation issued in a series of folios. 2nd. ed. Gainesville: Center for Environmental Policy; University of Florida, 2002. 40 p. (Emergy of Florida Agriculture. Folio #4).

BROWN, M. T. A picture worth a thousand words: energy systems language and simulation. **Ecological Modelling,** Amsterdan, NL, v. 178, p. 83-100, 2004.

BROWN, M. T.; BARDI, E. **Handbook of emergy evaluation.** Gainesville: Center for Environmental Policy, University of Florida, 2001. 90 p. (Emergy of Ecosystems. Folio #3).

BROWN, M. T.; PROTANO, G.; ULGIATI, S. Assessing geobiosphere work of generating global reserves of coal, crude oil, and natural gas. **Ecological Modelling,** Amsterdan, NL, v. 222, p. 879-887, 2011.

BROWN, M. T.; HERENDEEN, J. Embodied energy analysis and emergy analysis: a comparative view. **Ecological Economics,** New York, US, v. 1, p. 219-235, 1996.

BROWN, M. T.; ULGIATI, S. Emergy evaluation of the biosphere and natural capital. **Ambio,** Stockholm, SE, v. 28, p. 486-493, 1999.

BROWN, M. T.; ULGIATI, S. Emergy measures of carrying capacity to evaluate economic investments. **Population and Environment,** New York, US, v. 22, p. 451-471, 2001.

BROWN, M. T.; ULGIATI, S. Energy quality, emergy, and transformity: H.T. Odum's contributions to quantifying and understanding systems. **Ecological Modelling,** Amsterdan, NL, v. 178, p. 201-213, 2004a.

BROWN, M.T.; ULGIATI, S. Emergy analysis and environmental accounting. **Encyclopedia Energy,** v. 2, p. 329-354, 2004b.

BUANEC, B. Dix ans de culture motorisée sur um basin versant de Centre Côte d'Ivoire. **Agronomie Tropicale,** Paris, FR, v. 27, p. 1191-1211, 1972.

BUANEC, B. Observations on soil profile loosening in ferralitic soils: Effects on soil characteristics and growth of annual crops. **Agronomie Tropicale,** Paris, FR, v. 29, p. 1079-1099, 1974.

CAMPBELL, D. Emergy analysis of human carrying capacity and regional sustainability: an example using the state of Maine. **Environmental Monitoring and Assessment,** Dordrecht, NL, v. 51, p. 631-659, 1998.

CHARREAU, C.; NICOU, R. **L'amélioration du profil culturel dans les sol sableux et sablo-argileux de la zone tropicale séche ouest-africaine et ses incidances agronomiques (après les traveaux des recherches de l'IRAT em Afruqe de l'Ouest).** Paris: IRAT, 1971. 254 p. (Bulletin Agronomique, 23).

COHEN, M. J.; BROWN, M. T.; SHEPHERD, K. D. Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis. **Agriculture, Ecosystems & Environment,** Amsterdan, NL, v. 114, p 249-269, 2006.

DEMÉTRIO, F. J. C. **Avaliação de sustentabilidade ambiental do Brasil com a contabilidade em emergia.** 170 f. 2011. Thesis (Doctoral) - Universidade Paulista, São Paulo, 2011.

EMPRESA DE DESENVOLVIMENTO AGROPECUÁRIO DE SERGIPE. Informações básicas municipais: município de Frei Paulo. EMDAGRO, 2008. 25 p. Available at: <http://www.emdagro.se.gov.br/modules/wfdownloads/visit.php?cid=1&lid=195>, Assessed on: 23 nov. 2015.

FERRARO, D. O.; BENZI, P. A long-term sustainability assessment of an Argentinian agricultural system based on emergy synthesis. **Ecological Modelling,** Amsterdan, NL, v. 306, p. 121-129, 2015.

FOLEY, J. A.; RAMANKUTTY, N.; BRAUMAN, K. A.; CASSIDY, E. S.; GERBER, J. S.; JOHNSTON, M.; MUELLER, N. D.; O'CONNELL, C.; RAY, D. K.; WEST, P. C.; BALZER, C.; BENNETT, E. M.; CARPENTER, S. R.; HILL, J.; MONFREDA, C.; POLASKY, S.; ROCKSTRÖM, J.; SHEEHAN, J.; SIEBERT, S.; TILMAN, D.; ZAKS, D. P. M. Solutions for a cultivated planet. **Nature,** London, UK, v. 478, p. 337-342, 2011.

FOWLER, R.; ROCKSTRÖM, J. Conservation tillage for sustainable agriculture: An Agrarian revolution gathers momentum in Africa. **Soil and Tillage Research,** Amsterdan, NL, v. 61, p. 93-107, 2001.

FRANZESE, P. P.; CAVALETT, O.; HAYHA, T.; D'ANGELO, S. Integrated environmental assessment of agricultural and farming production systems in the Toledo River Basin (Brazil). In: UNESCO-IHP Water Programmed or Environmental Sustainability. Paris, FR, 2013. 71 p

GUTO, S. N.; PYPERS, P.; VANLAUWE, B.; RIDDER, de N.; GILLER, K. E. Socioecological niches for minimum tillage and crop-residue retention in continuous maize cropping systems in smallholder farms of central Kenya. **Agronomy Journal,** Madison, US, v. 10, p 1-11, 2011.

HEBBLETHWAITE, J.; SOZA, R.; FAYE, A.; HUTCHINSON, N. No-till and reduced tillage for improved crop production in sub-Saharan Africa. Achieving greater impact from research investments in Africa. In: WORKSHOP "DEVELOPING AFRICAN AGRICULTURE: ACHIEVING GREATER IMPACT FROM RESEARCH INVESTMENTS". **Proceedings**... Addis Ababa, ET, p. 195-199. 1996.

HELSEL, Z. R. Energy and alternatives for fertilizer and pesticide use. In: STOUT, B. A.; FLUCK, R. C. (Ed.). **Energy in world agriculture**, New York, US: Energy in farm production; Elsevier Science Publisher, 1992.. p. 177-201. V. 6.

HOBBS, P. R. Conservation agriculture: What is it and why is it important for future sustainable food production? **Journal of Agricultural Sciences,** v. 145, p 127-137, 2007.

HOBBS, P. R.; SAYRE, K.; GUPTA, R. The role of conservation agriculture in sustainable agriculture. **Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences,** London, UK, v. 363, p. 543–555, 2008.

HONG-FANG, L. L.; SHENG-FANG, L. A. N.; LEI, L. I.; SHAO-LIN; P. E. N. G. New emergy indices for sustainable development. **Journal of Environmental Sciences,** China, v. 15, p 562–569, 2003.

HOOGMOED, W. B. **Tillage for soil and water conservation in the semi-arid tropics**. 184 f. 1999. Thesis (Doctoral) - Wageningen University, Wageningen, the Netherlands, 1999.

JAT, R. A.; WANI, S.P.; SAHRAWAT, K .L. Conservation agriculture in the semi-arid tropics: prospects and problems. In: SPARKS, D. L. (Ed.). **Advances in Agronomy,** San Diego, US, v. 117, p. 191-273, 2012.

KALLIVROUSSIS, L.; NATSIS, A.; PAPADAKIS, G. The energy balance of sunflower production for biodiesel in Greece. **Biosystems Engineering,** Londres, UK, v. 82, p. 347-354, 2002.

KANGAS, P. C. **Handbook of emergy evaluation.** Gainesville: Center for Environmental Policy, University of Florida, 2002. 16 p. (Emergy of Landforms. Folio, 5).

KÖPPEN, W. Das geographisca System der Klimate. In: KÖPPEN, W.; GEIGER, G. (Ed.). **Handbuch der Klimatologie.** Gebruder Borntræger Verlagsbuchhandlung, 1936. p. 1–44, chapter 1.

LAL, R. Technological options for sustainable management of Alfisols and Ultisols in Nigeria. In: LAL, R.; STEWART, B. A. (Ed.). Soil Management. Experimental basis for sustainability and environmental quality. **Advances in Soil Sciences** – Series. CRC Press. Boca Raton. pp. 123-140. 1995.

LEFROY, E.; RYDBERG, T. Emergy evaluation of three cropping systems in southwestern Australia. **Ecological Modelling,** Amsterdan, NL, v. 161, p 195–211, 2003.

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

MATTOSO, M. J.; MELO FILHO, G. A. Coeficientes técnicos. In: CRUZ, J. C. (Ed.). Cultivo do milho. Sistemas de Produção, 2. ISSN 1679-012X Electronic version - 5th edition. Embrapa Milho e Sorgo. 2009.

MRABET, R. Differential response of wheat to tillage management systems under continuous cropping in a semiarid area of Morocco. **Field Crop Research,** Farnham Royal, GB, v. 66, p. 165-174. 2000.

MRABET, R.; IBNO-NAMR, K.; BESSAM, F.; SABER, N. Soil chemical quality and implications for fertilizer management after 11 years of no-tillage wheat production systems in semiarid Morocco. **Land Degradation and Development**, Chichester, GB,v. 12, p. 505-517, 2001a.

MRABET, R.; SABER, N.; EL BRAHLI, A.; LAHLOU, S.; BESSAM, F. Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotation and tillage systems in semiarid areas of Morocco. **Soil and Tillage Research**, Amsterdan, NL, v. 57, p. 225-235, 2001b.

NICOU, R. Contribution on the study and improvement of the porosity of sand and sandy-clay soil in the dry tropical zone. **Agronomie Tropicale**, Paris, FR, v. 29, p. 110-127, 1974.

NUNES, H. V. Plantio direto e decomposição de restos culturais em diferentes sistemas de cultivos. 86 f. 2006. Thesis (Doctoral) - Universidade Federal da Paraíba. Areia, PB, Brazil, 2006.

NYE, P. H.; GREENLAND, D. J. Changes in the soil after clearing tropical forest. **Plant and Soil**, The Hague, NL, v. 21, p. 101-112, 1964.

ODUM, H. T.; ODUM, E. C. **A Prosperous way down**: principles and policies. Colorado, US: University Press of Colorado, 2008. 344 p.

ODUM, H. T. Energy analysis of the environmental role in agriculture. In: STANHILL, G. (Ed.). **Energy and Agriculture**. Berlin, GE: Springer-Verlag, 1984. p. 24-51. (Advanced Series in Agricultural Sciences, 14).

ODUM, H.T. Self-organization, transformity, and information. **Science**, Washington, US, v. 242, p. 1132–1139, 1988.

ODUM, H.T. **Environmental accounting**: emergy and environmental decision making. New York, US: John Wiley and Sons Inc.,1996. 384 p.

ODUM, H. T. Emergy evaluation. In: ULGIATI, S.; BROWN, M. T.; GIAMPIETRO, M.; MAYUMI, K.; HENDERSON, R. (Ed.). Advances in Energy Studies: energy flows in ecology and economy. Roma, IT: MUSIS, 1998. Proceedings of the International Workshop held at Porto Venere, Italy, May 26-30, p. 99-112, 1998.

ODUM, H. T.; BROWN, M. T.; BRAND-WILLIAMS, S. L. **Handbook of emergy evaluation.** Gainesville: Center for Environmental Policy, University of Florida, 2000.16 p. (Introduction and Global Budget. Folio, 1).

ODUM, H. T.; ODUM, E. C. **Energy analysis overview of nations**: concepts and methods. Working Paper. Laxenbourg, Austria: International Institute of Applied Systems Anlysis, 1983. 469 p.

PACHECO, E. P.; MARTINS, C. R.; BARROS, I. de. **Viabilidade econômica do sistema plantio direto de milho consorciado com forrageiras, no estado de Sergipe**. Aracaju: Embrapa Tabuleiros Costeiros, 2013. 7 p. (Embrapa tabuleiros Costeiros. Comunicado Técnico, 132).

PAUL, A.; SOUTHGATE, D. **McCance and widdowson's the composition of foods**. 4th. ed. New York, US: Elsevier/North-Holland Biomedical Press, 1978., 539 p.

PEEL, M. C.; FINLAYSON, B. L.; MCMAHON, T. A. Updated world map of the Köppen-Geiger climate classification. **Hydrology and Earth System Sciences**, Karlsruhe, GE, v. 11, p. 1633–1644, 2007.

RODRIGUES, G. S.; KITAMURA, P. C.; SÁ , T. D. de A.; VIELHAUER, K. Sustainability assessment of slash-and-burn and fire-free agriculture in Northeastern Pará , Brazil. In: BIENNIAL EMERGY CONFERENCE, 2., 2002, Florida. theory and practice of the emergy methodology. Gainesville, US: Center for Environmental Policy, University of Florida, , p. 95-107, 2002.

ROTOLO, G.; FRANCIS, C.; CRAVIOTTO, R.; VIGLIA, S.; PEREYRA, A.; ULGIATI, S. Time to re-think the GMO revolution in agriculture. **Ecological Informatics**, Adelaide, AU, v. 26, p. 35–49, 2015a.

ROTOLO, G.C.; FRANCIS, C.; CRAVIOTTO, R.M.; ULGIATI, S. Environmental assessment of maize production alternatives: Traditional, intensive and GMO-based cropping patterns. **Ecological Indicators**, Adelaide, AU, v. 57, p. 48-60, 2015b.

RYDBERG, T.; JANSEN, J. Comparison of horse and tractor traction using emergy analysis. **Ecological engineering**, Oxford, GB, v. 19, p. 13-28, 2002.

SERRAJ, R.; SIDDIQUE, K. Conservation agriculture in dry areas. **Field Crops Research**, Farnham Royal, GB, v. 132, p.1-6, 2012.

SILVA NETO, L. F. **Influência do plantio direto e da cobertura vegetal sobre os atributos físicos e matéria orgânica do solo e produtividade do milho**. 41 f. 2003. Monography. Universidade Federal da Paraíba, Areia,BR, 2003.

SILVA, A. S. **Propriedades físicas e químicas do solo, sistema radicular e produtividade do milho sob diferentes sistemas de manejo na microrregião de Guarabira-PB**. 80 f. 2002. Dissertation (Master) - Universidade Federal da Paraíba, Areia, PB, 2002.

SILVA. A. S.; SILVA, I. F.; SILVA NETO, L. F.; SOUZA, C. Semeadura direta na produção de milho em agricultura de sequeiro na região nordeste do Brasil. **Ciência Rural**, Santa Maria, RS, v. 41, p.1556-1562, 2011.

STEINER, K.; DERPSCH, R.; KOLLER, K. Sustainable management of soil resources through zero tillage. **Agriculture Rural Development**, Bruxelas, BE, v. 1, p. 64-66, 1998.

THORNTHWAITE, C. W.; MATHER, J. R. **The water balance**. Centerton, US: Drexel Institute of Technology; Laboratory of Climatology, 1955. 104 p. v. 8, n. 1, Publications in Climatology, 1955.

ULGIATI, S. A comprehensive energy and economic assessment of bio-fuels: when green is not enough. **Critical Review in Plant Sciences**, Florida, US, v. 20, p. 71–106, 2001.

ULGIATI, S.; BROWN, M.T. Monitoring patterns of sustainability in natural and man-made ecosystems. **Ecological Modelling,** Amsterdan, NL, v. 108, p. 23–36, 1998.

ULGIATI, S.; ODUM, H.T.; BASTIANONI, S. Emergy use, environmental loading and sustainability. An emergy analysis of Italy. **Ecological Modelling**, Amsterdan, NL, v. 73, p. 215–268, 1994.

ZHANG, L. X.; SONG, B.; CHEN, B. Emergy-based analysis of four farming systems: Insight into agricultural diversification in rural China. **Journal of Cleaner Production**, Amsterdan, NL, v. 28, p. 33–44, 2012.

Appendix

Appendix 1. Calculation notes for maize production systems in Table 1.

Note	Description	Value	Unit	Source
1	**Solar radiation**			
	Energy received over land = solar radiation ($kWh.m^{-2}.day^{-1}$) x (3.6E+06 J/kWh) x (1 – albedo) x 10 000 $m^2.ha^{-1}$ x 365 days.year $^{-1}$.			
	Insolation	4.628	$kWh.m^{-2}.day^{-1}$	http://maps.nrel.gov/swera
	Albedo	14	%	http://eosweb.larc.nasa.gov
	Insolation energy	*5.23E+13*	*$J.ha^{-1}.year^{-1}$*	
2	**Wind Kinetic Energy**			
	Energy of wind (KANGAS, 2002 Folio #5): 0.5 x density of air (1.2E-1 $g.cm^{-3}$) x wind velocity^2 ($cm.s^{-1}$) x Eddy diffusion coefficient (2.8E+4 $cm^2.s^{-1}$ – ODUM AND ODUM, 1983) x $1.d^{-1}$ (d = height of boundary layer = 1E+4 cm) x 2.38E+11$kcal.erg^{-1}$ x 3.15E+07$s.year^{-1}$ x 1E+08$cm^2.ha^{-1}$ x 4186 $J.kcal^{-1}$.			
	Average wind velocity	5.781	$m.s^{-1}$	http://maps.nrel.gov/swera
	Wind Kinetic Energy	*1.76E+11*	*$J.ha^{-1}.year^{-1}$*	
3	**Rain geopotential**			
	Geopotential energy of rain: rain (m) x runoff fraction (%) x 10 000$m^2.ha^{-1}$ x mean elevation (m) x density of water (1000 $kg.m^{-3}$) x gravity (9.8 $m.s^{-2}$)			
	Average rainfall	551.5	mm	Direct measurement
	Runoff fraction	2.24	%	BARROS et al. (2013)
	Mean elevation	272	m.a.s.l.	Direct measurement
	Geopotential energy of rain	*5.28E+08*	*$J.ha^{-1}.year^{-1}$*	
4	**Chemical energy of rain**			
	Chemical energy of rain: Evapotranspiration of crops ($m.year^{-1}$) x 10 000 $m^2.ha^{-1}$ x density of water (1000 $kg.m^{-3}$) x Gibbs free energy of rainwater (4940 $J.kg^{-1}$)			
	Evapotranspired water calculated using water balance by Thornthwaite and Mater (1955) with following data: Average temperature (°C): Jan: 26.27; Feb: 26.17; Mar: 26.03; Apr: 25.50; May: 24.79; Jun: 23.87; Jul: 23.22; Aug: 23.63; Sep: 24.77; Oct: 26.04; Nov: 26.52; Dec: 26.68 (http://maps.nrel.gov/swera) Average rainfall (mm): Jan: 16.20; Feb: 36.00; Mar: 34.90; Apr: 51.50; May: 82.70; Jun: 59.20; Jul: 94.40; Aug: 60.90; Sep: 34.20; Oct: 62.80; Nov: 18.70; Dec: 0.00 (From direct measurements) Latitude (Degrees): -10.9 (From direct measurements)			
	Evapotranspired water by maize	551.5	mm	THORNTHWAITE AND MATER (1955)
	Chemical energy of rain	*2.72E+10*	*$J.ha^{-1}.year^{-1}$*	

Continua...

Appendix 1. Continuação.

Note	Description	Value	Unit	Source
5	**Top soil loss**			
	Loss of top soil: erosion rate (g.m^{-2}.year^{-1}) x organic content in the soil (g.g^{-1}) x energy content of soil organic matter (5.40 kcal.g^{-1}) x 4186 J.kcal^{-1} x 10 000 m^{2}.ha^{-1}.			
	Erosion rates			
	5.1. Conventional tillage (CT)	31.5	g.m^{-2}.year^{-1}	BARROS et al. (2015a, b)
	5.2. Reduced tillage (RT)	19.6	g.m^{-2}.year^{-1}	BARROS et al. (2015a, b)
	5.3. No-till (NT)	16.4	g.m^{-2}.year^{-1}	BARROS et al. (2015a, b)
	Organic content in the soil	0.0186	g.g^{-1}	BARROS et al. (2015a, b)
	Energy in soil loss			
	5.1. Conventional tillage (CT)	*1.32E+08*	*J.ha^{-1}.year^{-1}*	
	5.2. Reduced tillage (RT)	*8.25E+07*	*J.ha^{-1}.year^{-1}*	
	5.3. No-till (NT)	*6.89E+07*	*J.ha^{-1}.year^{-1}*	
6	**Fuel & Lubricants**			
	Energy in fuel and lubricants: quantity of fuel and lubricants (l) x energy content (4.77E+07 J.l^{-1})			
	Machine-hours used up			
	6.1. Conventional tillage (CT)	8.32	m/h.ha^{-1}.year^{-1}	MATOSO AND MELO FILHO (2009)
	6.2. Reduced tillage (RT)	6.29	m/h.ha^{-1}.year^{-1}	MATOSO AND MELO FILHO (2009)
	6.3. No-till (NT)	4.32	m/h.ha^{-1}.year^{-1}	MATOSO AND MELO FILHO (2009)
	Average consumptions			
	Diesel	12	l.(m/h)$^{-1}$	Based on tractor power
	Lubricants	0.05	l.(m/h)$^{-1}$	Based on tractor power
	Fuel used: machine-hours (m/h) x consumption (l.(m/h)$^{-1}$)			
	6.1. Conventional tillage (CT)	100.01	l.ha^{-1}	
	6.2. Reduced tillage (RT)	75.58	l.ha^{-1}	
	6.3. No-till (NT)	51.89	l.ha^{-1}	
	Energy in fuels and lubricants:			
	6.1. Conventional tillage (CT)	*4.77E+09*	*J.ha^{-1}.year^{-1}*	
	6.2. Reduced tillage (RT)	*3.61E+09*	*J.ha^{-1}.year^{-1}*	
	6.3. No-till (NT)	*2.49E+09*	*J.ha^{-1}.year^{-1}*	

Continua...

Appendix 1. Continuação.

Note	Description	Value	Unit	Source
7	**Seeds**			
	Mass of seeds used: mass of seeds (g.ha^{-1}.year-^{1}) x (1-humidity)			
	Seeds used	3.0E+04	g.ha^{-1}.year^{-1}	From field work
	Humidity of seeds	0.13	g.g^{-1}	From seed supplier
	Mass of seeds used	*2.65E+04*	*g.ha^{-1}.year^{1}*	
8	**Nitrogen Fertilizer (N)**			
	Nitrogen fertilizer used: N in starter application (g.ha^{-1}.year^{-1}) + N in sidedress application (g.ha^{-1}.year^{-1})			
	N starter			
	MAP used (10-50-00)	2.0E+05	g.ha^{-1}.year^{-1}	From field work
	N content in MAP	0.10	g.g^{-1}	Supplier information
	N starter application	2.0E+04	g.ha^{-1}.year^{-1}	
	N sidedress			
	Urea used	4.0E+05	g.ha^{-1}.year^{-1}	From field work
	N content in Urea	0.45	g.g^{-1}	Supplier information
	N starter application	1.8E+05	g.ha^{-1}.year^{-1}	
	Nitrogen fertilizer used	*2.0E+05*	*g.ha^{-1}.year^{1}*	
9	**Phosphate Fertilizer (P_2O_5)**			
	Phosphate fertilizer used: P_2O_5 in starter application (g.ha^{-1}.year^{-1})			
	MAP used (10-50-00)	2.0E+05	g.ha^{-1}.year^{-1}	From field work
	P_2O_5 content in MAP	0.5	g.g^{-1}	Supplier information
	Phosphate fertilizer used	*1.0E+05*	*g.ha^{-1}.year^{1}*	
10	**Herbicide: Atrazine**			
	Herbicide consumption (Atrazine): Product consumption (l.ha^{-1}.year^{-1}) x active ingredient content (g.l^{-1})			
	Product consumption			
	10.1. Conventional tillage (CT)	4.0	l.ha^{-1}.year^{-1}	From field work
	10.2. Reduced tillage (RT)	4.0	l.ha^{-1}.year^{-1}	From field work
	10.3. No-till (NT)	0.0	l.ha^{-1}.year^{-1}	From field work
	Active ingredient content	500	g.l^{-1}	Supplier information

Continua...

Appendix 1. Continuação.

Note	Description	Value	Unit	Source
	Atrazine consumption			
	10.1. Conventional tillage (CT)	*2.0E+03*	*g.ha^{-1}.year^{-1}*	
	10.2. Reduced tillage (RT)	*4.0E+03*	*g.ha^{-1}.year^{-1}*	
	10.3. No-till (NT)	*0.0E+03*	*g..ha^{-1}.year^{-1}*	
11	**Herbicide: Glyphosate**			
	Herbicide consumption (Glyphosate): Product consumption (l.ha^{-1}.year^{-1}) x active ingredient content (g.l^{-1})			
	Product consumption			
	10.1. Conventional tillage (CT)	0.0	l.ha^{-1}.year^{-1}	From field work
	10.2. Reduced tillage (RT)	0.0	l.ha^{-1}.year^{-1}	From field work
	10.3. No-till (NT)	3.0	l.ha^{-1}.year^{-1}	From field work
	Active ingredient content	480	g.l^{-1}	Supplier information
	Glyphosate consumption			
	10.1. Conventional tillage (CT)	*0.0E+03*	*g.ha^{-1}.year^{-1}*	
	10.2. Reduced tillage (RT)	*0.0E+03*	*g.ha^{-1}.year^{-1}*	
	10.3. No-till (NT)	*1.44E+03*	*g..ha^{-1}.year^{-1}*	
12	**Agricultural machinery**			
	Machinery depreciation: Sum of (# of machines (#.ha^{-1}) x average weight (kg.machine^{-1}) x 1E+3 g.kg^{-1} / machine lifespan (hours) x machine-hours used up (hours.year^{-1}))			
	Total # of machines			
	12.1. Conventional tillage (CT)			
	12.1.1. Tractor (105 hp)	01	#.ha^{-1}	
	12.1.2. Disk plow (4 disks - reversible)	01	#.ha^{-1}	
	12.1.3. Disk harrow (14 disks 24″ off-set)	01	#.ha^{-1}	
	12.1.4. Sprayer	01	#.ha^{-1}	
	12.1.5. Row crop planter (5 rows)	01	#.ha^{-1}	
	12.1.6. Fertilizer distributor (24 m spam)	01	#.ha^{-1}	
	12.1.7. Cereal harvester (2 lines for corn)	01	#.ha^{-1}	
	12.1.8. Trailer (2 axles)	01	#.ha^{-1}	

Continua...

Appendix 1. Continuação.

Note	Description	Value	Unit	Source
	12.2. Reduced tillage (RT)			
	12.2.1. Tractor (105 hp)	01	#.ha^{-1}	
	12.2.2. Disk harrow (14 disks 24” off-set)	01	#.ha^{-1}	
	12.2.3. Chisel plow (7 tynes)	01	#.ha^{-1}	
	12.2.4. Sprayer	01	#.ha^{-1}	
	12.2.5. Row crop planter (5 rows)	01	#.ha^{-1}	
	12.2.6. Fertilizer distributor (24 m spam)	01	#.ha^{-1}	
	12.2.7. Cereal harvester (2 lines for corn)	01	#.ha^{-1}	
	12.2.8. Trailer (2 axles)	01	#.ha^{-1}	
	12.3. No-till (NT)			
	12.3.1. Tractor (105 hp)	01	#.ha^{-1}	
	12.3.4. Sprayer	01	#.ha^{-1}	
	12.3.5. Row crop planter no-till (5 rows)	01	#.ha^{-1}	
	12.3.6. Fertilizer distributor (24 m spam)	01	#.ha^{-1}	
	12.3.7. Cereal harvester (2 lines for corn)	01	#.ha^{-1}	
	12.3.8. Trailer (2 axles)	01	#.ha^{-1}	
	Average weight			
	Tractor (105 hp)	5,775	kg.machine^{-1}	Equipment’s technical manual
	Disk plow (4 disks - reversible)	947	kg.machine^{-1}	Equipment’s technical manual
	Disk harrow (14 disks 24” off-set)	600	kg.machine^{-1}	Equipment’s technical manual
	Chisel plow (7 tynes)	290	kg.machine^{-1}	Equipment’s technical manual
	Sprayer (Condor M12 Jacto)	255	kg.machine^{-1}	Equipment’s technical manual
	Row crop planter (5 rows)	792	kg.machine^{-1}	Equipment’s technical manual
	Row crop planter no-till (5 rows)	1,093	kg.machine^{-1}	Equipment’s technical manual
	Fertilizer distributor (24 m spam)	280	kg.machine^{-1}	Equipment’s technical manual
	Cereal harvester (2 lines for corn)	2,100	kg.machine^{-1}	Equipment’s technical manual
	Trailer (2 axles)	1,500	kg.machine^{-1}	Equipment’s technical manual

Continua...

Appendix 1. Continuação.

Note	Description	Value	Unit	Source
	Machine lifespan			
	Tractor (105 hp)	15,000	hours	KALLIVROUSSIS et al. (2002)
	Disk plow (4 disks - reversible)	2,500	hours	KALLIVROUSSIS et al. (2002)
	Disk harrow (14 disks 24″ off-set)	2,500	hours	KALLIVROUSSIS et al. (2002)
	Chisel plow (7 tynes)	2,500	hours	KALLIVROUSSIS et al. (2002)
	Sprayer (Condor M12 Jacto)	1,500	hours	KALLIVROUSSIS et al. (2002)
	Row crop planter (5 rows)	2,000	hours	KALLIVROUSSIS et al. (2002)
	Row crop planter no-till (5 rows)	2,000	hours	KALLIVROUSSIS et al. (2002)
	Fertilizer distributor (24 m spam)	2,500	hours	KALLIVROUSSIS et al. (2002)
	Cereal harvester (2 lines for corn)	2,500	hours	KALLIVROUSSIS et al. (2002)
	Trailer (2 axles)	15,000	hours	KALLIVROUSSIS et al. (2002)
	Machinery depreciation			
	12.1. Conventional tillage (CT)	9.59E+03	*$g.ha^{-1}.year^{-1}$*	
	12.2. Reduced tillage (RT)	4.36E+03	*$g.ha^{-1}.year^{-1}$*	
	12.3. No-till (NT)	3.39E+03	*$g.ha^{-1}.year^{-1}$*	
13	**Transport bags**			
	Transport bags: yield ($kg.ha^{-1}$) / ($60kg.bag^{-1}$) x (cost of bag ($US\$.bag^{-1}$))			
	Average yield			
	13.1. Conventional tillage (CT)	8,238	$kg.ha^{-1}.year^{-1}$	From field work
	13.2. Reduced tillage (RT)	8,051	$kg.ha^{-1}.year^{-1}$	From field work
	13.3. No-till (NT)	8,268	$kg.ha^{-1}.year^{-1}$	From field work
	Cost of bag	0.53	$US\$.bag^{-1}$	PACHECO et al. (2013)
	Transport bags			
	13.1. Conventional tillage (CT)	*80.30*	*$US\$.ha^{-1}.year^{-1}$*	
	13.2. Reduced tillage (RT)	*80.30*	*$US\$.ha^{-1}.year^{-1}$*	
	13.3. No-till (NT)	*80.30*	*$US\$.ha^{-1}.year^{-1}$*	

Continua...

Appendix 1. Continuação.

Note	Description	Value	Unit	Source
14	**Labor**			
	Energy of human labor: working hours (hrs.ha^{-1}.year^{-1}) x 312.5 kcal.hour^{-1} x 4.186E+06 J.kcal^{-1}			
	Working hours			
	14.1. Conventional tillage (CT)	38.32	hrs.ha^{-1}.year^{-1}	MATOSO AND MELO FILHO (2009)
	14.2. Reduced tillage (RT)	35.32	hrs.ha^{-1}.year^{-1}	MATOSO AND MELO FILHO (2009)
	13.3. No-till (NT)	32.32	hrs.ha^{-1}.year^{-1}	MATOSO AND MELO FILHO (2009)
	Energy of human labor			
	14.1. Conventional tillage (CT)	*5.01E+07*	*J.ha^{-1}.year^{-1}*	
	14.2. Reduced tillage (RT)	*4.62E+07*	*J.ha^{-1}.year^{-1}*	
	13.3. No-till (NT)	*4.23E+07*	*J.ha^{-1}.year^{-1}*	
15	**Services**			
	Soil analysis	0.97	US$.ha^{-1}	1 sample for each 10 ha
	Machinery maintenance	2.02	US$.(m/h)$^{-1}$	www.portalklff.com.br
	Machinery insurance	0.30	US$.(m/h)$^{-1}$	www.portalklff.com.br
	Services			
	14.1. Conventional tillage (CT)	*21.90*	*US$.ha^{-1}.year^{-1}*	
	14.2. Reduced tillage (RT)	*17.10*	*US$.ha^{-1}.year^{-1}*	
	13.3. No-till (NT)	*12.50*	*US$.ha^{-1}.year^{-1}*	
16	**Maize output**			
	Energy in maize grains: (mass of grains(g.ha^{-1}.year-^{1}) x grain humidity (g.g^{-1}) x protein content (g.g^{-1}) x energy of protein (J.g^{-1})) + (mass of grains(g.ha^{-1}.year^{-1}) x grain humidity (g.g^{-1}) x carbohydrate content (g.g^{-1}) x energy of carbohydrate (J.g^{-1})) + (mass of grains(g.ha^{-1}.year^{-1}) x grain humidity (g.g^{-1}) x fat content (g.g^{-1}) x energy of fat (J.g^{-1}))			
	Mass of grains			
	16.1. Conventional tillage (CT)	8.238E+06	g.ha^{-1}.year^{-1}	Direct measurement
	16.2. Reduced tillage (RT)	8.051E+06	g.ha^{-1}.year^{-1}	Direct measurement
	16.3. No-till (NT)	8.268E+06	g.ha^{-1}.year^{-1}	Direct measurement

Continua...

Appendix 1. Continuação.

Note	Description	Value	Unit	Source
	Standard grain humidity	0.130	$g.g^{-1}$	From field work
	Protein content	0.136	$g.g^{-1}$	PAUL AND SOUTHGATE (1978)
	Carbohydrate content	0.789	$g.g^{-1}$	PAUL AND SOUTHGATE (1978)
	Fat content	0.079	$g.g^{-1}$	PAUL AND SOUTHGATE (1978)
	Energy content of protein	24.0E+03	$J.g^{-1}$	PAUL AND SOUTHGATE (1978)
	Energy content of carbohydrate	17.0E+03	$J.g^{-1}$	PAUL AND SOUTHGATE (1978)
	Energy content of fat	39.0E+03	$J.g^{-1}$	PAUL AND SOUTHGATE (1978)
	Energy in maize grains			
	16.1. Conventional tillage (CT)	*1.436E+11*	$J.ha^{-1}.year^{-1}$	
	16.2. Reduced tillage (RT)	*1.401E+11*	$J.ha^{-1}.year^{-1}$	
	16.3. No-till (NT)	*1.439E+11*	$J.ha^{-1}.year^{-1}$	

Embrapa

Tabuleiros Costeiros

Ministério da
**Agricultura, Pecuária
e Abastecimento**

GOVERNO FEDERAL
BRASIL
PÁTRIA EDUCADORA