

Life cycle impact assessment of cotton production in the Brazilian Savanna

Ana Cristina Guimarães Donke* – Leticia De Santi Barrantes¹ – Michelle Tereza Scachetti¹ – Nelson Dias Suassuna² - Maria Clea Brito de Figueirêdo³ –Luiz Kulay⁴ – Marília Ieda da Silveira Folegatti Matsuura¹

**Embrapa Meio Ambiente, Rod. SP 340, Km 127,5, CP 69, 13820-000, Jaguariúna, SP, Brasil; 2Embrapa Algodão; 3Embrapa Agroindústria Tropical; 4Escola Politécnica da Universidade de São Paulo*

++55 19 33112731

ana.donke@gmail.com

URL: <http://www.cnpma.embrapa.br>

Abstract

Cotton is a product of great economic importance for Brazil – the world's fourth largest producer and fifth largest exporter of this fiber. Cotton cultivation is in full expansion; the current area planted with the crop occupies 1.38 million hectares, of which 99% is in the Savanna biome. In the 2010/2011 harvest, 2.0 million tons of cotton plume were produced for the textile industry and 5.2 million tons of seed were used for oil extraction. Cotton linter is a residue from the oil production, whose use is being studied in the production of cellulose nanoparticles within the Agronano research project of Embrapa. The physical properties of nanomaterials - reduced size, varied shape and high surface area - can cause harmful effects to living organisms, requiring evaluation in relation to their potential impacts on the environment and human health. The assessments started after preparing the life cycle inventory of the agricultural cotton production phase, according to the statements of ISO standards 14040 and 14044. The production system studied employed no-tillage and was used in rotation with millet - one of the most commonly used system for the cultivation of cotton in the Brazilian Savanna. Cotton is a highly demanding crop with respect to inputs such as chemical fertilizers and pesticides. Cultivation carried out according to the technical recommendations for this crop employs over 43 different pesticides, including products for seed treatment, herbicides, insecticides, fungicides, growth regulators and maturation agents. The agricultural use of these products, particularly the fertilizers – which are carriers of heavy metals –, as well as their production, can generate severe impacts, mainly in the categories related to Toxicity and Eutrophication. Cotton production is the process responsible for the main emissions and impacts among all processes considered in this study. Rationalization of the use of agricultural inputs is clearly the way to reduce the environmental impact caused by cotton production. Other agricultural production systems, as also the fiber extraction and the production of nanofibers, will be assessed following the conclusion of this work.

Keywords: LCI, production system, agricultural input, fertilizer, pesticide, Toxicity, Eutrophication

1 Introduction

Brazil is currently the World's fourth largest producer and fifth largest exporter of cotton and its derivatives. The Brazilian cotton crop has been growing vertiginously due to production modernization and favorable environmental conditions in the country. In the 2010/2011 harvest, the area cultivated increased by 551,000 ha, signifying an increase of 65.9%. Currently it occupies 1.38 million hectares as against 836,000 ha planted in 2009/2010. According to the National Supplies Company, 2.0 million tons of cotton plume were produced in the 2010/2011 harvest – a production 70% higher than in the previous harvest; seed productivity reached 3762 kg/ha – 3.5% greater than the performance registered in the previous period; and the productivity in fiber reached 1490 kg/ha – slightly greater than the maximum yield of 1487 kg/ha registered in 2007/2008 (Anuário Agrícola do Algodão 2011; Conab 2011). Such an important expansion in area and production results in impacts of various natures, the emission of greenhouse gases (GHG), derived from the land use change (LUC), being particularly important, and regional outreach impacts also deserve attention.

The cotton plant presents some particularities and vulnerabilities, such as the production of nectar, which makes it very attractive to insects, amongst which the cotton boll weevil (*Anthonomus grandis*) stands out, a pest which is difficult to control. It also shows some particular metabolic characteristics and leaf architecture, which make it sensitive to interference by weeds (Beltrão 2003; Fonseca et al. 2011). In order to combat the pests and diseases, the cotton producers apply a battery of various insecticides, fungicides and herbicides. These, together with the products used in the treatment of the seeds, desiccant herbicides, growth regulators and maturing agents, can add up to more than 50 assets applied in the productive cycle, with a high potential for ecotoxicity and human toxicity impacts.

Cotton linter is an important co-product of cotton fibers; it corresponds to about 12.5% of the total composition of the cotton seed and consists of short fibers, containing more than 90% cellulose. Of the various applications of cotton linter, the production of hydrophyllic cotton wool, surgical tissue, mixed tissues and cellulose stand out ought to be highlighted. The project “Nanotechnology applied to agribusiness” (AgroNano), developed by the Brazilian Agricultural Research Company (Embrapa) has carried out research into the use of cotton linter in the production of cellulose nanostructures. The interactions between these nanostructures and living organisms are still not fully understood, and toxicological studies have indicated the occurrence of noxious effects on microorganisms, algae, fish, rats and human cells (Paschoalino et al. 2009). However, the preliminary results of *in vivo* toxicological studies performed with cellulose nanostructures obtained from coconut, cotton and sugarcane, found no toxicity in these materials.

The commercial use of nanomaterials could promote their dissemination into different environmental compartments and hence any risks related to their presence must be evaluated throughout their entire life cycle: from the production of the raw material (cotton), until the production of the nanofibers themselves. The objective of the present study was to evaluate the

environmental performance at the cotton production phase using the Life Cycle Assessment approach. This analysis allowed for the orientation and adjustment of the new technology, still under development, to the environmental requirements. Other agricultural production systems, as also the fiber extraction and nanofiber production, will be evaluated in sequence to the present work.

2 Methodology

2.1 Definition of the Goal and Scope

The methodology used in this study was based on the technical requirements of the ISO 14044 standard. The *Objective* of the study was “to assess the environmental performance of the agricultural production phase in which the cotton boll destined for fiber production is obtained. Co-products, such as seeds and cotton linter, are also produced. Cotton linter is used in the production of cellulose nanostructures – our final product”.

The following *Scope definition* statements were adhered to:

Product system: agricultural production of cotton.

Function: to produce cotton destined for the production of cellulose nanostructures.

Reference flow: production of 1 ton of cotton boll.

System boundaries: the system studied encompassed the production of cotton (boll), agricultural inputs, diesel, and electrical energy.

Life Cycle Impact Assessment (LCIA) method and impact categories: ReCiPe Midpoint H. There were considered all the impact categories from the method except Marine Ecotoxicity.

Data quality requirements: *Temporal dimension* - 2011/2012 harvest; *Geographic dimension* - Brazilian Savanna; and *Technological dimension* - no-tillage system in rotation with millet, non-irrigated – the most representative system used in Brazil. Regarding to *Data source*, primary data were used for the agricultural production; and secondary data – technical and scientific literature, consulting specialists, and the Ecoinvent database – were considered for the other processes.

Allocation: no allocation were carried out to the study.

2.2 Elaboration of the LCI

Considering the cotton crop expansion in Brazil, the study evaluated two possible scenarios: 1) the substitution of native wasteland (of the Savanna) for the cultivation of cotton (worst scenario); and 2) the substitution of another annual crop by cotton (best scenario). The carbon stock data for the living biomass, the dead organic matter and the soil type were obtained from the “Second Brazilian Inventory of Greenhouse Gas Emission and Anthropogenic Removal” (MCT 2010); the carbon dioxide (CO₂) emissions derived from LUC were estimated using the IPCC method (2006). Atmospheric emission of CO₂ due to the use of lime; of CO₂ and ammonia (NH₃) from the use of urea; of nitrous oxide (N₂O) generated by the use of nitrogenous fertilizers and crop residues; and the nitrate (NO₃) flows to groundwater, also resulting from the use of nitrogenous fertilizers, were

all calculated according to the IPCC guides (2006). On the other hand, estimations of the atmospheric emissions of methane (CH_4), due to the reduction in soil retention capacity caused by the use of nitrogenous fertilizers; of nitrogen oxides (NO_x), corresponding to a fraction of the N_2O emissions; and of the flow of heavy metals originating in the fertilizers to surface waters, were made according to Canals (2003).

The direct emissions of nitric oxide (NO) from the use of nitrogenous fertilizers; the phosphate (PO_4) losses to groundwater and to the soil due to the use of phosphate fertilizers; and the heavy metals originating in the fertilizers to surface waters and the soil, were estimated according to Schmidt (2007).

Since cotton is a crop involving an intense use of pesticides, special attention was dedicated to the emissions resulting from this use. The fate analysis was used to estimate the distribution of these pesticides in the environmental compartments, according to the model suggested by Haushild (2000), modified by Haushild & Birkved (2002) and by Canals (2003), assuming some premises: The pesticides used to treat the seeds, applied in a closed equipment, and the herbicides used in the plant pre-emergence phase and applied directly to the soil, did not drift due to the wind, nor were they retained by the plant.

For all the pesticides, of the total amount of each product applied, only that applied to the border area of the plantation (22.6% of the total area) was affected by drift. An emission factor of 3.5% due to drift was adopted, recognizing cotton as a crop of low stature (Canals 2003).

The retention factor of the pesticides by the plants was obtained from Linders et al. (2000), considering the chronogram of applications of a standard farm and the phenological stage of the plants.

The chronogram of applications was also used to estimate the fraction of pesticide degraded in the soil, which is a function of the number of days passed between application of the product and harvest.

The daily rates of loss by evaporation from the plant and from the soil adopted were those cited by Canals (2003). The physical and chemical characteristics of the pesticides were obtained from the "Pesticide Properties Database" (PPDB). The physical and chemical characteristics of the soil used to calculate leaching were those indicated by Paraiba et al. (2003), and corresponded to the most common type of soil in the region.

Emissions generated by the burning of diesel oil were calculated based on Nemecek & Kagi (2007). The times spent on each operation were obtained from the standard farm, with the exception of fertilization, for which information from Ecoinvent database was used.

3 Results and Discussion

LCI for the agricultural phase of the cotton production covered 214 environmental aspects. It included the consumption of seeds, lime, six types of fertilizer and 43 types of pesticide, apart from the diesel oil used in the agricultural operations (Table 1). In all, 171 output flows of substances from the productive system to the environmental compartments were estimated, the

majority derived from the use of pesticides.

Data from Table 1 indicates that most expressive impact were those of Terrestrial and Freshwater Ecotoxicity. The same result was also found recently by Silva et al. (2012).

The extremely high fertilizer and pesticide consumptions resulted in impacts related to Human Toxicity and Terrestrial and Aquatic Ecotoxicity. The agricultural production was indeed the main process contributing to the first two impacts, being responsible for 95.8% and 99.3%, respectively. For Human Toxicity the heavy metals present in these agrochemicals were the most important toxic substances; in terms of Aquatic Ecotoxicity the pyrethroid insecticides must to be highlighted.

Table 1: Natural resources, inputs from and outputs on the technosphere, for 1 ton of cotton

Known outputs to technosphere	
Cotton production, kg	1.00E+03
Known inputs from nature (resources)	
Occupation, ha	2.78E-01
Transformation of, ha	2.78E-01
Transformation to, ha	2.78E-01
Known inputs from technosphere	
Seeds, kg	8.67E+00
Lime and gypsum, kg	5.88E+02
Urea, kg	3.93E+01
Triple superphosphate, kg	8.13E+01
Potassium chloride, kg	5.99E-02
Zinc sulfate, kg	2.78E+00
Borax, kg	5.05E+00
Ammonium sulfate, kg	5.56E+01
Insecticides (24 products), kg	8.84E+00
Fungicides (5 products), kg	6.75E-01
Glyphosate, kg	1.00E+00
Diuron 500 SC, kg	1.50E+00
Other herbicides (6 products), kg	2.42E+00
Growth regulators (4 products), kg	1.12E+02
Diesel oil, kg	4.67E+01

Regarding to Aquatic Toxicity, in addition to the cotton production, the production processes of the growth regulators, insecticides and herbicides also contributed. For this category the substances showing the greatest impact were again that one from the pyrethroid group.

The cotton production process, together with the production of the phosphate fertilizers and the growth regulators, generated contaminants responsible for the Aquatic Eutrophication impact.

Evidently, the inventories of the cotton produced in the two different LUC scenarios varied with

respect to the area of natural vegetation altered and also with respect to the amount of GHG emissions. In the scenario in which the native vegetation was substituted by cotton, 0.286 m² of area were altered and 78.9 ton CO₂-eq/ ton cotton were emitted. In the scenario which predicted the installation of the cotton crop in an area previously dedicated to another annual crop, the emissions corresponded to 4.1 ton CO₂-eq/ton cotton. The actual cotton production was the process that most contributed to the Climate Change impact. The CO₂ emitted as a function of LUC, when this occurred (in the worst scenario) and the N₂O emissions from nitrogen fertilization were the main GHG emitted.

4 Conclusions

Cotton production is the process responsible for the main emissions and impacts among all processes considered in this study. An improvement in the environmental performance of cotton production depends on rationalization of the use of agrochemicals, particularly the pesticides. Even if the fragility of the cotton crop limits the adoption of alternative methods for pest control, the chemical control should be optimized, including opting for the use of more selective and safer molecules.

Embrapa recommends Integrated Pest Management, which consists of monitoring the insect-pest populations in order to orientate pesticide applications, which should occur using only the truly necessary pesticides, using an adequate amount at the correct point in time (when the insect density starts offering a risk to the crop, although still below the level of causing economic damage). This allows for an association of the chemical and biological methods and a reduction in the use of pesticides.

With respect to the Climate Change impact caused by emissions generated by the LUC, this presents the challenge of finding an equilibrium between an increment in productivity, which signifies an increase in production without increasing the area, and a reduction in the use of chemical inputs.

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