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YIELD, COST AND LCA OF DIFFERENT GROWING SYSTEMS IN THE TEXAS HIGH PLAINS

Marion I. Tobler and Simone Schaerer
Institute for Manufacturing Automation Sustainable Textiles
ETH Zurich
Zurich, Switzerland

Abstract

The aim of this study was to compare some of the most common growing practices in terms of yield, cost and environmental impacts. Generally the applications of fertilizers, pesticides and auxiliaries show significant impacts on costs and the quality of the harvested fiber as well as on the environmental impacts. Relevant effects and stages of cotton production are pointed out to allow comparison of the environmental impacts of cotton production with impacts of other textile production steps as well as other fiber textile materials. Among a great variety of applied practices five cotton cultivation scenarios were selected, based on the same variety HS 26 to be investigated and compared by means of LCA. Particular interest was put on irrigation systems since they are considered to have a high impact on the environmental situation of the Texas High Plains. The scenarios are: "BDryland" (rain grown cotton), "BFurrow" (furrow irrigated cotton), "BLEPA" (irrigation with a LEPA system), "WOrganic" (with LEPA system), "WRR" (Roundup Ready with LEPA system), whereby the first initials of the scenarios indicate the farm where the cotton was grown.

Detailed data (inventories) of all scenarios was collected in 2001, and environmental impacts were assessed by means of Life Cycle Assessment with the LCA software tool SimaPro. As the functional unit "1/kg harvested cotton" was chosen. For comparison the inventory was assessed with the method of the Center voor Milieukunde (CML) (Heijungs 1992) and the "critical surface time" (CST). The last method was recently developed at the Swiss Federal Institute of Technology Lausanne (Margni in press) particularly for LCA in agriculture.

Yields ranged from 100 lbs/acre ("BDryland") to 1300 lbs ("WRR"). In our study we found the Lepa irrigated "WRR" and "WOrganic" scenarios, cultivated on the same farm as best yielding, followed by "BFurrow", "BLEPA and BDryland. BDryland cotton was the most expensive, mainly due to its low yield. However costs did not exactly show the same ranging as yield: "WOrganic" as the second best yielding scenario caused a little higher costs than "BFurrow" (the third best yielding scenario). Considering yields and cost one has to admit that 2001 has been an extreme year regarding weather conditions.
Considering environmental impacts, all investigations show that the "WOrganic" growing scenario has a very small influence on the environment compared to the other growing scenarios, as expected. In the conventional growing scenarios the active ingredients of the used pesticides lead to dominant environmental effects in the categories "terrestrial ecotoxicity" and "aquatic ecotoxicity". Of all the rated pesticides, the insecticides Fyfanon and Temik have the highest impact on the environment. The "BDryland" scenario has the highest impact on the environment in all classes, mainly because the yield was very small in 2001. Next highest impacts were caused by the "BFurrow" irrigation scenario, followed by the two "BLEPA" scenarios and the "WOrganic" with the best ecological rating. However, the difference in impacts between the same irrigation practices is huge. In the best rated scenario ("WOrganic") the lower impacts are caused by the emissions of fuel and the application of manure.

Yield proved to be the most important factor. Lower yield is not only correlated with higher costs but also with higher environmental impacts. Irrigation water, a very important resource for cotton growing, is not cost effective, and water consumption is not rated in CML method for LCA. By considering the declining level of ground water in the Texas High Plains the environmental performance of irrigation system, including the amount of irrigation water, should become more cost effective. LCA methods should be improved in order to include water consumption, based on regional differences.

Introduction

Cotton growing is commonly indicated to be the crop with the highest amount of agrochemical applications and a tremendous consumption of irrigation water. Such statements are often listed by environment protecting groups, indicating greatest global impacts. Unquestionably sustainable development of agriculture is of global concern, and its importance for agriculture may not be under estimated. Even if one might assume that farmers knew best practices for a sustainable agriculture, political and economical frame conditions as well as new developments in industry make it difficult to find appropriate solutions for a sustainable agriculture.

Based on the commitments in 1992 for a local agenda 21, many nations have developed their own indicator systems for environment and sustainability according to the UNO Commission for Sustainable Development (BFS und BUWAL 1999). Knowledge of national indicators is helpful to develop a national environmental policy and guidelines for practices, particularly for agriculture (Rossier and Gaillard 2001). However, such indicators base on specific national conditions like structure of the agricultural sector, economics, topography, climate and many others.

Encouraged by the WTO, the OECD is developing global environmental indicators in order to provide a global perspective for agriculture. For establishing OECD indicators for agriculture many data has to be collected on national levels, mainly based on statistics. For cotton growing national statistics on yield are available (USDA 2000), while information on costs and growing practices are not available in many nations. This process, launched by the OECD, involves researchers from many countries and will allow mutual learning especially for global crops like cotton. Consequently impacts of growing conditions will become transparent. Such agreements might contribute to a deeper understanding and acceptance of regional goals for sustainability. The process of establishing international indicators will support nations to develop or adjust their own national or regional guidelines. Unfortunately the USA, owning the largest cotton growing area, does not participate in this process, although they are OECD member.

Although the USDA defined some general guidelines for sustainable agriculture, there are no such guidelines for different growing regions and agricultural practices. One of the biggest growing areas for cotton lies in Texas. Our own studies on the environmental balance (Spaar 1997) in the Texas High Plains showed a not sustainable consumption of irrigation water. Although statistical and economical information on water consumption is available for a long period (Spaar 1997 and Hauser 2000) no political decision is taken. Based on such findings we developed environmental indicators (Hauser 2000) for the Texas High plains. As such rating is semi quantitative (Tobler 2001) we investigated the most common scenarios by means of LCA.

In this paper different irrigation practices like furrow irrigation and the LEPA system are compared to dry land cotton by means of a Life Cycle Assessment (LCA), analyzing the environmental impacts.

Materials and Methods

The Texas High Plains are a major cotton production area of 1.4 – 1.6 million hectares, representing over 60% of the state's acreage. Main varieties which are grown are mid staple stripper varieties HS 200 and HS 26 with a 10-year average yield of 485 lbs/acre. We choose the Texas High Plains because of the availability of regional statistics but also because of the support of Texas Tech in Lubbock, the International Textile Center (ITC) in Lubbock and of many farmers in the region.

In the Texas High Plains the water for irrigated cotton is taken from the Oghellala aquifer, a large underground lake. However, the level of this aquifer is lowered year by year, because consumption exceeds refilling by rainfalls and surface water. Two actual irrigation scenarios are chosen: the water saving LEPA system and the older furrow irrigation.

LEPA, which stands for _L_ow _E_nergy _P_recision _A_pplication is a type of center-pivot irrigation system that does not spray water through the air onto crops. It consists of small water sprayers hanging down from a water-carrying pipe. At the bottom of each pipe, very close to the ground, is a nozzle situated, that sprays water onto the crops. With this equipment less water is lost to evaporation and wind drift than with a traditional spray-irrigation system. Besides electricity savings these systems allow more than 90-percent of the water efficiency to be used by the crop (USGS, 2001).

Probably one of the oldest methods of irrigating fields is furrow irrigation, a type of flood irrigation. Farmers flow water down small trenches running through their crops made by tillage implements. It is a cheap and low-tech but not very efficient method. Although less water is lost to evaporation than in spray irrigation, more water can be lost from runoff at the edges of the fields (USGS, 2001).

Other practices like spray-irrigation with high-power spray units or spraying by aircraft have been applied in earlier times. Unfortunately no drip irrigation scenario was applied (with the same cotton variety) on the two farms. The further regimes are so called “environmental friendly scenarios”: organic and dry land (rain grown) cotton. Organic cotton is grown without any pesticides (see agricultural practices). Dry land cotton is not irrigated. Generally rainfall with an average of 18 inches is considered adequate for crop production. The high variability within years makes non-irrigated crop production a much higher risk than irrigated production. This risk has even increased by the draught of the last few years.

System Borders and Alocation

For the LCA the season 2001 for cotton was taken as inventory. All inputs and outputs of agrochemicals (including their Life Cycles) as well as all mechanical operations for applications are included. Production of machinery for tillage and for the irrigation systems is not included because this may be different from farmer to farmer. An overview of the five scenarios is given in table 1. On farm B “BDryland”, “BFurrow” and “BLEPA” cotton is cultivated, while “WOrganic” and “WRR” (GMO: Roundup Ready) are LEPA systems, both cultivated on farm W. Since both farmers have grown the same variety HS 26, no differences should occur due to specific requirements for individual varieties. The allocation of the impacts, achieved by the product cotton fibers and its by-product seeds, is based on economic values.

LCA Method

Classical LCA method (Heijungs 1992 and SETAC 1996) includes the three steps classification & characterization, normalization and evaluation. The method applied so far is CML 92 and the calculations were elaborated by means of the computer software SimaPro. In the classification step, all substances are sorted into classes according to the impact type they have on the environment, for example to the greenhouse effect or to ozone layer depletion. For each impact category a lead substance has been selected and all other contributions are set in relevance to that lead substance, according to the proved effect. The magnitude is dealt with by applying weighting factors. This step is referred to as the characterization step. The calculated effect scores can be displayed as a graph, giving the highest calculated effect score 100%. Thus, in classification the effects of materials can be compared within the impact category but not against other impact categories. In the normalization step the impacts are set in relation to an average effect. The CML 92 method normalizes with effects caused by the average European during a year. Normalization enables you to see the relative contribution from the material production to each already existing effect. In the evaluation phase the normalized effect scores are multiplied by a weighting factor representing the relative importance of the effect. This step is not calculated due to the lack of approved weighting factors in the USA.

Results

Different irrigation systems and dry land cotton cultivated by different farmers show differences in yield (see Fig. 1). Yields ranged from 100 lbs/acre ("BDryland") to 1300 lbs ("WRR"). In our study we found the Lepa irrigated "WRR" scenario, cultivated on the same farm best yielding, followed by "BFurrow", "BLEPA" and "BDryland". As expected the growing scenarios also require different amounts of water (see Fig. 2). The same farmer cultivated the scenarios "BDryland", "BLEPA" and "BFurrow", while "WOrganic" and "WRR" were cultivated by another farmer. The comparison between the two LEPA scenarios indicates differences generated by the different farmers (practice) and different sites (weather conditions). The water consumption may not be considered without reference to the yield (Fig. 1).

The most important factor for the farmers is cost per kg cotton (see Fig. 3). "BDryland" cotton was the most expensive, mainly due to its low yield. However costs did not exactly show the same ranging: "WOrganic" as the second best yielding scenario caused a little higher costs than "BFurrow" (the third best yielding scenario). Considering yields and cost one has to admit that 2001 has been an extreme year regarding weather conditions.

The presented results on LCA of the growing systems "BDryland", "BFurrow", and "BLEPA" (Fig. 4-6) all show the great impact of pesticides applied. The impacts are focused on ecotoxicity, since no other impact category indicates a significant impact according LCA method. Differences between individual irrigation systems become almost irrelevant, especially if we compare the two LEPA systems "BLEPA" and "WRR" (Fig.6), where environmental impacts of "WRR" is a factor 1000 lower. In "BDryland" the impacts is caused by *Fyfanol UL mit*, while in "BFurrow" and "DLEPA" the impact of *Fyfanol mit* is surpassed by *Thimet 20G mit*. In the second LEPA system "WRR" *Cyclone mit* followed by *Trifluralin 4EC mit* cause the impact. In this case the *GMO Roundup Ready* is cultivated by a different farmer.

All other impact categories: greenhouse, ozone layer, human toxicity, eutrophication, acidification and summer smog mark only marginal effects compared to ecotoxicity. Nevertheless they are also calculated in the characterization. Comparison of the two LEPA systems shows, that in the "WRR" little pesticides is applied. Consequently impacts caused by energy production and use become relatively more important. Only in "WOrganic", where no pesticides are applied, other impacts than pesticides become relevant. The impacts however, are a factor of 10 000 smaller than all growing regimes cultivated by farmer B (see also Fig. 8). The impacts categories ecotoxicity and summer smog are mainly influenced, followed by greenhouse. The effects are mainly caused by the manure applied and the gas used as energy source. In LCA all impacts of pesticides from production to effect are included. Fig. 9 shows the differences for *Malathion*, whereby all impacts are compared to production (100%). Application includes all mechanical work for the application of the field, except the substance itself. The latter is represented by the effect.

Discussion

Comparison of the Different Growing Scenarios

The chosen growing season of 2001 with draught and diseases, was one of the "worst year since the Civil War". In certain regions up to 60-70% of the crop was lost because of a hale storm on May 31st. Therefore the results may not be representative in quantitative data (water consumption and yield). Since costs are correlated with yield (see Fig. 1), which again is dependant of the water supply, the consequences for the growing scenarios become strikingly clear: In a dry season Dry land cotton becomes very expensive due to yield losses. Farmer W, situated 60 miles north of farmer B might have had the benefit of more rainfall (see table1). However, farmer B applied about the double amount of irrigation water per ha and still had a very small yield. The small yields of "BFurrow" and "BLEPA" cannot be explained only by lacking water.

LCA Results

The presented results do not allow a ranking between irrigation systems. The highest differences between irrigation systems are of a factor 2 (Fig 4-6), while differences between cultivation practices of individual farmers with the same irrigation system show a factor 1000 (see Fig. 7). Consequently, individual management practices prove the most important influence on impacts. In Fig. 8 the effect of a GMO variety becomes visible, since "WRR" affords much less pesticides compared to the same variety, grown with the same irrigation system. In "BLEPA" a considerable amount of pesticides was applied. Because the *Roundup Ready* variety ("WRR") was grown by a different farmer the effect of good management practices and the GMO cannot be proved independently.

The example of the pesticide *Malathion* (Fig. 9) indicates that impacts in production exceed the impacts of application and effect. This relation is not given for every pesticide and is highly dependant on the application type. In the case of *Trifluralin* the relation is inversed (not shown here).

As shown for other agricultural systems (Rossier et Gaillard 2001) environmental impacts highly depend on individual farmer's practices. Nevertheless improvements in specific growing regimes can be achieved regarding the different impacts caused by the application of different pesticides. Besides this ecological rating, costs and yield have to be considered. The great impacts of the regimes "BDryland", "BFurrow" and "BLEPA" are mainly caused by very small yields (Fig.11). All scenarios showed a great impact caused by the application of pesticides, so that the small yields cannot be related to a lack of pesticide input. If yields can be improved by altering management practices, without increasing pesticide application, impacts per kg cotton will decline and profit of farmers will increase.

The inventory (season 2001) for this study has just recently been completed. All LCA calculations with CML 92 method proved the great impacts of pesticides. It is known that other methods have a slightly different weighting of impacts. This fact requires further analyses and calculations to provide a deeper insight into impact assessment. Other methods will be applied (CML 2, Eco Indicator and Margni 2001), and a sensitivity analyze will be performed. With this restriction the here presented results have to be taken as preliminarily.

The most important conclusions are the following: A comparison of costs and environmental impacts (Fig 10) shows clearly, that low environmental impacts can be achieved with low costs scenarios ("WRR" and "WOrganic"). Yield proved to be the most important factor. Consequently, lower yield is not only correlated with higher costs but also with higher environmental impacts (see Fig. 11). Irrigation water, a very important resource in cotton growing, does not influence costs in a regulative way, and the irrigated water consumption not rated in LCA. Considering the declining level of ground water in the Texas High Plains the environmental performance of irrigation system, including the amount of irrigation water, should become more cost effective. LCA methods should be improved in order to include water consumption as well, based on regional differences.

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Table 1. Inventory of the growing scenarios, irrigation type and input of agrochemicals.

	BDryland	**BFurrow**	**BLEPA**	**WOrganic**	**WRR**
Acreage	58.26 ha	8.33 ha	77.68 ha	24.78 ha	24.78 ha
Irrigation	none	Furrow	LEPA	LEPA	LEPA
Water use	none	3.5 Mio l /ha	2.3 Mio l /ha	1.3 Mio l /ha	1.3 Mio l /ha
Variety	Paymaster HS26	Paymaster HS26	Paymaster HS26	Paymaster HS26	Paymaster 2326RR
Fungicide	Captan	Captan	Captan	none	many
Herbicides	Trifluralin Caparol	Trifluralin Caparol	Trifluralin Caparol	none	Trifluralin Caparol Roundup Ultra
Insecticides	Malathion	Thimet Malathion	Thimet Malathion	none	Temik Orthene
Growth Regulator	none	none	none	none	Pix
Defoliants	Cyclone	Cyclone	Cyclone	none	Cyclone
Fertilizer	none	none	Nitrogen	Manure	Manure

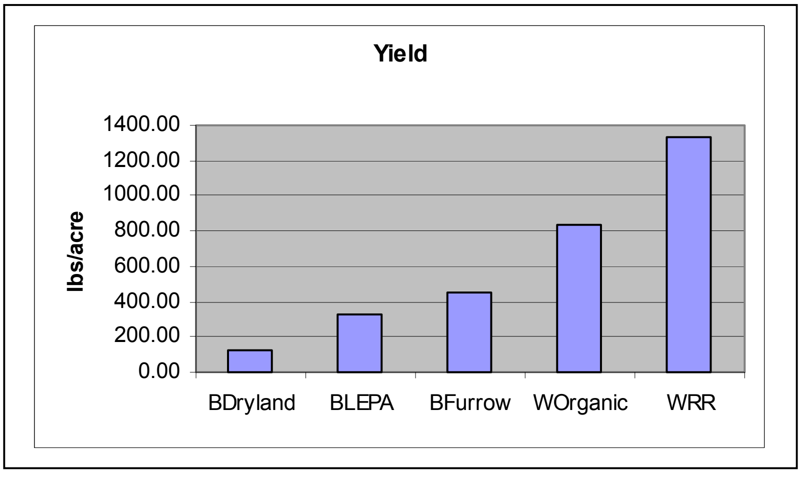

Figure 1. Yields (kg /ha) of the different growing scenarios.

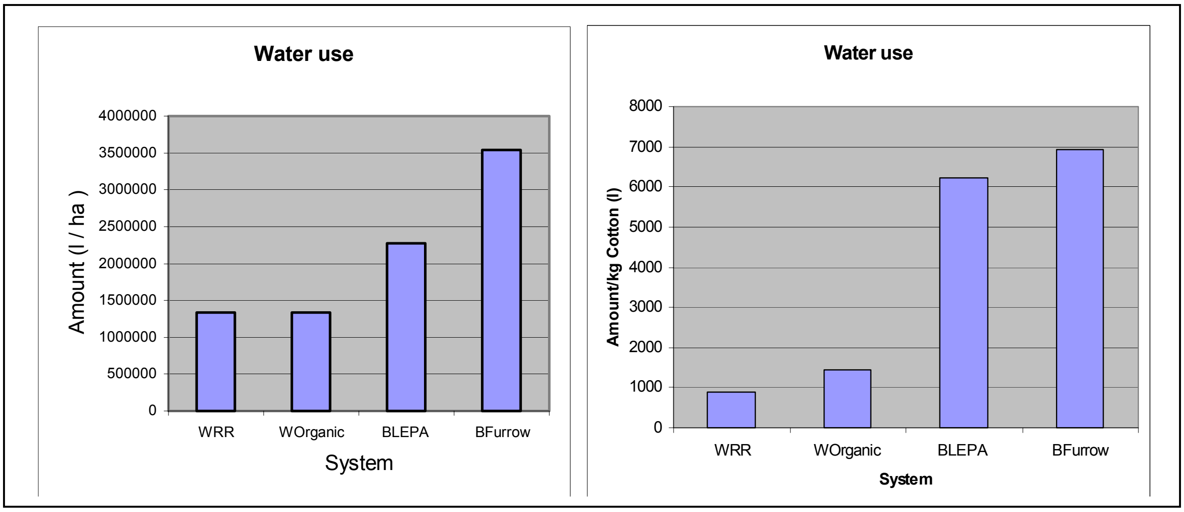

Figure 2. Water consumption per kg cotton and ha of the irrigated growing scenarios.

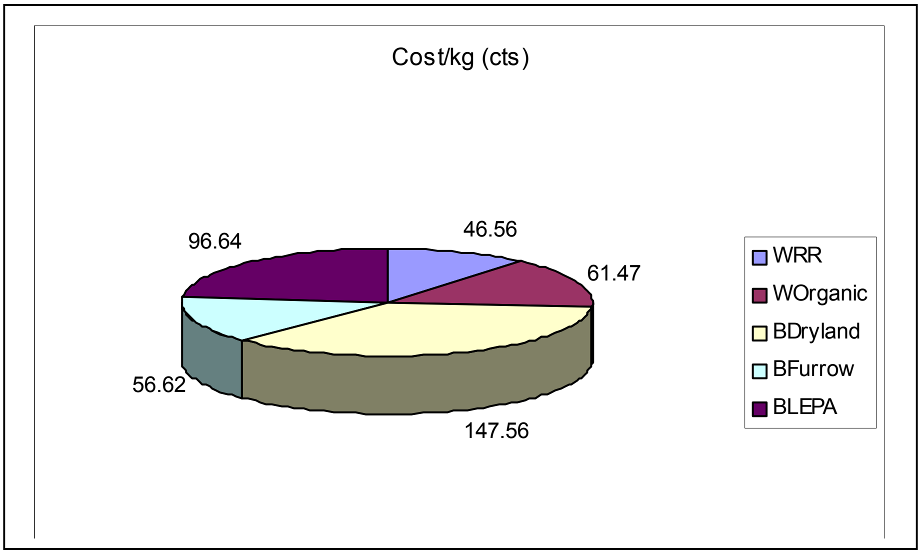

Figure 3. Costs per kg cotton of the different growing scenarios.

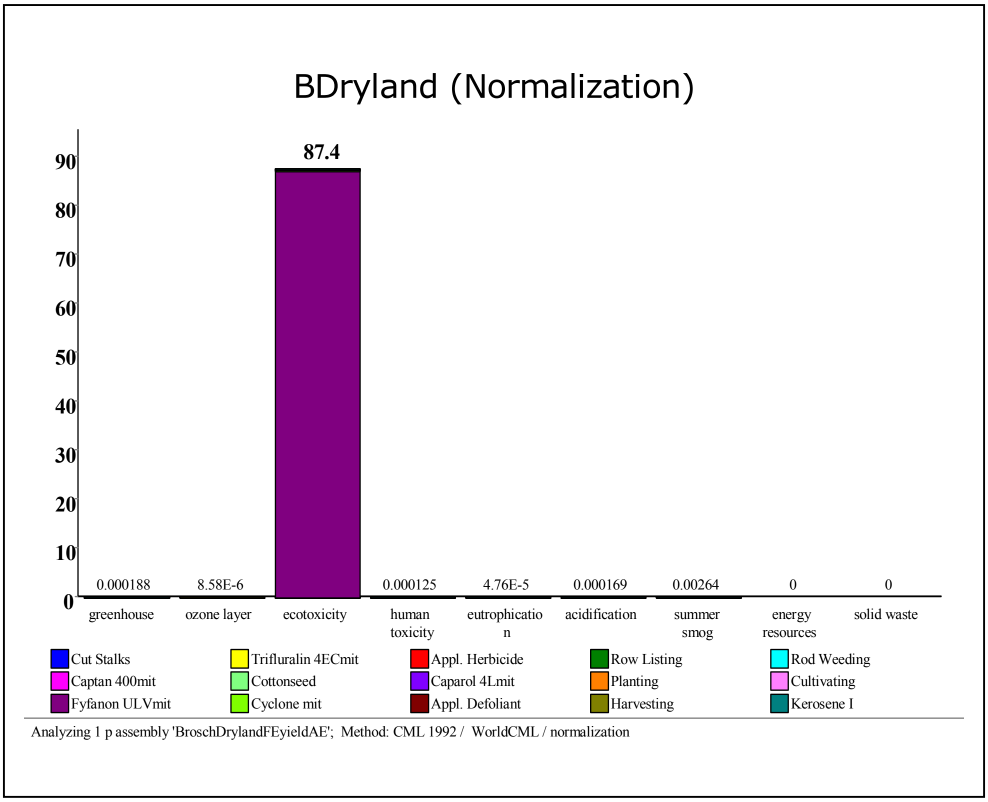

Figure 4. Impact score of dry land cotton (in millipoints).

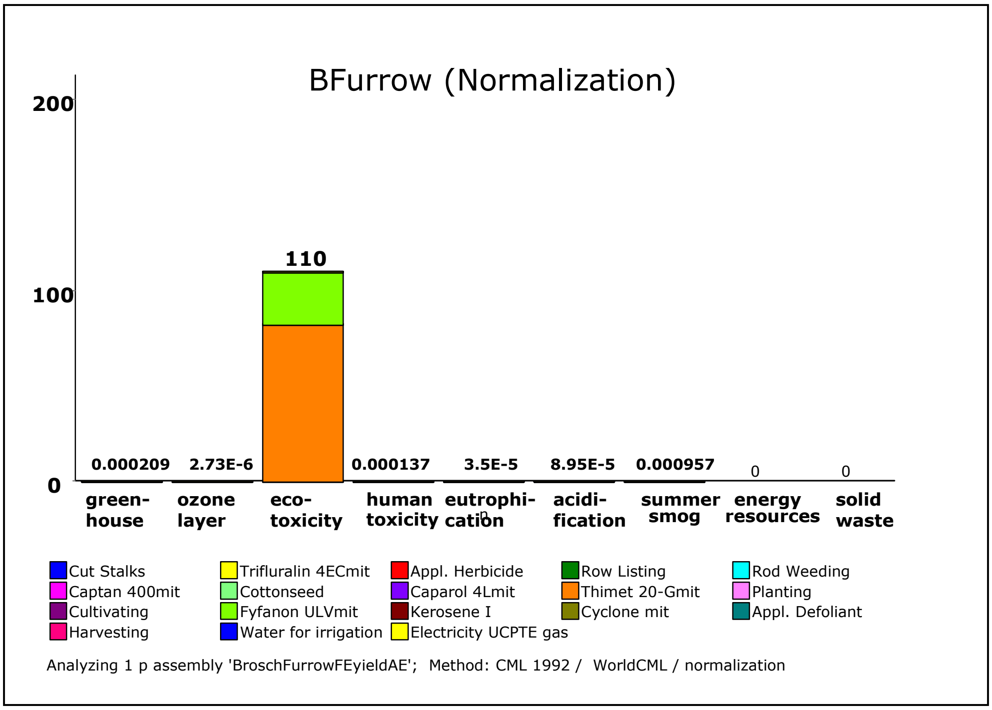

Figure 5. Impact score of furrow irrigated cotton (in millipoints).

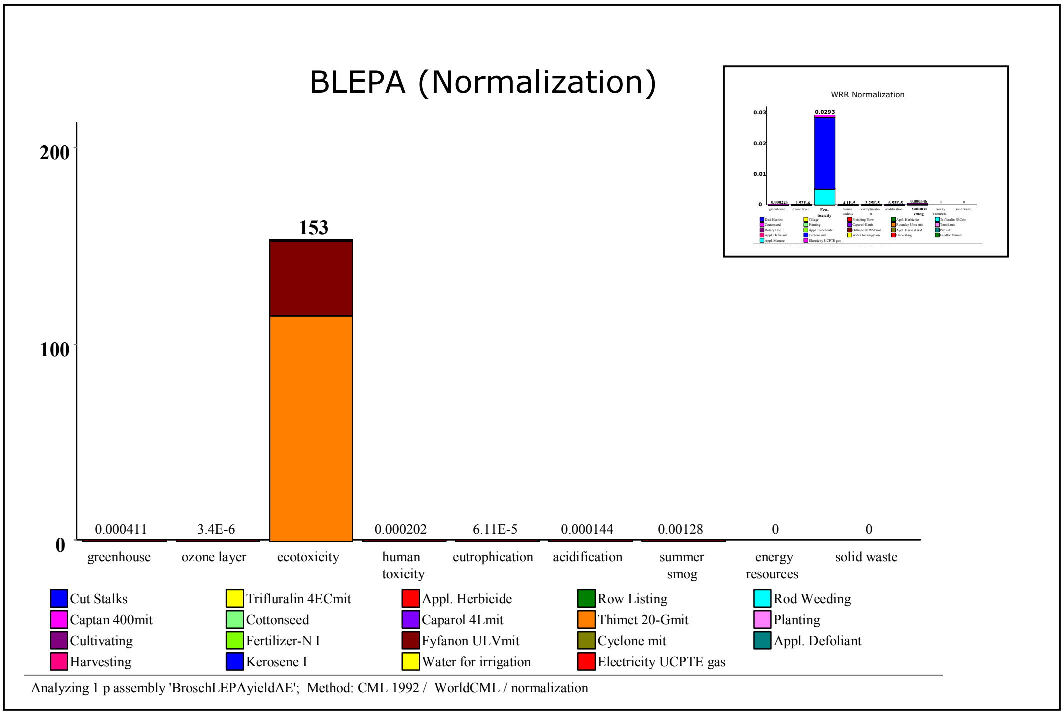

Figure 6. Impact scores of LEPA irrigated Cotton produced by two farmers. The relation of the full scale of the master graph and the inserted graph is 200: 0.3.

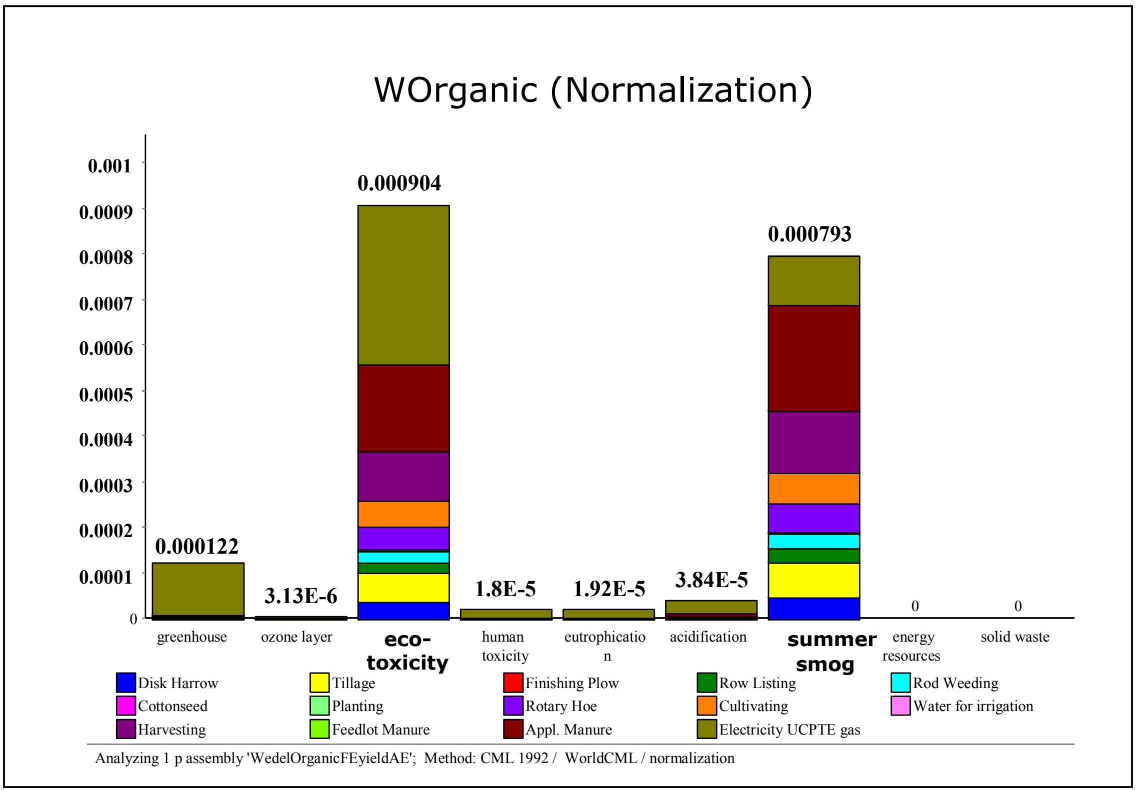

Figure 7. Impact score of "WOrganic", a "BLEPA" irrigated cotton. Full scale of this score is 10 000 times smaller than in Fig. 4-6.

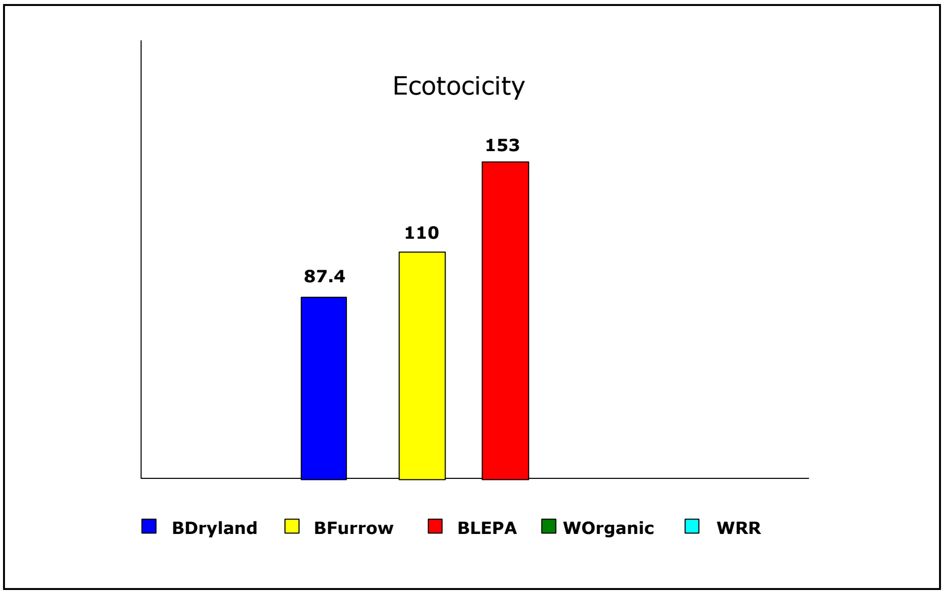

Figure 8. Simplified LCA of all growing scenarios.

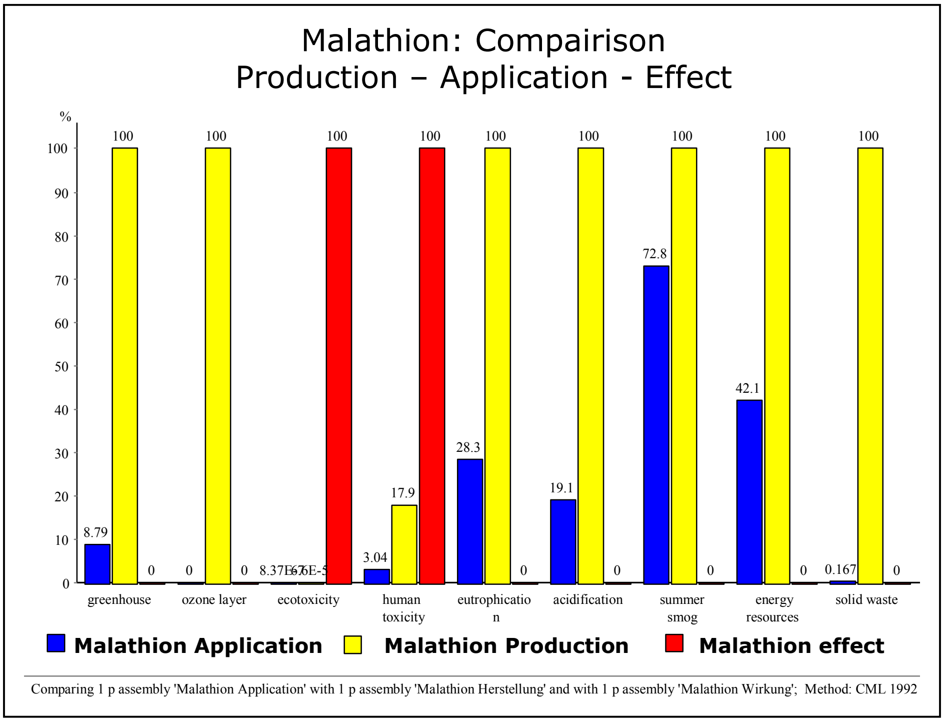

Figure 9. Relations of environmental impacts in production, application (treatment) and effect of the substance.

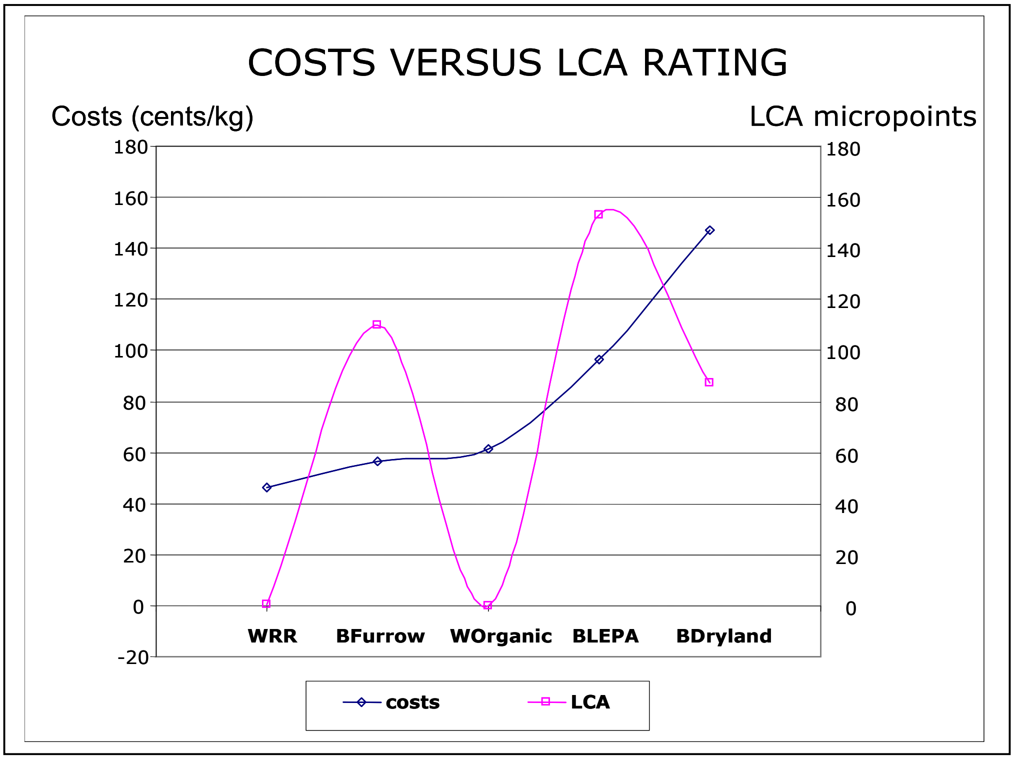

Figure 10. Relation of costs and LCA rating.

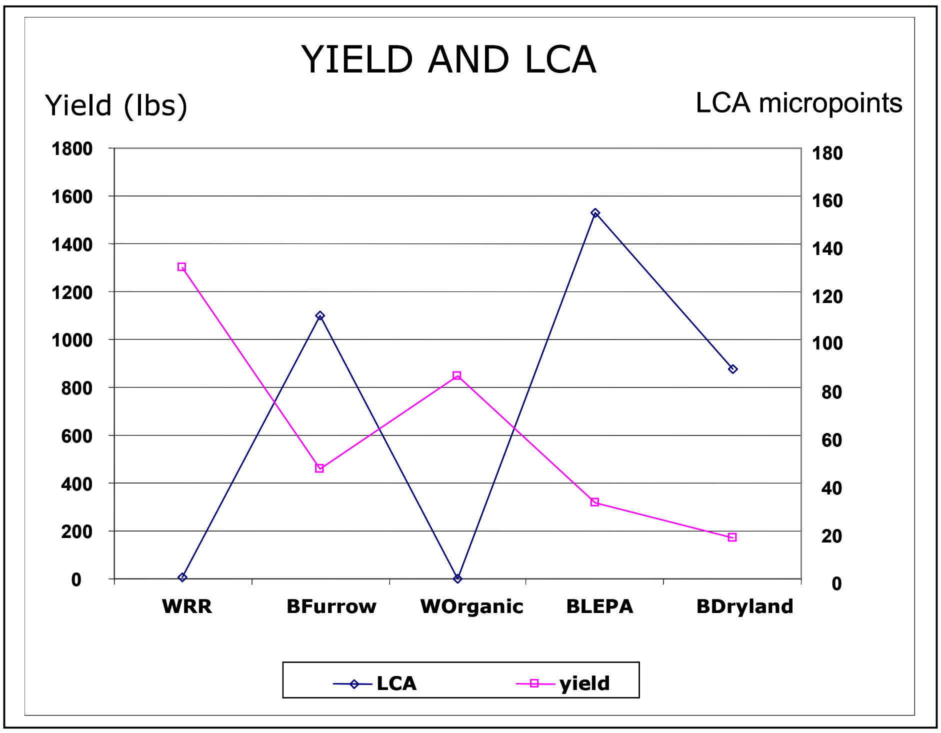

Figure 11. Relation of Yield and LCA Rating.