The sustainability of cotton

Consequences for man and environment

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Biological Farming Systems, Wageningen University

Chapter 5 written by Rhiannon Pyburn
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Science Shop Wageningen UR
April 2006

Report 223

Colofon/Colophon

De duurzaamheid van katoen
Gevolgen voor mens en milieu

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Wageningen, April 2006

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This project was commissioned by Goede Waar & Co, association for consumers. Goede Waar & Co represents the interests of socially and environmentally conscious consumers. Based on extensive research into sustainability, the organisation informs you on how clothing and food products affect you as a consumer and how they effect the world around you.

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Activities at the Biological Farming Systems Research and Education Group are geared towards the development and transfer of new scientific knowledge to analyze, design, and evaluate sustainable agricultural farming systems where natural ecological processes are utilized to the maximum possible. Research is focused on mixed animal and plant production systems and specialised plant production systems (if possible in collaboration with animal production systems).

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Dutch low-budget citizen groups are welcome at the Science Shop of Wageningen UR. We help realising research projects in the fields of nutrition and health; sustainable agricultural systems; environmental quality and processes of social change.

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Preface

It's hard to find two product groups closer to our skin than food and clothing. This is why Goede Waar & Co, as an association for socially responsible consumers, has been concentrating on these themes for the last years. More and more consumers want to know under which circumstances their food products and garments have been produced. What impact does the production have on people, animals and the environment?
This demand for information led, amongst others, to the 2004 'Cotton Checker' campaign: consumers were able to look up their favourite clothing brand on the internet and see how it performed on a number of social and environmental indicators, concentrating on cotton production. The consumers could also ask 'their' brands for an increased use of organic cotton.
Certainly this last aspect caused a lot of discussion in newspapers and scientific journals. Clothing brands were claiming the organic cotton production was too low to satisfy their demand; scientists were arguing that organic cotton shared various sustainability problems with 'regular' cotton. As Goede Waar & Co concentrates on providing dependable information, this called for more research. For this, we sought co-operation with the Science Shop (Wetenschapswinkel) and the IBL, Innovation centre for Organic Agriculture, both part of Wageningen University and Research Centre.
I am pleased to announce that the report you are about to read is the well-defined scientific base for this research. For example, thanks to this report we now have indicators to compare the environmental impact of conventional, 'Integrated Pest Management' (IPM) and organic production systems. We have starting points to discuss the social aspects relevant for trade in sustainable cotton. And we know that even organic production can cause unsustainable use of water for irrigation.
In other words, we have completed a promising first step. I am confident we will be able to give the consumer the full 'sustainability picture' at the end of the road. Although one thing is already clear: as far as the sustainability of cotton production goes, there is still a world to be won.

Mira A. Vendrig
Director of Goede Waar & Co

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Karst Kooistra, Rhiannon Pyburn and Aad Termorshuizen

Abstract

The sustainability of cotton – Consequences for man and environment

The environmental impacts associated with cotton production are increasingly in the spotlight however, data on the sustainability of cotton production are scanty and not widely available. As such, the goals of this current project were as follows:

1. To summarise literature that compares conventional, IPM, and organic cotton production systems in terms of environmental impact;
2. To select indicators, based on literature resources, which can be used to formally compare the environmental impact of conventional, IPM, and organic cotton production systems and to carry out comparisons based on these indicators;
3. To suggest starting points for discussion on the social aspects relevant for trade in sustainable cotton.

Cotton is produced in more than 100 countries, the most important countries being: China (24% of global cotton production), the USA (19%), India (16%), Pakistan (10%), Brazil (5%) and Uzbekistan (4%). Three types of cotton cultivation are distinguished in this study: conventional systems (representing about 80% of cotton production internationally), Integrated Pest Management (IPM) systems (approximately 20%); and organic systems (0.04%). This study provides an extensive description of the cultivation practices of each of system in the major cotton producing countries and the related environmental effects.

Despite the general lack of accurate data, it is concluded that water and pesticide use cause the most significant environmental problems in cotton systems. The use of pesticides in several developing countries is of particular concern. While organic systems are quite well-defined through standards and regulations and are third-party verified, the lack of definition and monitoring as to optimal (i.e. most sustainable) conventional and IPM cotton for both rain-fed and irrigated systems hampers interpretation as to their sustainability. To address this, certification of conventional and IPM systems and appropriate product labelling is recommended. In addition, water and land use indicators for all cotton systems need further development and implementation to allow more comprehensive estimates of the environmental impacts of cotton production.

If cotton production and processing are to be sustainable in a more holistic sense, then social and trade aspects need to be addressed in addition to environmental indicators. IFOAM Basic Standards for organic agriculture address baseline social standards which ensures that all IOAS-accredited certification bodies include some social elements in their own standards. Coordinated efforts with other more comprehensive social standard-setting bodies are however necessary in order to ensure an end product that is verified as socially and environmentally sustainable. For cotton, certification packages that address the many steps of the supply chain (production, ginning, spinning, dying, weaving/knitting, cut-make-trim) need formulation.

Korte samenvatting

De duurzaamheid van katoen – gevolgen voor mens en milieu

De invloed van de productie van katoen op het milieu krijgt internationaal steeds meer aandacht. Aangezien er geen gebundeld overzicht bestaat van de milieu-effecten van de productie van katoen was het doel van dit onderzoek:

1. Samenvatting van de literatuur waarin milieu-effecten vergeleken worden van gangbare, IPM (Integrated Pest Management = geïntegreerde landbouw) en biologische katoenproductie;
2. Selectie van indicatoren op basis van literatuurgegevens die gebruikt kunnen worden om het milieu-effect van gangbare, IPM en biologische katoenproductie in kaart te brengen;
3. Start van een discussie over duurzame aspecten van katoenproductie en -handel.

Katoen wordt geproduceerd in meer dan 100 landen, met China (24% van de wereldproductie), de VS (19%), India (16%), Pakistan (10%), Brazilië (5%) en Oezbekistan (4%) als belangrijkste producenten. In het algemeen worden drie productiewijzen onderscheiden: gangbare systemen (80% van de katoenproductie), IPM (20%) en biologische (0,04%). In dit rapport wordt voor de belangrijkste katoenproducerende landen een uitgebreide beschrijving gegeven van de cultuurmaatregelen in deze teeltsystemen en hun milieu-effecten.

In verhouding tot de omvang van de katoenteelt is het aanbod aan betrouwbare gegevens over de invloed van katoenproductie op het milieu beperkt. Desondanks kan geconcludeerd worden dat water- en bestrijdingsmiddelengebruik in de katoenteelt de belangrijkste milieu-effecten hebben. Vooral het gebruik van bestrijdingsmiddelen in een aantal ontwikkelingslanden is zeer verontrustend. Terwijl biologische teelt tamelijk goed is gedefinieerd, is het gebrek aan een algemeen aanvaarde omschrijving van de randvoorwaarden voor de teelt van gangbare en IPM katoen lastig voor de interpretatie van de milieu-effecten van deze systemen. Dientengevolge wordt geconstateerd dat er een grote variatie is in milieu-effecten van individuele systemen. Certificering en labeling van gangbare en IPM katoenteelt wordt aanbevolen. Ook wordt aanbevolen de duurzaamheid van water- en landgebruik verder te ontwikkelen voor alle teeltsystemen zodat deze gebruikt kan worden bij milieu-effectrapportages van katoenproductie.

Duurzaam geproduceerde katoen betekent dat naast een duurzame teelt van de plant ook de keten in zijn geheel duurzaam en sociaal rechtvaardig dient te zijn. De regels van de IFOAM voor biologische landbouw garanderen minimumeisen. Deze zouden nog verder uitgebreid moeten worden in samenwerking met certificeringsorganisaties die specifiek gericht zijn op deze elementen. Voor katoen dient dit gespecificeerd te worden voor alle elementen uit de keten.

Summary

The sustainability of cotton – Consequences for man and environment

Cotton cultivation represents over 31 million hectares or 2.4% of global arable land, involving about 20 million farmers who completely depend on cotton production and another 30 million farmers who include cotton into their rotation scheme. The environmental impact of cotton production is increasingly in the spotlight with the main problems being salinisation, desertification and poisoning of the environment including human health. To date, there is insufficient insight as to the degree of (un)sustainability of the systems in place. In addition, Integrated Pest Management (IPM) and organic systems are usually assumed without critical analysis, to have lower environmental impacts than conventional production. Therefore, the goals of this project were:

1. To summarise literature that compares conventional, IPM, and organic cotton production systems in terms of environmental impact;
2. To select indicators, based on literature resources, which can be used to formally compare the environmental impact of conventional, IPM, and organic cotton production systems and to carry out comparisons based on these indicators;
3. To suggest starting points for discussion on the social and trade sustainability of cotton.

Cotton is produced in more than 100 countries with the major producers being: China (6.3 Mt of raw cotton, representing 24% of global production), the USA (5.1 Mt, 19%), India (4.1 Mt, 16%), Pakistan (2.5 Mt, 10%), Brazil (1.2 Mt, 5%) and Uzbekistan (1.1 Mt, 4%). Although global cotton production and yield per unit area have increased steadily over the last three decades, the area used for the cotton for a given country is quite variable, especially for organically grown cotton.

Cotton requires large amounts of water both for cultivation and processing. Irrigation is used in areas where normal precipitation quantities do not match the requirements for the crop being cultivated. 53% of cotton fields worldwide are irrigated and because irrigated cotton generally has higher yields per unit of area, this translates to 73% of all cotton production. The most commonly used irrigation system for cotton cultivation is the flood-or-furrow irrigation system, which although easiest to install, has the lowest water efficiency, 40% at most. More efficient irrigation systems are more expensive to install. Soil salinisation is a common outcome of poor irrigation. One-third of irrigated land is already or will soon be affected by salinisation: the numbers are likely to be higher for cotton as it tends to be cultivated in more sensitive areas. Other negative side-effects of irrigation are water shortage and pollution downstream. An estimated 5 Mha of arable land (4% of the world total) is abandoned due to former intensive cotton cultivation with soil salinisation being the main reason.

15% of cotton yield loss is due to insect damage. Fungal and bacterial plant pathogens, viruses, and nematodes are of lesser importance. Cotton cultivation has been estimated to consume 11% of the world's pesticides while it is grown on only 2.4% of the world's arable land. Insecticides used in cotton cultivation represent 25% of the global consumption. In developing countries it is estimated that approximately 50% of all pesticides are applied in cotton cultivation. In addition, pesticide use and storage are often badly managed. The techniques used for pesticide application strongly affect environmental impact, especially in terms of human exposure. An estimated 13% of the cotton growing areas are aerial sprayed. Cases of contamination of neighbouring villages due to aerial spraying for cotton production have been reported. Field spraying by hand accounts for application in 52% of the world's cotton fields. While cheap and effective, poisoning of workers who apply the pesticides is common in developing countries. The remaining 35% of cotton fields are treated by tractor spraying. Recommendations as to pesticide application need to be implemented.

A wide array of pesticides are being applied on cotton, among them are those listed by the World Health Organisation (WHO) as highly hazardous, including: monocrotophos, triazofos, parathion, parathio-methyl, phosphamidon, methamidophos, demeton-S-methyl. In various countries some of these pesticides are no longer permitted but without adequate verification systems, they are still in use. Many older, non-patented, toxic, environmentally persistent and inexpensive chemicals are used extensively in developing nations, creating serious acute health problems as well as local and global environmental contamination. The quantity of these illegal pesticides is very

difficult to estimate. In more developed countries, pesticides are regulated and hazardous insecticides are not allowed.
In general, three types of cotton cultivation are recognised: conventional (farming systems that are neither organic nor IPM; approximately 80% of cotton production), Integrated Pest Management (IPM; 20%) (systems designed to minimise pesticide and often also fertiliser use), and organic (a certified farming system that amongst other standards, does not permit synthetics in farming such as synthetic pesticides, fertilisers and genetically modified organisms; 0.04%). In this report an extensive description of cultivation practices in the major cotton-producing countries is provided.
If cotton production and processing are to be sustainable in a more holistic sense that goes beyond environmental indicators, then social and trade aspects need to be addressed. A robust approach to social sustainability includes the following aspects: freedom of association and right to collective bargaining; working hours; seasonal workers, contracts; child labour; health and safety; wages; discrimination; and disciplinary practices. IFOAM Basic Standards for organic agriculture address baseline social standards which ensures that all IOAS-accredited certification bodies include some social elements in their own standards. Coordinated efforts with other more comprehensive social standard-setting bodies (i.e. Social Accountability International, Sustainable Agriculture Network of the Rainforest Alliance, and Fair Trade Labelling Organisations International) are however necessary in order to ensure an end product that is verified as socially and environmentally sustainable. For cotton, certification packages that address the many steps of the supply chain (production, ginning, spinning, dying, weaving/knitting, cut-make-trim) need formulation.

The report arrives at the following conclusions:

- Water use (including the potential negative consequences of salinisation and water resource depletion) and pesticide use represent the greatest environmental problems in cotton systems. Water use and type of irrigation are not explicitly included in the standards for organic production at present. In principle, unsustainable water use may occur in all three farming types, although the majority of organic cotton systems are not irrigated. In developing countries most organic cotton is rain-fed while the majority of the IPM and conventional cotton is irrigated. The environmental impact of water use is considerably lower for rain-fed than for irrigated cotton, however the opportunities for yield gains by optimising water applications are also consequently lower.
- The widespread use of extremely and highly toxic pesticides in developing countries is a major concern both for the natural environment and for people who are exposed, especially workers applying these pesticides. Pesticide application methods strongly affect the potential impact on field workers and the environment; thus, the way field workers apply pesticides needs to be better understood.
- Biodiversity is negatively affected through the use of broad-spectrum pesticides, through conversion of natural habitats and through loss of land to degradation or shifting farming practices. For cotton production systems biodiversity is addressed through the land use and toxicity indicators. The effect on biodiversity of cropping vast areas of monoculture of cotton needs additional attention.
- Limited data on the environmental impact of cotton systems is available. In addition, the great heterogeneity of farm types hinders data extrapolation.
- Because of the great diversity in farming practises it is difficult to express the environmental impact of conventional, IPM and organic cotton farming on a systems level. The use of pesticides is highly problematic in several important cotton-producing countries and here the distinction between conventional and organic cotton production is evident.
- In developed countries conventional cotton production may to some extent approach IPM given that the most persistent and hazardous pesticides are not allowed and because inputs are increasingly optimised for cost reasons. However, the lack of clear-cut definitions for IPM and conventional systems also contributes to this conclusion.
- Organic farming is a certified type of production, while conventional is not, and IPM is generally not. With certified production it is easier for retailers and consumers to understand the history of the produce and thus make inferences about environmental impact. Although the general aims of organic farming are to promote an overall sustainable approach, the standards need improvement as they do not sufficiently address land and water use issues. For optimal,

highly-technological conventional cotton production systems, a standards and verification system is necessary because otherwise there is no way to differentiate clearly unsustainable conventional farming systems from more sustainable conventional farming systems.
- Reflecting on the desirability of organic cotton production, water and land use issues should be kept in mind. Expanding the organic cotton area in rain-fed regions by converting low-input conventional farms to organic could be an optimal approach as yields can be as high as those in IPM and conventional cotton, water use can be generally sustainable, and no pesticides are used. This applies especially to countries that apply relatively hazardous pesticides. However, for conversion to organic cotton in irrigated areas it is necessary to address water and land use issues. Organic cotton production on eroded, pesticide-polluted and/or salinised soils would not be a viable option. Conversion to organic cotton production on large tracts of land that are mainly conventional can be a challenge if pest pressure is high.

Recommendations
- The current study could be extended by an analysis of each of the approaches against their characteristic visions and ultimate goals. Descriptions and definitions of optimal, most sustainable conventional and IPM cotton systems for both rain-fed and irrigated cotton are needed. Certification of such systems and labelling of products should be considered.
- Knowledge of what happens in the field is the basis for recommendations. Clearly for such an important crop as cotton more field work is needed to collect quantitative field data on environmental impact and yields in various developing and developed countries. This could lead to an extended Life Cycle Assessment comparing conventional/IPM and organic farms in several countries using the following indicators: Water use, Human and environmental toxicity, Global warming, Eutrophication, Acidification, Erosion, Land use, Biodiversity and Salinisation. Also the environmental impact of cotton production should be compared with the production of other fibres such as polyester, viscose, hemp, and linen (but see Cherrett et al., 2005 for first results on a comparison of cotton, polyester, and hemp).
- Further research is needed on how various stakeholders influence cultivation methods.
- Water and land use indicators need further development and implementation in LCA-cotton studies. The standard for organic production should also address these elements.
- The social, environmental, and trade-related issues that are particularly relevant for cotton production in different country contexts and at different points along the supply chain merit further research in order to build a comprehensive picture of sustainable cotton beyond just environmental indicators.
- Organic certification done by an IOAS-accredited certification body assures that a baseline level of social justice is maintained at the production level. To address more than these minimal social concerns, to address trade-related concerns and to address the other parts of the supply chain, other means are necessary. For example, Fair Trade Labelling Organisations (for small producer organisations) or Social Accountability International (for larger operations and other steps along the supply chain) are possible certification partners.
- Certification packages need to be constructed that address environmental, social, and trade-related concerns throughout the whole supply chain. Costing and traceability for such a system clearly needs attention.
- Verification and certification bodies in the three sustainability areas (social, environment, trade) should study how they can co-operate.

Samenvatting

De duurzaamheid van katoen – gevolgen voor mens en milieu

Katoen is een belangrijk gewas: het wordt geteeld op 31 miljoen hectare; dit is 2,4% van het oppervlak dat wereldwijd beschikbaar is voor landbouw. Naar schatting zijn 20 miljoen boeren volledig afhankelijk van katoen en nog eens ongeveer 30 miljoen hebben katoen in hun vruchtwisseling opgenomen. De invloed van de productie van katoen op het milieu krijgt steeds meer aandacht, maar precieze gegevens over de milieubelasting zijn in de literatuur lastig te vinden. Verder wordt een geringe milieubelasting van geïntegreerde en biologische katoenteelt tamelijk kritiekloos aangenomen, hoewel ook hier een literatuuroverzicht ontbreekt. Het doel van dit onderzoek was daarom als volgt:
1. Samenvatting van de literatuur waarin milieu-effecten vergeleken worden van gangbare, IPM (Integrated Pest Management = geïntegreerde landbouw) en biologische katoenproductie;
2. Selectie van indicatoren op basis van literatuurgegevens die gebruikt kunnen worden om het milieu-effect van gangbare, IPM en biologische katoenproductie in kaart te brengen;
3. Start van een discussie over duurzame aspecten van katoenproductie en -handel.

Katoen wordt geproduceerd in meer dan 100 landen, met China (6,3 Mt ruwe katoen, 24% van de wereldproductie), de VS (5,1 Mt, 19%), India (4,1 Mt, 16%), Pakistan (2,5 Mt, 10%), Brazilië (1,2 Mt, 5%) en Oezbekistan (1,1 Mt, 4%) als belangrijkste producenten. Hoewel wereldwijd de katoenproductie en de productie per oppervlakte-eenheid de laatste dertig jaar sterk is toegenomen, is de hoeveelheid geteelde katoen per land aan tamelijk sterke veranderingen onderhevig, met name voor biologisch geteelde katoen.
Katoenproductie vraagt grote hoeveelheden water, zowel tijdens de teelt als tijdens de verwerking. Irrigatie is nodig op 53% van het katoenareaal, waarmee 73% van de wereldkatoenproductie behaald wordt. Het waterverbruik per eenheid katoen wordt sterk bepaald door het type irrigatie. Het meest gebruikte type is 'flood-or-furrow'-irrigatie, waarvan de efficiëntie slechts ca. 40% bedraagt. Andere, meer efficiënte irrigatiesystemen zijn echter voor de meeste landen te duur. Als gevolg van inefficiënte irrigatie treedt verzilting op. Ongeveer éénderde van alle geïrrigeerde landbouwgebieden is aangetast door verzilting. Katoen heeft hierin een relatief groot aandeel omdat dit vaak geteeld wordt in gebieden die gevoelig zijn voor verzilting. Ook de relatieve zouttolerantie van katoen draagt hier aan bij. Een neveneffect van irrigatie is dat het benedenstroomse areaal aangetast kan worden door verzilting, waardoor watergebrek kan ontstaan. Inmiddels is ca. 100 miljoen hectare land (8% van het oppervlak dat beschikbaar is voor landbouw) braakliggend ten gevolge van verzilting door niet-duurzame landbouwmethoden, en hiervan is een groot gedeelte veroorzaakt door de teelt van katoen.
Insectenaantastingen veroorzaken in de katoenteelt opbrengstverliezen van gemiddeld 15%. In het algemeen zijn schimmel-, bacterie-, virus- en nematodenaantastingen van geringer belang. Katoenteelt vergt met zo'n 11% van het wereldwijde gebruik relatief veel gewasbeschermingsmiddelen. Insecticiden, gewasbeschermingsmiddelen tegen plaaginsecten, vergen in de katoenteelt zo'n 25% van het wereldwijde gebruik. In ontwikkelingslanden worden gewasbeschermingsmiddelen relatief nog het meest in de katoenteelt ingezet: naar schatting 50%. Bovendien worden in ontwikkelingslanden gewasbeschermingsmiddelen op gevaarlijke wijze toegepast en worden middelen gebruikt die niet toegestaan zijn in meer ontwikkelde landen. De wijze van toepassing bepaalt in hoge mate de blootstelling van mensen en het milieu, en daarmee de mate van ongewenste neveneffecten. Op ongeveer 13% van het wereldwijde katoenareaal worden gewasbeschermingsmiddelen toegepast met vliegtuigen. In 52% van het katoenareaal worden gewasbeschermingsmiddelen met handsproeiers toegepast. Dit is goedkoop en effectief, maar vergiftiging van veldwerkers komt frequent voor in ontwikkelingslanden. Bij de rest van het katoenareaal (35%) worden gewasbeschermingsmiddelen met tractoren met daarop spuitinstallaties geïnstalleerd aangewend. Aanbevelingen over veilige methoden van toepassing van gewasbeschermingsmiddelen dienen snel te worden beschreven en geïmplementeerd. Om een inschatting te kunnen maken over de effecten van gewasbeschermingsmiddelen op het milieu dient nauwkeurig bekend te zijn hoe deze middelen zijn toegepast.
Vele soorten gewasbeschermingsmiddelen worden in de katoenteelt toegepast, waaronder een aantal die door de Wereldgezondheidsorganisatie WHO geclassificeerd zijn als hoogriskant

('highly' of 'extremely hazardous'): monocrotophos, triazofos, parathion, parathio-methyl, phosphamidon, methamidophos en demeton-S-methyl. In verscheidene landen worden niet-toegestane gewasbeschermingsmiddelen gebruikt. Het illegale gebruik van gewasbeschermingsmiddelen is moeilijk in te schatten, maar waarschijnlijk zorgen zij voor grote milieu- en gezondheidsproblemen in veel landen. In meer ontwikkelde landen is het gewasbeschermingsmiddelengebruik gereguleerd en zijn hoogriskante middelen veelal niet toegestaan.
In het algemeen worden drie teeltsystemen onderscheiden: gangbare systemen (systemen die niet gerangschikt kunnen worden onder IPM of biologisch; 80% van de katoenproductie), geïntegreerde landbouw ('integrated pest management', IPM; systemen die tot doel hebben het gewasbeschermingsmiddelengebruik en vaak ook de bemesting te minimaliseren; 20%) en biologische (een gecertificeerd type van productie waarin synthetische gewasbeschermingsmiddelen en kunstmest niet zijn toegestaan; 0,04%). Een uitgebreide beschrijving van de cultuurmaatregelen in deze teeltsystemen en hun milieu-effecten wordt gegeven voor de belangrijkste katoenproducerende landen.
Sociale en handelsaspecten van katoenproductie zijn van belang om de duurzaamheid van de gehele keten te beschouwen. Aspecten die hierbij van belang zijn omvatten vrijheid van organisatie van arbeiders, recht van onderhandelen, seizoensarbeid, arbeidsduur, kinderarbeid, contractplicht, gezondheid en veiligheid, salarissen en discriminatie. De organisatie die de standaard voor biologische landbouw bepaalt, IFOAM, heeft ook basisvoorwaarden gesteld aan sociale aspecten. Om werkelijk een sociaal duurzaam katoenproduct te garanderen is samenwerking met certificeringsorganisaties nodig die gespecialiseerd zijn op dit gebied, zoals 'Social Accountability International', 'Sustainable Agriculture Network of the Rainforest Alliance' en 'Fair Trade Labelling Organisations International'. Voor katoen dient dit gespecificeerd te worden voor alle elementen uit de productieketen.

Het rapport komt tot de volgende conclusies en aanbevelingen:

Conclusies

- Watergebruik, samen met de potentiële gevolgen hiervan (verzilting en uitputting in de geïrrigeerde gebieden), en gewasbeschermingsmiddelengebruik zorgen voor de grootste problemen in katoenteelt. Duurzaamheid van watergebruik is momenteel niet expliciet beschreven in de regels voor biologische productie. In principe kan niet-duurzaam watergebruik dus optreden in alle teeltsystemen, hoewel op dit moment de grote meerderheid van biologische katoensystemen gesitueerd is in niet-geïrrigeerde gebieden.
- Het brede gebruik van riskante gewasbeschermingsmiddelen in vooral de ontwikkelingslanden is zeer zorgelijk, zowel voor het milieu als voor mensen die aan deze middelen worden blootgesteld. De wijze van toepassing van gewasbeschermingsmiddelen beïnvloedt in hoge mate de effecten op mens en milieu. Meer inzicht in de praktijk van wijze van toepassing van gewasbeschermingsmiddelen is daarom sterk gewenst.
- Biodiversiteit wordt negatief beïnvloed door gewasbeschermingsmiddelen met een breed werkingsspectrum en door toename van het benodigde landareaal voor katoenteelt. Meer aandacht dient te worden besteed aan het effect op biodiversiteit van de teelt van enorm grote, monotone oppervlaktes katoen in ontwikkelde landen.
- Slechts een beperkte hoeveelheid milieugegevens over het effect van katoenteelt op het milieu is beschikbaar. De aanzienlijke diversiteit in de wijze van katoenteelt bemoeilijkt de extrapolatie van gegevens.
- Gezien de grote variatie in de katoenteelt kan op systeemniveau geen algemene uitspraak gedaan worden over de invloed op het milieu van gangbare, IPM en biologische landbouw. Het gebruik van gewasbeschermingsmiddelen is met name in ontwikkelingslanden zeer problematisch en daarmee onderscheidt biologische katoenteelt zich duidelijk van de gangbare en IPM katoenteelt.
- In meer ontwikkelde landen kan het milieu-effect van de gangbare katoenteelt tot op zekere hoogte die van IPM-katoenteelt benaderen, omdat daar ook in de gangbare teelt de meest gevaarlijke gewasbeschermingsmiddelen niet zijn toegestaan. Deze conclusie kan overigens worden beïnvloed doordat gangbare en IPM-katoenteelt lang niet altijd scherp gedefinieerd zijn.

- Biologische teelt is een gecertificeerd type van productie. Gangbare teelt is dat niet, en IPM meestal niet. Voor handelaren en consumenten is met gecertificeerde teelt gemakkelijker in te zien wat de historie is van het product en dus wat de milieu-effecten zijn geweest. Hoewel het algemene doel van biologische landbouw een zo duurzaam mogelijk productiewijze is, zijn er op het vlak van land- en watergebruik zeker verbeteringen mogelijk. Een duidelijk omlijnd en gecertificeerd productiesysteem is ook nodig voor de gangbare en IPM-katoenteelt aangezien alleen dan de duurzaamheid van zo'n systeem ingeschat kan worden.
- Als de wenselijkheid van biologische katoen overwogen wordt dan moet water- en landgebruik hierbij betrokken worden. In gebieden waar irrigatie niet nodig is door voldoende regenval is omzetting van niet-duurzame, gangbare systemen in duurzame, biologische systemen aan te bevelen. In deze gebieden kan de opbrengst aan katoen in kg/ha even hoog zijn als die in IPM en gangbaar geteelde katoen. Het voordeel is groter naarmate er op dit moment meer gevaarlijke gewasbeschermingsmiddelen worden ingezet. Als echter het doel is om gangbare katoenteelt in geïrrigeerde gebieden om te zetten in biologische teelt dan dient land- en watergebruik in de discussie expliciet te worden betrokken. Biologische katoenteelt op geërodeerde, verzilte en met gewasbeschermingsmiddelen vervuilde gronden dient niet overwogen te worden. De introductie van biologische katoenteelt in gebieden waar de gangbare teelt overheerst is niet aan te bevelen vanwege de daar veelal hoge druk aan plaaginsecten.

Aanbevelingen

- Een analyse is nodig van de karakteristieke uitgangspunten en doelen van ieder van de teeltsystemen en hoe deze in de praktijk gebracht worden. Er is behoefte aan de beschrijving en definitie van een optimaal, maximaal duurzaam gangbaar en IPM katoenteeltsysteem voor zowel niet- als wel-geïrrigeerde gebieden. Certificering van zo'n systeem en de ontwikkeling van een label voor producten is nodig.
- Kennis over de praktijk van katoenproductie is de basis voor aanbevelingen. In relatie tot de omvang van de katoenteelt is verrassend weinig bekend over de milieu-effecten van verschillende katoensystemen en daarom is meer veldwerk in zowel meer als minder ontwikkelde landen dringend noodzakelijk. Dit zou kunnen leiden tot een uitgebreide levenscyclusanalyse van verschillende teeltmethoden van katoen in diverse landen met gebruik van de milieu-indicatoren watergebruik, milieu- en humane toxiciteit, 'global warming', eutrofiëring, verzuring, erosie, landgebruik, biodiversiteit en verzilting. Het effect op het milieu van katoenproductie dient te worden vergeleken met de productie van andere vezels zoals polyester, viscose, linnen en hennep (een deelstudie hierover werd recentelijk verricht door Cherrett et al., 2005).
- Onderzoek is nodig over hoe de diverse belangenbehartigers in de katoenketen de katoenteeltmethoden beïnvloeden.
- Indicatoren voor water- en landgebruik dienen te worden ontwikkeld voor gebruik in levenscyclusanalyses. Dit dient ook te worden meegenomen in de standaarden voor biologische katoenteelt.
- De sociale, milieu- en handelsgerelateerde aspecten in de katoenketen dienen integraal meegenomen te worden in overwegingen over de duurzaamheid van katoenproductie.
- Biologische certificering door een IOAS-geaccrediteerde organisatie verzekert een basaal niveau van sociale rechtvaardigheid in de katoenteelt. Certificering van katoen met inbegrip van sociale rechtvaardigheid verderop in de katoenketen dient te worden gedaan door 'Fair Trade Labelling Organisation International' (voor kleine producenten) of 'Social Accountability International' (voor grote producenten).
- Naast de katoenproductie dient de gehele katoenketen te worden gecertificeerd. De kosten hiervan en de traceerbaarheid van gecertificeerde katoen verdienen met name aandacht.
- Controle- en certificeringsorganisaties zouden moet onderzoeken hoe beter samengewerkt kan worden op het gebied van duurzaamheid van milieu, sociaal en handel.

1 Introduction

Cotton is cropped over large areas in many subtropical and tropical countries: approximately 31 million hectares (2.4% of the arable land) (ICAC, 2005) is cultivated with cotton. Cotton production involves about 20 million farmers who completely depend on cotton production and another 30 million farmers who include cotton into their rotation scheme. Cotton fibre makes up roughly 50% of world fibre consumption. Cotton fibre consumption is steadily increasing and a shortage of 15% has been predicted for 2010 (Acordis in Scheffer, 2005). Increasing attention is being given to the environmental impact of cotton production. As will be outlined in the subsequent chapters, many cotton production systems face majors problems related to salinisation, desertification and poisoning of the environment, including ill effects to human health. The Aral Sea area is the most impressive example of this (cf. Chapter 2; Reganold et al., 2001; Opp, 2005). Cotton is primarily a non-food crop, which lessens constraints on pesticide use as compared to those imposed on food crops. In many countries where cotton is cropped, pesticide use is poorly regulated or not monitored.

The lack of discussion as to the desirability of more sustainable cotton cultivation systems may well be a reflection of insufficient research and reflection as to the degree of (un)sustainability of the systems currently in place. In addition, lower environmental impact of Integrated Pest Management (IPM) and organic systems is usually assumed. As such the goals of this project were:

1. to summarise literature that compares conventional, IPM, and organic cotton production systems in terms of environmental impact;
2. to select indicators, based on literature resources, which can be used to formally compare the environmental impact of conventional, IPM, and organic cotton production systems and to carry out comparisons based on these indicators;
3. to suggest starting points for discussion on the social aspects relevant for trade in sustainable cotton.

Chapter 2 is a general introduction as to cotton cultivation with an emphasis on factors that may be predominant in affecting sustainability: irrigation, fertilisers, pests and diseases, pesticides, and genetic modification (Chapter 2.3). In chapter 3, the major types of cotton cultivation systems are introduced, conventional, organic, and IPM, and a description of these systems within the major cotton-producing countries is presented. In chapter 4, environmental problems related to cotton cultivation are discussed using ten potential indicators. Their potential to define the sustainability of cotton cultivation is discussed. Chapter 5 deals with social and trade issues related to the cotton production chain. Finally chapter 6 presents a general discussion, conclusions and recommendations.

2 Cotton

2.1 The cotton plant

The cotton plant includes 40 species in the genus *Gossypium* (family Malvaceae), and is native to tropical and subtropical regions. The seeds are contained in a boll and the fibres on the seed constitute cotton lint. Species of cotton used for commercial purposes are *G. hirsutum* ('Upland cotton', native to Central America, the Caribbean and South Florida), *G. arboreum* ('Tree cotton', South Asia), *G. herbaceum* ('Levant cotton', South Africa), and *G. barbadense* ('Creole cotton' or 'Sea island cotton', South America). The naturally occurring colours of cotton lint are white, brown, and green. However, many coloured varieties have been banned due to fears of genetic contamination of the white cotton (UNCTAD, 2005). Genetically modified cotton varieties were developed to reduce insecticide and herbicide use and are now being introduced widely (ICAC, 2005).

2.2 Global cotton production overview

Cotton is produced in more than 100 countries, with 78% of all cotton produced in 6 countries. China is the main producer with 6.3 Mt of raw cotton, representing 24% of the world's total production, followed by the US, (5.1 Mt, 19%), India (4.1 Mt, 16%), Pakistan (2.5 Mt), Brazil (1.2 Mt) and Uzbekistan (1.1 Mt) (ICAC, 2005) (Table 1). Cotton production per unit surface area varies considerably from below 429 kg per hectare for India and West Africa up to 1760 kg per hectare for Australia (Table 1).

Table 1. Selected statistics on cotton production for the major cotton producing countries (ICAC, season 2004/05).

	Average production (kg ha^{-1})	Hectares cropped to cotton ($x10^3$)	Cotton production (Mtonnes)	% of world production
China	1100	5650	6.3	24
USA	960	5284	5.1	19
India	429	9500	4.1	16
Pakistan	780	3200	2.5	10
Brazil	1150	1020	1.2	4.5
Uzbekistan[1]	1300	846	1.1	4.2
West Africa[2]	450	2400	1.0	3.8
Turkey	1300	700	0.9	3.4
Greece	1030	375	0.39	1.5
Australia	1760	198	0.35	1.3
Syria	1400	230	0.34	1.3
Egypt	940	300	0.28	1.1
Total		29703	23.6	90
World production		31000	26.2[2]	100

[1] Source: FAS (2005).

[2] Mali, Burkina Faso, Niger, Nigeria, Ivory Coast, Togo, Ghana, Benin, Chad, Cameroon.

World cotton production over the past three decades has been subject to varying trends. In particular the land area cropped to cotton is fairly variable (Figures 1 and 4). However, world cotton production (Figure 2) and cotton yield per unit area (Figure 3) are steadily increasing. This is likely due to the development of high-yielding cotton cultivars, especially cotton hybrids. Locally, the production per unit area shows significant changes. Since 1960 and compared to

2001, the area dropped by 7.4% in the former USSR as well as in Sudan (69%), Brazil (50%) and Mexico (90%). On the other hand, production in Pakistan increased by 27%, Paraguay by 54% and Iran by 25%. During this period, yields rose on average by 28%, and in India yields in some areas rose by 74% (ICAC, 2002). The general trend has been decreased production in Latin American countries and Africa (except Egypt), and an increase in Asian production, mainly due to a change in labour costs (ICAC, Cotton statistics 2002).

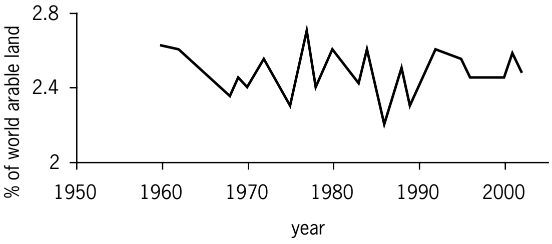

Figure 1. World cotton area expressed as percentage of the world arable land (1950-2004) (ICAC, 2003).

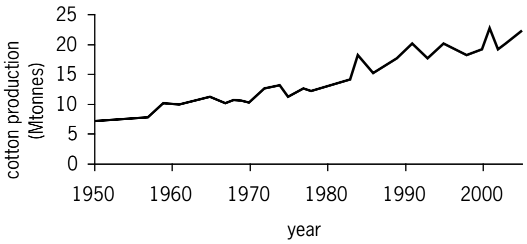

Figure 2. World cotton production (1950-2004) (ICAC, 2003).

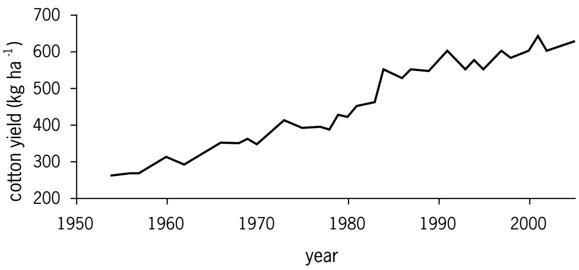

Figure 3. World cotton yield (1950-2004) (ICAC, 2003).

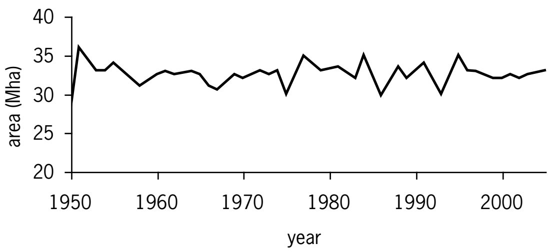

Figure 4. The world cotton area (Mha; 1950-2004) (ICAC, 2003).

2.3 Cotton cultivation

Cotton is considered to be quite a difficult crop to grow because it is sensitive to drought, low temperatures and attacks by various insects.

Plant spacing normally varies between 50/100 x 30/50 cm. Germination is optimum at temperatures between 18-30°C, with minimum and maximum temperature 14°C and 40°C respectively. For early vegetative growth temperatures must be higher than 20°C, optimally 30°C. Proper bud formation and flowering requires daytime temperatures between 20-40°C and night time temperatures between 12-27°C. Optimum temperatures for maturation and boll development are 27-32(-38)°C. Cotton is a short-day plant although a few day-neutral varieties exist. Flowering is influenced by a combination of day length and temperature. Determined by climate and variety, 50-85 days from planting to first bud formation are required, 25-30 days for flower formation and 50-60 days from flower opening to mature boll. Both vegetative growth and boll formation continues during flowering (Figure 5) (UNCTAD, 2005).

Depending on climate and length of the total growing period, cotton needs 500-1300 mm of water. During the early vegetative period, water requirements are low, about 10% of the total needs, and during flowering the water requirements are at maximum (50-60% of the total needs) (UNCTAD, 2005).

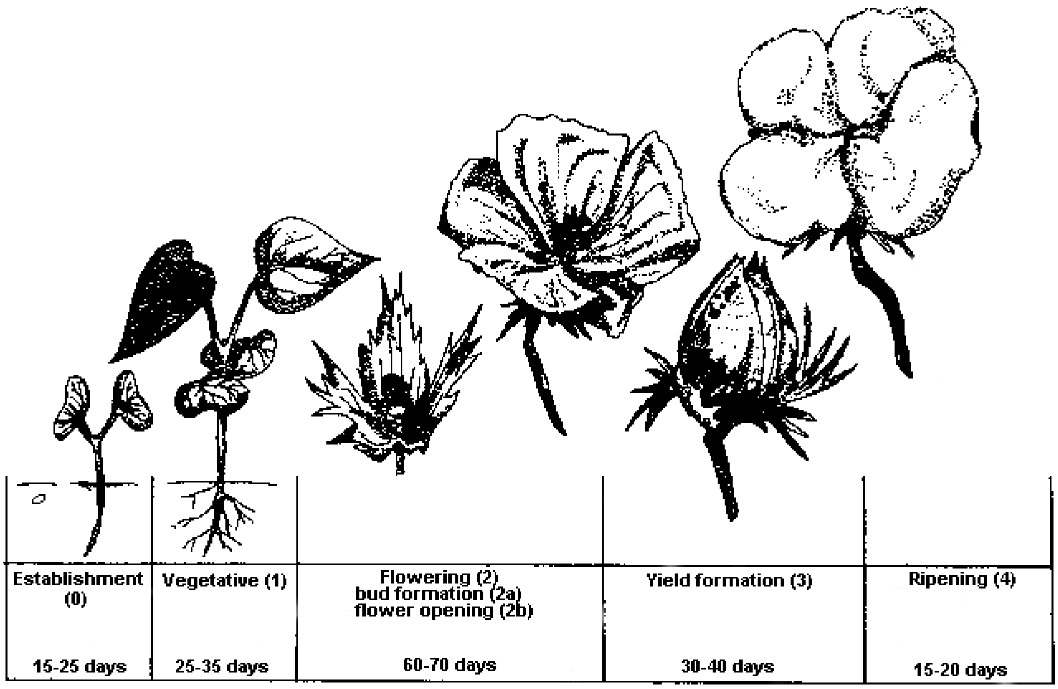

Figure 5. The developmental stages of the cotton plant (taken from Walker in FAO-AGLW, 2005).

Cotton is extensively grown under rain-fed conditions. Heavy rainfall can cause lodging although the crop is relatively resistant to short periods of water logging. Continuous rain during flowering and boll opening will impair pollination, reduce fibre quality, and provoke boll rot, which is caused by plant pathogens. Flower buds and young bolls can fall due to heavy rainfall and cold winds during flowering and maturation.

Cotton is grown on a wide range of soils but medium and heavy textured, deep soils with good water holding capacity are preferred. Acid or dense sub-soils limit root penetration. The pH range is 5.5-8.0 with 7.0-8.0 regarded as optimum. The nutrient requirements of cotton under irrigation are 100-180 kg per hectare N, 20-60 kg per hectare P and 50-80 kg per hectare K. Two-thirds of the nutrients are taken up during the first 60 days of the growing period (Peel, 1998).

High-technological cotton production (large fields, use of machinery, sometimes precision farming etc.) typically occurs in the US and Australia while low-technological farming (small fields, often less than 1 hectare with nearly all practises done by hand and animal traction) occurs in large areas of China, Africa, and India. The Aral sea area of Central Asia (Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan) has intensive cotton production, but there is large environmental impact due to high pesticide use and water use through inefficient irrigation systems.

Often cotton is cultivated in rotation with other crops so as to maintain soil fertility and structure, reduce erosion and to manage soilborne plant pathogenic fungi and nematodes. However, as cotton crops bring in significantly more income than other crops, it can be tempting for the farmer to reduce narrow rotations or eliminate them altogether. This may lead to increased pressure from soilborne pathogens and, consequently result in the intensive use of soil fumigants. Rotation also serves to spread the workload, reduce losses due to unfavourable weather conditions, and reduce large income variation. On the other hand, with an increasingly wide rotation, the complexity of farming increases because the farmer must be able to grow a variety of crops. Additional planning and management skills are required (Peel, 1998).

2.3.1 Irrigation

Cotton requires large amounts of water both for cultivation and processing. Irrigated cotton cultivation requires 550-950 l per square meter with an average production of 1600 kg raw cotton per hectare or 550 kg lint cotton per hectare. Otherwise stated, to produce 1 kg of cotton lint, 10,000-17,000 litres of water are needed. In areas where the normal precipitation quantity or pattern does not match the requirements of a cultivated crop, irrigation is applied. For this, rivers must be diverted, dams constructed, or soil water pumped up. Irrigation systems differ considerably in terms of efficiency, reliability and price. Irrigation is applied to 53% of the world's cotton fields, generating 73% of the world's cotton production because irrigated cotton on average results in higher yields per unit of area (Hearn in Soth, 1999). It has been estimated that cotton cultivation accounts for 1-6% of world's total freshwater withdrawal (Soth, 1999). The major irrigation systems in use for cotton cultivation are described below:

- *Flood-or-furrow irrigation.* This is the most common type of irrigation. In this system, water is directed from a river or from deeper soil layers to the cotton field that is to be flooded. When the cotton plants are planted on ridges the system is referred to as furrow irrigation. It is a cheap and simple technique with the main investment being for pumps and the levelling of the fields. For Australia, fixed costs (investment, levelling) were estimated at 24 US$ per hectare per year and variable costs (handling, electricity) at 26 US$ per hectare per year (Bryant et al., 2004). The flood-or-furrow system is applied on approximately 95% of irrigated cotton fields in India, Uzbekistan, Australia, Mexico, the Yellow River region of China and the United States both on large and small scale farms. Supply driven water distribution exists, for example, in Pakistan, India, Uzbekistan and Egypt (Gleick, 1993) amongst others and results in a loss of between 50 and 80% of the freshwater used (Shiklomanov, 1996, in Soth, 1999). The water efficiency (water that reaches the plant / water at source x 100%) of the flood-or-furrow system is approximately 40%, due to evaporation, seepage losses and mismanagement (Gleick, 1993), although water efficiencies as low as 20-50% have also been reported (Shiklomanov, 1996). Elements of mismanagement include: allowing (much) more water than the plants require which leads to runoff; unworkable distances between the water source and application, and leaking irrigation canals (Gilham et al., 1995; Kirda et al., 1999; Reller, 1997). An important factor related to the inherent low water efficiency of the flood-or-furrow system is that it is difficult to fine-tune the irrigation system to the needs of the crop.
- *Mobile irrigation system.* An overhead mobile irrigation system is usually made of aluminium piping with attached wheels that allow the system to be moved. This option has the ability to irrigate a very large area. Currently it is applied to only 2% of world's cotton areas (ICAC, 2005). The mobile irrigation system is mostly used in the US and Australia. Trees in and near the fields must be cut in order to use this irrigation system. The average water efficiency is high: 80-90% (TWDB, 2003). It is a capital-intensive irrigation system with fixed and variable costs of about 122 US$ and 49 US$ per hectare respectively. For countries where labour is expensive it can be an attractive option.
- *Drip irrigation.* A branched polypropylene pipe system doses the amount of water required by the plant and places the water exactly at the plant's root. Drip irrigation is being applied on less than 1% of the cotton fields (Postel, 1999). The technique is relatively expensive. For example, in the USA the cost is roughly 200–600 US$ per hectare per year (Thompson & Enciso-Medina, 2002). Developments are however underway to reduce the costs of this system considerably (e.g. Polak, 2004). For example, there are currently a range of low cost drip systems on the market for small-holders e.g. in India (see e.g. www.cseindia.org/dte-supplement/water-index.htm). Drip irrigation can reduce the amount of water used by at least 16-30 % compared to the most efficient flood-or-furrow systems (Hodgson, 1990), and is likely much higher when compared to many poorly functioning flood-or-furrow systems. The average water efficiency of drip irrigation is 90-98%. (TWDB, 2003).

Furrow irrigation at small holder farm, Maharashtra, India. (Kooistra, 2004)

Due to the high number of inefficient flood-or-furrow irrigation systems globally, the average efficiency of irrigation systems is estimated to be 40%, meaning that 60% of all water used for irrigation does not reach the plant (Stockle, 2001).
The potential to substantially increase irrigated land area is limited. Gains from new capacity are expected to be largely offset by land losses due to water logging, salinisation, and exhaustion of water reserves. Currently the most prospective innovation is the implementation of efficient irrigation techniques (Stockle, 2001), but investment costs are usually lacking.
In addition to optimization of irrigation techniques, the water needs of the cotton crop should also be evaluated. According to recent studies, cotton can also be grown under controlled water stress (deficit irrigation) without severe negative impacts on yield and sometimes with quality improvements (Kirda et al., 1999). Plant breeding may further reduce the water needs of cotton.
The main rain-fed cotton areas are in India, Brazil and West Africa. Yields are often considerably lower than those of irrigated cotton. Dependency on rain is the main constraint.

Table 2. Dependence on irrigation facilities of some important cotton producing countries (Gilham, 1995, elaborated).

Country	Region	Rainfall during growing season (mm)	% of cotton area irrigated	Source of irrigation[1]
Egypt	South	0	100	–
	Central	<10	100	–
	North	<20	100	–
Uzbekistan		30-70	100	– –
Pakistan		100-200	100	–
Mexico		25-2000	84-95	–[2]
China	NW-Xinjiang	0-200	100	– –
	N-Yellow River	500-700	75-95	– –
	S-Yangtse River	700-1000	75-95	–
India	North	200-400	100	– –
	Central	800-1200	29-40	+
	South	400-1000	29-40	–[2]

[1] – – = severely threatened, – = threatened, + = largely sustainable.

[2] Pers. comm. Richard Holland, WWF.

Environmental impact

An estimated area as large as 10^8 (hundred million) hectares (representing 8% of the world's total arable land) is abandoned due to former use for intensive cultivation (especially cotton cultivation, although the share is not precisely known), soil salinisation being the main reason (FAO, 2002), despite the cotton plant's moderate resistance to salinity (Ashraf, 2002). Soil salinisation occurs when evapo-transpiration exceeds rainfall and is as such a threat for irrigated areas in particular. Irrigation water dissolves calcium carbonate and soluble salts in the soil. Since calcium carbonate is relatively insoluble, it accumulates in the topsoil leading to additional salt deposition (originally from the irrigation water) and water logging. Soil salinisation may also occur when the groundwater of land that sits near a sea is overused. In such cases seawater replaces the use of fresh water e.g. as has been reported in Israel (Postel, 1999) and Northern China (East Hebei Plain, Jin et al., 1999).

In the twelve leading cotton producing countries an estimated 12-36% of the area under cotton cultivation is affected to some degree by salinisation (Stockle, 2001). In Uzbekistan 44% of the land is now unproductive due to salinisation (Opp, 2005). Current estimates for salinisation-affected cotton areas are as follows: for India 27-60% of the irrigated land, for Pakistan 14%, Israel 13%, Australia 20%, China 15%, Irac 50%, and Egypt 30% (Stockle, 2001). The areas facing major irrigation problems are listed in Table 2. One-third of irrigated land is affected by salinity or is expected to become affected by salinity in the near future. This share will quite likely be higher for cotton since it tends to be cultivated in more sensitive regions (Droogers et al., 2001).

Usually a soil is considered to be saline at EC < 4 dS m^{-1} (EC = electrical conductance, for soils usually expressed in deci-Siemens per metre (1 dS = 0.1 S), where 1 Siemens = 1 kg^{-1} m^{-2} s^3 A^2 = 1 Ω^{-1}). At this level, germination of cotton seed is hampered and yields are reduced. At EC 12 dS m^{-1} yield is reduced by 25% and at EC 16 dS m^{-1} the yield reduction is 50%. Although cotton is relatively salt tolerant, an example of a shift from cotton to other (even more salt tolerable) crops like wheat can be found in the salinised regions of Pakistan and Northern India (CAZS, 2005). Saline-tolerant cotton plants that could be cultivated on moderately salinised soils either through classical breeding techniques or by genetic modification are under development (Ashraf, 2002; Ganesan & Jayabalan, 2004).

Apart from the direct effects of unsustainable water use on soil productivity there are additional significant side-effects. For large-scale irrigation projects, rivers are diverted and dammed, resulting in significant downstream effects, namely water shortages with significant effects on wildlife and water availability for human consumption. Surface water levels may drop as a result of overuse, a notable example being the Aral Sea area. A consequence of the overuse in the Aral Sea area was the concentration of pollutants in the water. The Aral Sea area has been the main cotton provider for the USSR since 1938, a situation that lead to significant ill effects, including: a 75% drop sea area (200,000 km^2 in 1920, 50,000 km^2 in 2005), a 92% drop in fish species (1500 to 120 fish species), and an 88% drop in plant species (1800 to 200). In 1920, 60,000 fishermen were active, whereas today the fishing industry has completely collapsed (Reganold et al., 2001; Calder and Lee, 1995). Water shortages downstream of dam projects is very common. This is true for the Nile (Egypt), Ganges (India), Yellow River (China), the Colorado River (USA), and to a lesser extent the Rio Grande (USA) where very little or no fresh water reaches its final destination for significant stretches of time (Barlow, 2003; Postel, 1999). In these areas, an estimated 20% (Egypt), 30% (India), 40% (China), 25% (Colorado River USA) and 10% (Rio Grande, USA) of irrigated land is used for cotton production (Postel, 1999).

The use of groundwater for irrigation projects can be considered unsustainable if more water is used than that provided by rainfall. In the case of isolated aquifers, groundwater can be regarded as a non-renewable resource. For example, the depletion of the High Plains Ogallala aquifer stretching 1300 km from the Texas to South Dakota (USA), is estimated to be 8 times faster than nature is replenishing it and in the San Joaquin Valley (California, USA), the groundwater table has decreased by 10 m within 50 years mainly due to agricultural use (Postel, 1999). In the latter case, however, a relatively small portion of irrigation water is allocated to cotton cultivation. Other examples of water table depletion as a result of agricultural water use prevails in the literature e.g. for other Chinese regions (Bejing), and large parts of Australia (New South Wales).

Factors determining the environmental impact of irrigation are the vulnerability of the source (i.e. is depletion higher than the replenishment), the quality and quantity of the water being used, likelihood of salinisation, and efficiency of use.

Water use can be reduced by introducing more sustainable irrigation techniques, by breeding

An example of mixed cropping: strip cropping of cotton and pigeon-pea, Andhra Pradesh, India. (Kooistra, 2004)

for cultivars with increased water use efficiency (e.g. Stiller, 2005) and, as mentioned above, increased tolerance to salinity. Shifting from flood-or-furrow irrigation to drip irrigation would significantly increase water efficiency for use in cotton production. These systems could be combined with 'irrigation-on-demand', using GPS-based techniques (Sun & Peng, 2003). However, due to the high investment costs required, these high-tech developments are not expected to be implemented in many cotton producing countries in the near future (Raine et al., 2000) unless subsidies are provided (Luqueta et al., 2005). However, even furrow irrigation can be optimised through the use of conservation techniques, for example mulches (Jin et al., 1999).

2.3.2 Fertilisers

Common synthetic fertilisers used for cotton are typically combinations of nitrogen (N - usually in the form of ammonium or nitrate), Phosphorus (P), and Potassium (K). Airborne N_2 is the source of ammonium and nitrate, and phosphorus and potassium are mined. Much of the world's phosphate rock originates in the US, China, and Russia's Kola Peninsula. Smaller deposits are found throughout North Africa and in the oceans (e.g. near the coast of South Africa). Phosphate present in guano plays a minor role in terms of worldwide supply. Nonetheless, the Nauru-island deposit produces annually 2 Mt, and is important to local users in Australia and New Zealand. Potassium (K_20) is produced in the few countries where the economic ore reserves are located: Canada and the former Soviet Union alone account for 55-60% (IFA, 2002).

Livestock manure is the key nitrogen (N) fertiliser for organic farming. In addition, legumes cropped in mixture or in rotation with cotton contribute to soil N-fertility and serve in many cases as feed for animals. Manure and legumes both are options for maintaining plant nutrition in subsistence farming for which synthetic fertilisers are too expensive. Over the past several decades, widespread availability of synthetic nitrogen fertiliser in many nations has resulted in a major decrease in legume cultivation. Manure is applied to the field in either a raw (fresh or dried) or composted state. Apart from supplying nutrients to the crop, it contributes to soil organic matter, which in turn stimulates soil biological processes, soil structure, root penetrability and water retention. The quantity of nitrogen biologically fixed by legumes can be up to several hundreds of kilograms per hectare (e.g. soy-bean) (Power, 1987).

Environmental impact

To determine the effectiveness on crop growth and the environmental impact of fertiliser use, the most important factors to consider are: rainfall patterns, types and levels of fertiliser used, and timing of fertiliser application.

Organic fertilisers include animal manure, green manure crops (usually legumes) and compost. Apart from nourishing the crop, the goal of these organic fertilisers is to maintain organic matter

content in the soil (Hansen et al., 2001). A disadvantage of using animal manure as a primary source of nitrogen is that organic nitrogen must first decompose microbially to ammonium and nitrate before it can be taken up by plants. Therefore, losses may happen via volatilisation (in the case of ammonia) or leaching to deeper soil layers (for nitrates) if the supply of mineralised nitrogen is not synchronised with crop demands (Kirchmann et al., 1998). By contrast, synthetic fertiliser can be taken up instantaneously by a plant and if an amount is applied according to the plant's needs, virtually no fertiliser will be lost to the environment. Nitrogen losses associated with the use of organic sources must be balanced against the positive effect of carbon additions to the soil that maintain or increase organic matter in the soil and against the negative effects of synthetic nitrogen fertiliser (see below). Additional carbon storage in the soil may also increase the nitrogen storage (Poudel et al., 2001).
Phipps & Crosson (1986) and Nielsen & Lee (1987) (cited in Uri, 1998) estimate that 50-70% of nitrogen and phosphorus found in surface or groundwater originate from fertiliser applications. Nitrate moves with water and leaches easily to surface and groundwater. Phosphorus binds to sediment and contributes to eutrophication if soil is eroded (McDowell & Sharpley, 2004; Smith et al., 1987). Eutrophication can have a devastating effect on aquatic ecosystems leading to, for example, algae growth, depletion of oxygen and a decline in aquatic plants and animals (Uri, 1998; Spalding & Exner, 1993).
For the production of nitrate and ammonium much energy is needed, which contributes to global warming (see Chapter 4). Mining phosphorus and potassium may cause environmental impacts including changes in the landscape, water contamination, excessive water consumption and air pollution. The impact on a single farm is, however, negligible and therefore not generally taken into account when estimating the environmental impact of farming systems (Higgins, 2001).
Crews & Peoples (2004) concluded that the environmental impact of nutrient loss related to fertiliser type (organic versus synthetic manure) is marginal especially when best management practises are compared. The energy base for N_2 fixation in legumes versus the energy consumed for synthetic fertilisers is arguably the greatest factor differentiating the two systems (Crews & Peoples, 2004), giving organic manure a slight advantage over synthetic.

2.3.3 Pests and diseases

Worldwide 15% of cotton yield loss is due to insect damage. The economically most important insect pests include: *Pectinophora gossypiella* (pink bollworm), *Anthonomus grandis* (boll weevil = bollworm), *Earias insulana* (egyptian bollworm), *Diparopsis castanea* (red bollworm), and *Bemisia gossypiella* (white fly), all of which have very wide distribution. Among the nematodes, *Meloidogyne incognita* (root-knot nematode) and *Rotylenchulus reniformis* (reniform nematode) are considered to be the most important (Watkins, 1981).
In general fungal, viral and bacterial plant pathogens as well as nematodes are of lesser importance in cotton cultivation than insects. In areas without a cold period between cotton seasons in particular, fungal and bacterial pathogens can be an important source of production loss. The most important bacterial pathogen is *Xanthomonas malvacearum* (= X. *campestris* pv. *malvacearum*), the causal agent of bacterial blight. A wide range of fungal plant pathogens are described in Watkins (1981). Important pathogens include: *Fusarium oxysporum* f.sp. *gossypii* (syn. f.sp. *vasinfectum*) and *Verticillium dahliae*, both causal agents of vascular wilting of the plant. *Phymatotrichum omnivorum*, *Thielaviopsis basicola*, *Sclerotium rolfsii*, and *Macrophomina phaseolina*, are all causal agents of root rot. Leaf spots can be caused by a wide array of fungi and bacteria. The same is true for boll rot: it can be caused by at least eight true pathogens and various saprophytic fungi can be associated with the rate of boll rotting (Watkins, 1981).
Before the development of synthetic pesticides, pests were managed by cultural practices such as crop rotation, mixed cropping systems and manipulating planting densities. Also, smaller fields tend to exhibit reduced impact of pest organisms. Nonetheless, losses have been considerable. Since the 1950s, pesticides have been used as an efficient solution for addressing most pest problems (TMC, 2003).

2.3.4 Pesticides

In conventional and IPM systems (for definitions of these systems, see Chapter 3), pesticides are applied mainly to control insects and to fumigate soil in order to control soilborne plant pathogens. By using herbicides, weeds are controlled before sowing (or, in the case of glyphosate-resistant GM-cotton, after seedling appearance), and when harvesting is done mechanically, cotton plants

Unprotected field spraying of pesticides inflicts great risks to the farm. (Kooistra, 2004)

are defoliated prior to harvest. As different pesticide application techniques strongly influence environmental impact, human exposure in particular, a short overview of the various techniques used is presented below.

- *Aerial spraying*. An estimated 13% of cotton growing areas are sprayed via airplanes (ICAC, 2005), resulting in fast but often inaccurate application and considerable risk in terms of pesticide drift. Cases of contamination of neighbouring villages have been reported for cotton production in California (Scarborough et al., 1989), worker contamination in Uzbekistan (IATP, 2002) and water, crop, and cattle contamination in Colombia (CIP, 2005).
- *Tractor spraying*. Approximately 35% of the cotton growing areas are sprayed using tractors (ICAC, 2005). Tanks containing pesticides are attached to the back of the tractor and beams are used to cover as wide a range as possible.
- *Field spraying*. Hand pumps and power sprayers are applied in 35% and 17% of cotton fields respectively (ICAC, 2005). It is cheap and effective, but poisoning of the workers who apply the pesticides is common in developing countries (Friedrich, 2001; Mancini et al., 2005). A power sprayer has a wider range, so a field is sprayed more quickly with a power sprayer than with a hand pump. In both cases the field worker sprays the area ahead of him/her and then walks through the freshly sprayed plants. A gas mask for protection against the pesticide sprayed is indispensable for worker health, although they are still very often not used in developing countries.

Bos et al. (2005) made the following recommendations for conducting "Good Practice for the Application of Pesticides":

- spraying of pesticides must be carried out by trained personnel. This should be proven by certificates or be made credible in other ways;
- spraying should be carried out with the appropriate, calibrated and well-maintained equipment;
- only (nationally or regionally) approved and correctly labelled pesticides should be used;
- labels should be retained for use in the case of accidents;
- health of the operators should be monitored by keeping health records and ensuring regular medical checkups;
- pesticides should be stored and transported in their original transport containers and packages and out of reach of people, particularly children, and domestic animals;
- spillage incidents must be accurately recorded and appropriate authorities must be notified of larger spills;

- an action plan should be in place to combat larger spills, including access to first aid equipment in the case of personal contamination and poisoning;
- during spraying, operators should use sufficient protective clothing. This should at least include impenetrable boots, impenetrable gloves, overalls, face or mouth masks, hats and eye and face protection. These garments should not be worn during other occasions or be used for other purposes;
- similar protective clothing should be worn when handling the pesticides pre-treatment (diluting, pouring into the spraying equipment) and post-treatment (rinsing, disposal);
- there should be a system with which all relevant information of pesticide treatments is recorded and archived. This should at least include the place and date of the treatment, the amount and type of pesticide used, the location and surface of the sprayed area, the names of the operators, and the equipment used;
- operators should carefully wash themselves after spraying, particularly exposed body parts, and certainly before eating, drinking, smoking or going to the toilet;
- empty containers and packages should be rinsed and/or cleaned thoroughly and be made unsuitable for second-hand use;
- washing of the containers, packages and equipment should take place at special cleaning stations where contamination of soil, surface and drinking water is avoided;
- contaminated containers, packages and clothing should be disposed of in the appropriate ways according to (national) legislation;
- spraying equipment should be stored dry, empty and out of reach of people, particularly children, and domestic animals.

The uptake of the above-mentioned practices requires the basic conditions of farmers in developing countries to be improved with regard to literacy, information and access to credit (other than from seed/chemical companies).
The selection of pesticide type and quantity depends on location and type of cultivation. In subsistence farming, often no pesticides are used due to lack of capital or because they are simply not available. Although not officially certified, such farms could be considered as *de facto* organic. On small holder cotton farms however, highly toxic pesticides are often still used, including pesticides classified by the World Health Organisation (WHO) as highly or extremely hazardous (Table 3). Thus, monocroptophos and methamidophos, both classed by the WHO as ‘highly hazardous’, still constitute 9% and 6% of the cotton insecticide market (Table 3). In addition, various pesticides classed as ‘extremely hazardous’ are still in use though information is not available as to the volumes (Table 3). India is an example of a country (amongst others) where some of these pesticides, such as parathion, while no longer officially permitted, due to poor monitoring and verification systems, continue to be in use. In Kyrgyzstan, banned pesticides are smuggled into the country (Hadjamberdiev & Begaliev, 2004). Many older, non-patented, toxic, environmentally persistent and inexpensive chemicals are used extensively in developing nations, creating serious acute health problems and local and global environmental contamination (Ecobichon, 2001; Wesseling et al., 2005). The quantity of these illegal pesticides is very difficult to estimate. In more developed countries, pesticides are regulated and hazardous insecticides are not allowed.
The cultivation of cotton has been estimated to consume 11% of the world’s pesticides while it is grown on just 2.4% of the world’s arable land. For insecticides alone, this represents 25% of world consumption (FAOstat, 2000). In developing countries it is estimated that roughly 50% of all pesticides are applied in cotton cultivation (Caldas, 1997). In addition, pesticide use and storage are often badly managed. In India two pieces of out-of-date legislation regulate pesticide use: the Insecticide Act (IA), which was passed in 1968, and Insecticide Rules (IR), passed in 1971. Toxicological data are required in order to apply for registration of pesticides, however, they are still registered without taking into full account the acceptable daily exposure and maximum residue levels. In addition, the fact that cotton is often regarded as a cash crop means that farmers may be more willing to increase their yields even given the environmental costs (CIBRC, 2005).

Table 3. Major pesticides used to control insect pests in cotton according to Allan Woodburn Associates (1995).*

Chemical name (trade name)	Chemical group[1]	WHO toxicity class [2]	% Global cotton insecticide market[3]
deltamethrin (Decis)	p	II	12
lamda cyhalothrin (Karate)	p	II	9
monocrotophos (Azodrin)	o	Ib	9
alpha-cypermethrin (Fastac)	p	II	8
chlorpyriphos (Dursban, Lorsban)	o	II	7
esfenvalerate (Sumi-alpha)	p	II	7
methamidophos (Tamaron B)	o	Ib	6
dimethoate (Rogor; Perfekthion)	o	II	5
thriazofos	o	Ib	n.k.[4]
demeton-S-methyl		Ib	n.k.
parathion	p	Ia	n.k.
parathion-methyl	p	Ia	n.k.
phosphamidon		Ia	n.k.

* No more recent data known by author.

[1] p = pyrethroids, o = organophosphate.

[2] Ia: extremely hazardous Ib: highly hazardous; II: moderately hazardous.

[3] The remaining 37% are smaller amounts of another 250 insecticides (Allan Woodburn Associates, 1995).

[4] n.k. = not known.

Until 1995, the organophosphate group, one of the most hazardous in terms of worker's risks, represented the majority of the insecticide market in cotton cultivation in many developing countries. A shift has taken place towards much less persistent and less toxic pyrethroids in recent years. Organophosphates include aliphatics (malathion, monocrotophos (Azodrin), oxydemetonmethyl (Meta Systox), dicrotophos (Bidrin), acephate (Orthene)), phenyl derivatives (parathion, methyl parathion, profenofos (Curacron), fenthion (Dasanit)), and heterocyclic derivatives (chlorpyrifos (Dursban, Lorsban, Lock-On), chlorpyrifos-methyl (Reldan)). While all are significantly toxic to vertebrates, most are not very persistent. The pesticides on this list are substitutes for the more persistent organochlorines. Due to their high toxicity, organophosphates are being banned in many countries. They affect the nervous system, which results in rapid twitching of voluntary muscles and finally paralysis. In the 1990s some organochlorines (e.g. endosulphan) were re-introduced in West-Africa as they became cheaply available and were seen as highly effective (Ajayi et al., 2002).
The pyrethroids include permethrin, introduced in 1972-1973 and are used because of their insecticidal activity (0.1 kg active ingredient per hectare) and photostability. The following trademarks are permethrin-based: Ambush, Astro, Dragnet, Flee, Pounce, Prelude, Talcord, and Torpedo. The current generation of pyrethroids has even higher effectiveness than their precedents (ranging from 0.01 to 0.06 kg active ingredient per hectare). These include bifenthrin (Capture, Talstar), lambda-cyhalothrin (Demand, Karate, Scimitar, Warrior), cypermethrin (Ammo, Barricade), deltamethrin (Decis), and zeta-cypermethrin (Mustang, Fury) (Ware et al., 2004). Pyrethroids have an effect resembling that of DDT. Pyrethroids affect both the peripheral and central nervous system of insects, stimulate nerve cells to produce repetitive discharges and eventually cause paralysis. Many of these compounds are also extremely toxic to fish. Pyrethrins and pyrethroids adsorb strongly to soil and volatilise from soil surfaces very slowly. These compounds are eventually degraded by microorganisms in the soil and water. They can also be degraded by sunlight at the surface of water, soil or plants. However, some of the more recently developed pyrethroids persist in the environment for a few months before they are degraded.
Herbicides are used to control weeds in the fields. The most important herbicides worldwide in cotton are listed in Table 4.

Table 4. Major herbicides used for cotton production in 1997 (USDA, 1998).

Active ingredient	Area applied[1] (%)	WHO tox. Class[2]	Applications (cultivation^{-1})	Dose (kg ha^{-1} yr^{-1})	Total applied (Mkg)
triazines					
cyanazine	18	Ib	1.3	1.1	1.0
prometryn	19	U	1.2	0.74	0.76
other herbicides					
trifluralin	55	U	1.1	0.85	2.5
MSMA	29	n.l.	1.4	1.46	2.2
fluometuron	44	U	1.3	0.94	2.2
pendimethalin	28	III	1.1	0.77	1.1
norflurazon	13	U	1.0	0.71	0.47
diuron	12	U	1.1	0.62	0.40
metolachlor	5	III	1.1	1.31	0.34
glyphosate	14	U	1.3	0.91	0.70
paraquat	n.k.	II	n.k.	n.k.	n.k.

[1] n.k.= not known.

[2] Ia: extremely hazardous Ib: highly hazardous; II: moderately hazardous, III = slightly hazardous, U = Unlikely to be hazardous, n.l. = not listed.

Overall, cyanazine (WHO toxicity class II, moderately hazardous) is the most toxic herbicide for human beings, and may be the most toxic of all herbicides found in drinking water (Eclipse Scientific Group, 2004) (Klotz-Ingram, 1999). Paraquat is also moderately toxic. For defoliation the main herbicides applied are: dimethipin (WHO toxicity class III - slightly hazardous), thidiazuron (WHO toxicity class U - unlikely to be hazardous), sodium chlorate (WHO toxicity class III), diuron and tribufos (WHO toxicity class not listed).

Insecticide sales are globally approx. 9.1 billion US$ in 2000 (EPA, 2002) and 23% of this is applied in cotton cultivation (Dinham, 2005). The agrochemical market is dominated by Bayer (20% of the world market for pesticides), Syngenta (17%), BASF (15%), DOW (14%), Monsanto (6%), and DuPont (6%) (EPA, 2002; Dinham, 2005). The use of pesticides will always lead to the exposure of non-target organisms and unwanted side-effects that occur in some species, communities or complete ecosystems (Van der Werf, 1996).

Pesticides arrive at non-target sites through various channels: by aerial drift, run-off, evaporation, seeping, leakage to groundwater, washing of pesticide spray equipment, and the use of pesticide packages or buckets (used for mixing pesticides) for other purposes. Pesticides are removed from the environment by chemical degradation or microbial decomposition (Papadopoulou-Mourkidou et al., 2004).

Usually the negative side-effects of pesticide use are not calculated as costs (Pimentel, 2005). Obsolete pesticide stocks in developing countries are another pressing problem (Schimpf, 2004). The most significant factors influencing the environmental impact of pesticides are pesticide toxicity, spraying method, frequency of use and quantity used per application.

The so-called 'pesticide treadmill' emerges when dependency on pesticides increases over time reaching levels that are both economically and technically unfeasible (Twigg et al., 2002; Nicholls & Altieri, 1997). The development of such dependency is more likely to occur for cash crops (where loss of income is significant if there is a poor harvest), non-food crops (since pesticide residues present on the product are not ingested by people), and when pest or disease organisms seriously jeopardise the harvest. The pesticide treadmill was recently summarised for a cotton system in Central America (ISU, 2004). Cotton production increased steadily in the region from 1945 onwards. The presence of the Boll Weevil made pesticide application necessary. The effectiveness of the pesticides to control the Boll Weevil decreased over time due to increased resistance of the insect (e.g. Kranthi et al., 2002) and the inactivation of natural predators, leading to 40 times the initial levels of pesticide application per season in the 1970s. Finally, cotton cultivation became uneconomical, leading to soils being left fallow due to pollution and erosion, and very high rates of unemployment and associated problems (ISU, 2004). Currently over 500 species of insects, 180 weeds and 150 fungi have developed resistance to the pesticides developed for their eradication (Lotus, 2004). Other examples of pesticide treadmills have been described in Peru by Smith & van den Bosch (1967) and in Sudan by Eveleens (1983).

Human Impact

The potential negative consequences of pesticide use for human health are now widely recognised, however statistics are still rare. It has been estimated that at the global level annually 40,000 lives are lost due to pesticide application (WHO, 2002), representing 10% of all casualties in the agricultural sector (ILO, 1997). Although higher numbers have been asserted (Gaag, 2000) it is difficult to make reliable estimates due to a general lack of data and the inability to separate pesticide exposure from other causes of disease.

In India, Mancini et al. (2005) followed the health of 50 cotton growers over the course of one year during which she reported 323 events, of which 207 (84%) were associated with symptoms of mild to severe pesticide poisoning, and 32 (10%) were associated with symptoms typical of poisoning by organophosphates (used in 47% of the pesticide applications). Although in 6% of the spray sessions the workers' neurotoxic effects were serious, none sought medical care (Mancini et al., 2005). Scarborough (1989) reported 60-100% higher incidence of various disease symptoms (fatigue, eye irritation, rhinitis, throat irritation, nausea, and diarrhoea) for humans living or working near sprayed cotton fields relative to the comparison group. Lotus (2003) reported that 91% of professional pesticide workers experienced some type of health disorder. In Egypt in the 1990s, more than 50% of cotton workers suffered symptoms of chronic pesticide poisoning, including neurological and vision disorders. Benin has suffered from severe Endosulphan poisonings since the 1990s (Tovignan et al., 2001).

In 1985, in Malaysia and Sri Lanka 7-15% of farmers reported experiencing pesticide poisoning at least once in their lifetimes. In Thailand, a survey of 250 government hospitals and health centres revealed that approximately 5500 people suffered pesticide poisoning, of whom 384 died. In the Philippines 50% of rice farmers have suffered from sickness due to pesticide exposure. In Latin America 10-30% of agricultural workers show inhibition of the blood enzyme, cholinesterase, which is an indication of organophosphate poisoning. In Venezuela, approximately 10,000 cases of pesticide poisoning with 576 deaths occurred between 1980 and 1990. In the state of Santa Catarina (Brazil), 28% of farmers say they have been poisoned at least once. Likewise, in Parana state approximately 7800 people were poisoned through pesticide application between 1982 and 1992. In the USA, a 1987 National Cancer Institute Study found a nearly 7-fold higher risk of leukaemia for children whose parents used pesticides in their homes or gardens (Lotus, 2004). In China, 42,800 new cases of pesticide poisoning were reported in 1994, including 3900 fatalities. Many were said to be victims of home-made cocktails marketed illegally (Gaag, 2000).

Multiple reports exist on the unwanted side-effects of pesticides on wildlife. Over-spraying, accidents and aerial spraying are the most significant events affecting the environment (Mkuula, 1993; Carvalho et al., 2003). Pesticides end up in aquatic organisms (Kumar et al., 2003; Muschal & Warne, 2003; Erdogrul et al., 2005) and have been shown to bioaccumulate (Zhang et al., 2005) into birds (Eason et al., 2002).

Impact on the environment

Pesticides applied in cotton production have also been documented as adversely affecting river ecosystems in Australia, leading to lower quantities and lessened diversity of water organisms (Hose et al., 2003). In 1995, pesticide-contaminated runoff from cotton fields in Alabama killed 240,000 fish (Lotus, 2004). It is estimated that pesticides unintentionally kill 67 million birds each year (Lotus, 2004). Tariq (2003) reported pesticide contamination of groundwater due to cotton cultivation in Pakistan and Shukla et al. (2005) and for Hyderabad in India. CSE (2003) reported pesticides in the main brands of cola and packaged drinking water in India. Broad-spectrum pesticides very likely have a negative impact on multiple non-target insects and other micro-organisms, but to precisely estimate the effects is arduous.

2.3.5 Defoliation

Defoliation is done in order to clear the cotton plant of leaves before it is mechanically stripped during the harvest. Chemical defoliation is quick and effective. Low temperatures and forced water deficit also serve as natural defoliants (Chaudry, 1996). Chemical defoliants are estimated to be applied on 15% of the world's cotton production (ICAC, 2005). Most commonly applied defoliants are carfentrazone (not listed (n.l.) in the WHO toxicity classification), pyraflufen ethyl (n.l.), dimethipin, sodium chlorate, thidiazuron, MSMA (WHO toxicity class III, see also Table 4) and diuron (U) (Vargas et al., 2005). The environmental impact of defoliants on the natural and human environment resembles the effect of pesticides described in more detail above.

2.3.6 Yields

Farms demonstrate clear yield differences per unit of area. It is currently not clear whether production in conventional systems is different from that of organic systems, one of the reasons being that there is also a large within-system variability. For that reason, in Chapter 4 on environmental impact of cotton production systems, we divide conventional, IPM and organic systems all in 'high input' and 'low input' systems (cf. Table 10). Recent sources indicate yields in organic systems equal those of conventional systems (rain-fed, India: personal communication Eyhorn, Maikaal project; rain-fed, Paraguay: personal communication Ecklin, Arazy project; rain-fed, India: personal communication Lanting, ETC; Meyer, 2005). Other sources indicate a 25% drop in yields in the second year after conversion to organic for a highly productive farm in California (Swezey et al., 2004). Recent findings suggest that low-input cotton cultivation systems can even have slightly higher production as compared to certain conventional production systems (India: personal communication Eyhorn, 2005; Arazy project, Paraguay; Ecklin, 2005). In Turkey, the first few years after conversion to organic production yields were halved but three years later yields returned to the previous (conventional) yields (Zeegers, 1993).

The interpretation of comparisons between different farmers or farming systems can be prone to errors. There have been few organic projects and these projects likely have received considerable external support (educational, financial) while perhaps the majority of conventional farmers have not.

2.3.7 Genetically modified cotton

One of the first plants to be modified genetically at a commercial scale was the cotton plant, mainly in an effort to reduce the quantity of pesticides used. A gene conferring resistance to glyphosate (an active ingredient in herbicides such as Roundup) was transferred into cotton for the first time in 1987. Monsanto introduced the Bt-cotton variety in 1989. The Bt-toxin-producing gene of *Bacillus thuringiensis* (Bt) was introduced into the plant's genome resulting in plant resistance against pests, notably the Bollworm. In 1996 Bt-cotton was first planted at a commercial scale in Australia and the USA. Since then, Bt and glyphosate-resistant cotton varieties have been planted in more than 20% of the area under cotton cultivation (IIED, 2004). 50% of the cotton cropped in Mexico and South Africa has been genetically modified, compared to 80% in the USA and 66% in China. Argentina, Australia, India, and Indonesia have also approved the commercial planting of genetically engineered cotton in recent years (UNCTAD, 2005).

Since its release, Genetically Modified (GM) cotton has been the topic of considerable discussion. It is however not the goal of this study to present an extensive overview of the GM debate. Here, we limit ourselves to a short overview. In general, IPM and conventional systems are adopting genetically modified cotton (Bt-cotton and glyphosate-resistant cotton) while organic standards and regulations do not permit genetic modification.

On the positive side genetically modified cotton is said to reduce pesticide use. Significant and high reduction in pesticide use for Bt-cotton was reported by Edge et al. (2001; review of 12 studies). Bt-cotton has also been widely reported as leading to increased cotton yields (e.g. Layton et al., 2003; Robinson & McCall, 2001). Higher revenues have also been noted (e.g. Morse et al. (2005) in South Africa; Pray et al. (2001) in China; Traxler et al. (2005) in Mexico). However, the explanation of this reduction in pesticide use is unclear. One explanation could be that the Bt insecticide in the plant itself is not acknowledged: since the genetically modified plant contains an insecticide, it is obvious that no insecticide needs to be applied to control the insects concerned. On the negative side, pests that are not sensitive to Bt have been observed, which was suggested by ICAC (2005) for regions in China where the occurrence of red spider mites and aphids were reported (see also Shelton, 2005). Other negative features of Bt-cotton

include that the farmer may have a higher economic risk due to the genetic homogeneity of the cotton, seed is more expensive, the farmer is more dependent on the seed producer, there is a possibility of outcrossing with wild relatives, environmental risks (the spread of GM genes to related wild species with unknown consequences), and the lack of clarity as to how the costs associated with expensive genetically modified crops will affect rural farming communities in developing countries (Altieri & Rosset, 1999).
The most recent data generally agree that effects of Bt-crops are minimal on both airborne and soilborne organisms. While Losey et al. (1999) reported that Bt-pollen negatively affected the larvae of the protected monarch butterfly, this work was criticised (e.g. Crawley, 1999) and the more widely held scientific opinion now is that the monarch butterfly will not be significantly affected by Bt-corn (Stanley-Horn et al., 2001). Pilcher et al. (2005) reported 29-60% lower densities of *Macrocentrus cingulum*, a parasitoid (bio-control agent) of the European corn borer, in Bt-corn compared to control corn. Sims and Ream (1997) estimated that a potential maximum of 1.6 µg Bt-toxin (CryIIA protein) per gram soil would be formed during the decomposition of residues of Bt-cotton. Saxena et al. (2002) reported that the Bt-toxin is quite persistent in soil. It was found that root exudates from Bt-maize releasing the Bt-toxin remained insecticidal for up to 180 days, but no effects were found on protozoa or the microbial community, and only very minor, but significant, effects on the nematode community (Saxena et al., 2002; Griffiths et al., 2005; and references in these publications). Given however the huge areas that are now and will be in the future planted with Bt crops, continued research on potential negative side-effects is still needed.
Glyphosate-resistant cotton may reduce the use of herbicides since it can be applied more efficiently and thus less frequently. However, in conventional, non-genetically modified systems in Canada, applications of herbicides are already low (Blackburn & Boutin, 2003) so no further reduction in herbicide applications is expected. Weeds that have developed glyphosate-resistance have been reported (Nandula et al., 2005) and this may increase the use of multiple herbicides. Lotz et al. (2000) concluded that the available literature does not indicate that cultivating glyphosate-resistant crops has major effects on the environment compared to conventional crops, though they also identified some important knowledge gaps.
IFOAM (cited from the website: www.ifoam.org, end of 2005) is opposed to genetic engineering in agriculture due to the 'unprecedented danger' it represents for the entire biosphere and the particular economic and environmental risks it poses for organic producers. IFOAM believes that genetic engineering in agriculture causes, or may cause:

- negative and irreversible environmental impacts;
- release of organisms which have never before existed in nature and which cannot be recalled;
- pollution of the gene-pool of cultivated crops, micro-organisms and animals;
- pollution of farm organisms;
- denial of free choice, both for farmers and consumers;
- violation of farmers' fundamental property rights and endangerment of their economic independence;
- practices which are incompatible with the principles of sustainable agriculture;
- unacceptable threats to human health.

The general argument for not permitting genetic modification in organic agriculture is that this technique is synthetic and thus not natural. However, the natural, non-synthetic biocontrol product *Bacillus thuringiensis* is allowed as a natural pesticide in organic agriculture (e.g. Zarb et al., 2005).

2.3.8 Clearing of forest/natural area

Land clearing has been done since the beginning of agriculture. If additional land is needed for agriculture this often results in deforestation, conversion of grasslands, or draining of wetlands. For some tropical areas slash-and-burn systems are still part of traditional agriculture. Deforestation is particularly unsustainable if the soil is not suitable for long-term annual farming, resulting in fast degradation (Roper & Roberts, 1999). The main land clearing regions are situated in the Amazon, Central America, China and Indonesia (Wright, 2005). The major consequences of deforestation are loss of biodiversity, soil erosion and contributions to the greenhouse effect (Costa & Foley, 2000; Gash & Nobre, 1997).
The majority of deforested areas used for agriculture are not directly used for cotton production. For example, in Brazil, where cotton is being introduced into rotations with soybean, this is

becoming a relevant issue as the soybean expansion is converting natural grasslands and tropical rainforest. In west and east Africa cotton is grown by livestock farmers who move their herds around and create shifting patterns of cultivation. Land clearing is however still relevant for cotton when the yield per unit area changes as a result of changing farm management practices. Examples where deforestation has been carried out specifically for increasing the cultivated area of cotton have been described by Benjaminsen (2002) and Moseley & Ikubolajeh Logan (2004) for Mali (Benjaminsen, 2002), by Grauel (1996) for Paraguay, by the FAO (1999) for China (FAO, 1999), by the USDA (2001) for Brazil, and INSAE (1999) for Benin. For example, Benin receives 80% of its export revenues from cotton and as a consequence forests are cut for other crops. In total in Benin 100,000 hectares of forest is cut annually (Insae, 1999) and currently approximately 2000 hectares is converted to cotton production.
On a local scale agricultural policies, especially subsidy systems, changes in credit systems and provision of certain guarantees, may affect the total agricultural area and/or the area cropped to cotton. This is especially of concern where cotton is regarded as an export crop as sudden significant changes in land use may lead to deforestation as occurred in the pesticide treadmill example described in Chapter 2.3.4. Another example is provided by Chipika & Kowero (2000) for Zimbabwe.

3 Types of cotton production

Cotton can be grown using a wide range of cultivation practises determined by climate, soil type, availability of inputs, and possibly most importantly, the knowledge and skills of the farmer. Globally, cotton production is done by a relatively small number of large, mechanised farmers (Australia, USA, Brazil) and a very large number of smallholders (China, South Asia, West Africa) (IIED, 2004). It is estimated that there are approximately 20 million cotton farmers worldwide (Gala, 2005).
Within all the different management systems a few distinguish themselves by having a robust certification system (organic production) or being a technique well-described by the FAO and research institutes (Integrated Pest Management - IPM). We regard ICM (Integrated Crop Management) synonymous with IPM. All management systems that are not IPM or organic are considered to be conventional. Fair Trade systems require IPM with a strong social paragraph (cf. Chapter 5).
These three main approaches to cotton production are described in the subsequent paragraphs and the specifics of these farming systems for the major cotton growing regions are presented.

3.1 Conventional systems

Conventional farming systems refer to all farming systems that are neither organic nor IPM. Usually farming practices are set either by legal restrictions or by the availability of capital. Conventional farming includes a wide range of farms since size, agrochemical inputs/outputs, energy efficiency, production efficiency and the related environmental impact differ enormously among farms. Roughly 80% of world's cotton is produced under conventional management (ICAC, 2005).
In developing countries, farms are usually small (less than 5 up to 20 hectares, rarely more). These farms tend to be family-run and are usually part of a mixed cropping system. This multi-purpose farm produces food for family consumption and animal feed, and generates an income for the family through the cultivation of cash crops like cotton. Currently food security among smallholders, especially in West Africa, is being affected by pressure to produce cotton, which seems to be replacing mixed cropping systems (Williamson, 2003).
Intermediate-sized farms are for the most part situated in developing countries, and are usually family–run. They grow more cash crops than the smaller farms.
Larger farms (mostly greater than 20 hectares and up to 1200 hectares) are situated mainly in the USA and Australia. Continuous cropping (i.e., without crop rotation) is the main cropping system and is designed to generate as high an income as possible for the owner. In Uzbekistan only a few very large farms can be found. The degree of mechanisation is high since areas are too large to be picked by hand and the wages are high and costs of mechanisation are relatively low (ICAC, 2005).

Table 5. Frequency distribution (%) of farm sizes in the major cotton producing countries.

Country	Farm size (ha)					Total surface[6] (Mha)	% World production[6]
	< 6	6-10	10-20	20-100	>100		
China	100	0	0	0	0	5.6	24
US[1]	0	0	0	10	90	5.3	19
India	87	8	3	2	0	9.5	16
Turkey[2]	50	19	32	0	0	0.7	3
Pakistan[3]	6	90	4	0	0	3.2	10
W-Africa	100	0	0	0	0	2.4	4
Uzbekistan[4]	10	0	40	50	0	0.8	4
Australia	0	0	0	0	100	0.2	1
Egypt[5]	90	5	5	0	0	0.3	1
Mexico	5	3	65	27	0	0.2	0.4
share of world production (%)	45	11	4	4	18	31	82.4

[1] USDA, 2005.

[2] Turkey Case Study: Aslantas Dam / Ceyhan River Basin (1983).

[3] Pakistan Census of Agriculture (1990).

[4] State Committee on Statistics (2004).

[5] ICAC, 2002.

[6] ICAC, 2005.

The data per country are mainly derived from the September 2005 ICAC survey of cotton cultivation practises. This survey was done by national panels mainly consisting of staff from ministries of agriculture with information centrally collected by the ICAC. Since the sources are diverse, the information provided is mainly indicative.

China (24% of world production, 5.6 Mha)
China is the largest cotton producing country in the world with about 14 million farmers directly involved in cotton production (IIED, 2004). From 1978 to 1984, China's cotton output increased steadily, reaching 6.3 Mt in 1984; after 1984, cotton output fluctuated between 3.8-5.7 Mt, and again reached 6.3 Mt in 2004/05. China has three major cotton growing regions, the Xinjiang Autonomous Region, the Yangtse River Basin Region (which includes principally Jiangsu and Hubei), and the Huang-Huai Region (principally Hebei, Henan, and Shandong). The farm types in each production area are quite similar. Since China joined the WTO in 2001, both opportunities and challenges have arisen in the agricultural sector. Low production costs in China are a key factor for successful competition in the international cotton market (ICAC, 2002).
Chinese cotton farms are generally smallholders (less than 6 hectares; see Table 5), cultivating cotton on a small segment of their farm. 90,000 farms cultivate cotton (ICAC, 2005) with an average production of 1100 kg per hectare, and a range from 150-1800 kg per hectare. Virtually all cotton farms are irrigated: 90% with flood-irrigation, 5% furrow, 3% drip, and 2% sprinkler irrigation. The water originates from soil (74%) and rivers (26%). Fertiliser use per farm averages 225-300 kg N per hectare, 50-150 kg P per hectare, and 100-220 kg K per hectare. Approximately 60% of the area under cultivation is on sandy loam, 10% sand, and 30% clay. Weeds and cotton stalks are burned after harvest. A common rotation cycle is done with wheat: one year wheat and one year cotton. To a lesser degree rotations with other crops such as onion, garlic and potatoes are applied. Mixed cropping is rare (but see Van der Werf, 1996).
Most commonly used pesticides are monocrotophos (Azodrin, Ib), cyfluthrin (Baythroid, II), dicofol, (III), trichlorfon (Dipterex, II), imidacloprid (II), chlordimeform (Fundal, n.I.), and piperonyl butoxide (Pyrethrin, n.I.). Herbicides include: MSMA/prometryn (Caparol, III/U), glyphosate (Roundup, U), alachlor, (III) and fluometuron (Cotoran, U). On average the fields are sprayed 20 times per season and small-scale tractors are used for 90% of the land labour including pesticide

application. Defoliants are used on 5% of the surface, with the most important defoliant being MSMA (III). All cotton is hand-picked. GM cotton is widely accepted in China and constitutes 66% of the crop (UNCTAD, 2005).
UNEP (2002) advices to promote new hybrid cotton varieties (higher yield and higher pest resistance), to produce special purpose cotton like naturally pigmented cottons and special fibre length and strength, to establish cotton production cooperatives, to carry out integrated assessments of the environmental impact of cotton, and to decrease chemical fertiliser application.

United States (19% of world production; 5.3 Mha)
American cotton farms are situated in the warm southern states, mainly in Arizona, Texas, Florida, Georgia, California, Kansas, New Mexico, and Texas. In total 25000 farmers cultivate 5.3 Mha of cotton producing land. The cotton farms are usually very large (around 1200 hectares) and intensive monocultures using high-yielding varieties without rotation crops. The average production is around 960 kg per hectare, varying between 475 and 1726 kg per hectare.
Of the cotton fields 41% are irrigated (flood irrigation 50%, sprinkler irrigation 50%). Quantities of water applied differ widely between regions and exact data is not available. Fertiliser use averages 100 kg N per hectare, 90 kg P per hectare and 80 kg K per hectare. Almost all nutrients are applied as synthetic fertiliser. Cotton stalks tend to be left on the fields. The most frequently used insecticides are ferbam/parathion (Carbamate, U/Ia), organophosphates (ranging I-U) and pyrethroids (ranging II-U). An important fungicide is benzoate (n.I.). Important herbicides are dinitroaniline (soap, n.I.). It is estimated that 25% of all pesticides applied in the USA in agriculture are used for cotton, while cotton is cultivated on only 4% of agricultural land (USDA, 2005). Defoliants are applied on 70% of the surface, most commonly carfentrazone (n.I.), pyraflufen ethyl (n.I.), dimethipin (III), sodium chlorate (III), thidiazuron (O), and diuron (U) (Vargas, 2005). Genetically modified cotton covers approximately 80% of the cotton growing area in the US (UNCTAD, 2005).
Since the price of fertilisers, chemicals and recently energy have increased, cotton has be coined 'poverty weed' in the US (Meyer and MacDonald, 2001). Virtually all cotton farms in the USA are classified as poor or marginal (TA&M research, 2003). Still, subsidies of US cotton farmers (which number only 25,000) play a dominant role in recent WTO negotiations as they affect the export position of many cotton exporting developing countries. An American cotton farm must be at least 200 hectares to be economically viable, due to the need for economies of scale in order to justify high capital costs and machinery investments (TA&M research, 2003). For the US economy, cotton is marginally important, constituting in 2004 a mere 0.2% of the Gross Domestic Product (USDA, 2005).

India (16% of world production; 9.5 Mha)
Cotton farms in India are found in the 'cotton belt' that starts in the north-west, crosses through the centre of the country and ends in the south-east. An estimated 4 million farmers cultivate 9 Mha of cotton. In the central and south, cotton farms are usually family-run, mixed, not irrigated, and small (87% are less than 6 hectares). Larger farms are typically found in the north, where the cotton is grown more intensively and is under irrigation (IIED, 2004). The national average production is 429 kg per hectare, being the world's lowest average. 50% of the fields are fertilised with farm-yard manure, 30% with synthetic fertiliser and 20% are not fertilised. On average, synthetic fertiliser applications are 85-100 kg N per hectare, 32-50 kg P per hectare, and 0-50 kg K per hectare. 30% of the cotton area is irrigated. 50% of the cotton is cultivated on black soil, 25% on loamy soil and 15% on red soil. Weeds and cotton stalks are generally burned on the field or used as stove fuel.
Most commonly used pesticides include monocrotophos (Nuvacron,Ib), endosulfan (Thiodan, II), quinalphos (Ekalux, II), chlorpyriphos (Dursban, II), dimethoate (Rogor, II), methyl-o-dematon, Ib), fenvalerate (Fenvel, II), cypermethrin (Radar, Ib), Imidacloprid (Confidore, II), spinosad (Tracer, U). Popular herbicides include Fluchloralin (Basalin, III), diuron, (U), and pendimethalin (Stomp, III). Per season the fields are sprayed on average 8 times ranging from 0-40 times. No defoliants are applied.
Bt-cotton was approved by Government of India for commercial cultivation in March 2002. Bt-cotton was grown on 530800 hectares in 2004 (6% of the cotton-cropped area) (Manjunath, 2004). A nation-wide survey indicated that Bt-cotton growers in India obtained a 29% yield

increase due to the effective control of the Bollworm, a reduction in insecticide applications by 60% and an increase in net profit by 78% as compared to their non-Bt counterparts (Manjunath, 2004). The high investment costs of genetically modified cotton have however also resulted in negative revenues (Qayum et al., 2004) (see also Chapter 2.3.5.).

Pakistan (10% of world production; 3.2 Mha)
The main cotton areas in Pakistan are located in the south of the country and 1.3 million farmers grow cotton (Punjab: 2.6 Mha; Sidh: 0.6 Mha). The farms are mainly small-sized, averaging 2 hectares. Farms are family-run and quite extensive. In addition, there are 35 state farms cultivating cotton with an average farm size of 25 hectares (Tayyab, 2004). Average cotton production is 768 and 803 kg per hectare in Punjab and Sidh respectively. Hybrid varieties are most widely used. GM-cotton is currently not licensed, as Pakistan is still developing its own GM cultivars (NIBGE, 2004). Punjab receives 12 mm of rain per year and Sidh 21 mm. All fields are irrigated, 70% with flood irrigation and 30% furrow. During the growing season the average daily temperatures range between 25 and 43°C.
As to fertilisation, farm-yard manure is applied on 13% of the fields, and on the remaining 87% synthetic fertilisers are used (ICAC, 2005). Typical fertiliser application levels are between 75-150 kg N per hectare, 40-50 P per hectare, and 25-50 kg K per hectare. The major soil type is silty loam (75%). Cotton stalks and weeds are most commonly burned on the fields or used as stove fuel. Almost all cotton (more than 80%) is rotated annually with wheat.
The most commonly applied pesticides are imidacloprid (Confidor, II), thiamethoxam (Actara, n.l.), malathion (Arrivo, III), deltamethrin (Decis, II), bifenthrin (Talstar, II), triazophos/deltamethrin (Deltaphos, Ib/II), tracer (Spinosad, U), indoxacarb (Steward, n.l.), chlorpyriphos (Larsban, II), profenophos (Curacran, II). The most common herbicides: are pendimethalin (III), trifluralin (U), metolachlor (Dual gold, III), and pendimethalin (Stomp, III) (ICAC, 2005). No defoliants are applied (Banuri, 1998).
Cotton and textiles are vitally important for Pakistan's economy generating over 60% of the annual export income (Rao, 2005).

Brazil (5% of world production; 1 Mha)
In Brazil the cotton cultivation zone reaches from the south of the country to the northeast. In the central area (Mato Grosso) in particular, there is a trend towards expanding the area under soy-cotton rotation. This area currently has about 200 rain fed cotton farmers (averaging 2000 hectares of cotton per farm) and accounts for 50% of Brazil's cotton production (IIED, 2004), with yields up to 1290 kg per hectare (ICAC, 2005). The farms in the centre and the north of the country are on average up to 10 hectares in size and produce much less: 370 kg per hectare. Virtually no cotton is irrigated. The large scale farms in the west apply synthetic fertilisers averaging 180 kg N per hectare, 120 kg P per hectare, and 220 kg K per hectare. Only half of the northern farms apply synthetic fertilisers. Those that apply synthetic fertilisers do so in quantities of 30 kg N per hectare, 60 kg P per hectare, and 40 kg K per hectare (ICAC, 2005). The major soils are Oxisols (50%). Cotton stalks are usually left on the fields and weeds are burnt. The large western cotton farms cultivate soybeans every 4th year, as well as millet rotations every second year. Common pesticides include acetamiprid (Mospilan, n.l.), carbosulfan (Marshal, II), diafenthiuron (Polo, U), endosulfan (Thiodan, II), lambda cyhalothrin (Karate, II), cypermethrin (Fury, Ib), deltamethrin (Decis ultra, II), beta cyfulthrin (Bulldock, II), teflubenzuron (Nomolt, U), imidacloprid (Gaucho, II). Most commonly used herbicides are trifloxissulfuro (n.l.), clomazone (III), and diuron (U). The main defoliant applied is MSMA (III) (ICAC, 2005).
In the northern region rotation schemes are wider and more complicated, including corn, cowpeas and fallow periods. The most widely used pesticides in this region are melathion (III), metyl parathion (Ia), deltamethrin (II), and endosulfan (II). Usually five sprays per season are applied, and herbicides are not used (ICAC, 2005). Through mechanisation and support to farms with large economies of scale, Brazil is planning to expand its cotton growing area, especially in the central region.

Uzbekistan (4% of world production; 0.8 Mha]
The reliability of information obtained for this country may to some extent be questionable. For example, the high yields per unit of area mentioned in Table 1 is doubtful.
97% of crop production is done on irrigated land. Since the 1980s, cotton production has been reduced by half. Partial reform of the agricultural sector has resulted in a large increase in the number of family and small farms. Small farms are expected to become the main

agricultural producers in Uzbekistan: in 2002 there were approximately 72,000 small farms, 2000 cooperatives, 3.3 million family farms, and 500 other private sector farms (IIED, 2004). Defoliants are applied on 75% of the surface with mostly sodium chlorate (n.I.) being used. In 2000, cotton provided 12.9% of the GDP (Fortucci, 2000).
Pesticide use has been reported as high as 54.6 kg per hectare in some cotton growing areas of Uzbekistan (Libert, 1995). However, more and recent information is not available. Water use for cotton production has had and is still having a significant impact on the Aral Sea area (see Chapter 2.3.1, Environmental impact).

West Africa (4% of world production; 2.4 Mha)
In Africa, the western part is the main cotton cropping region, notably Benin, Cameroon and Mali with around 2 million cotton farmers (IIED, 2004). Benin cultivates 384,000 hectares with an average production of 504 kg per hectare (ranging from 200 to 1050 kg per hectare), Cameroon 215,000 hectares with an average production of 578 kg per hectare, and Mali cultivates 540,000 hectares, producing 435 kg per hectare.
Benin receives on average 1000 mm rainfall and has a temperature in the cotton season of about 30°C. Cameroon receives 1050 mm of rainfall and Mali 784 mm. This means that irrigation is not a prerequisite for cotton cultivation in the region. In all three countries hybrids are used.
In Benin farms tend to be very small: about 1 hectare. Still, 30% of the farms range from 5 to 10 hectares. In Cameroon all farms are smaller than 3 hectares and they are mainly situated on sandy loam soils. In Mali the average farm size is 5.3 hectares, and the cultivation takes mainly place on clay soils and sandy clay grits. In all of these countries crop rotations are done; in Benin with maize or cowpea, in Cameroon with cereal crops, and in Mali with corn, millet, or sorghum. Usually cotton cultivation is alternated with one other crop. Mainly manual and animal force is used for soil preparation. Benin and Cameroon rely for the most part on artificial manure (NPK, 74-46-28 and 42-27-24 kg per hectare respectively). In Mali, about 40% of the farms apply farm-yard manure as their single source of nutrients and the remaining 60% apply NPK (44-33-18 kg per hectare). In Benin, the most frequently used pesticides are endosulfan (II), cyfluthrine-chlorpyriphos (II/II), and lambdacyhalothrine (II); in Cameroon cypermethrin (Ib), endosulfan (II) and cetamipride (n.I.); and in Mali profenofos (Calfos 500, Cuacron 500, Tenor 500, II), endosulfan (Phaser 500, Phaser ultra caps, Thiofanex 500, II), cypermethrin (Cytofos 286, Cyperfos 336, Conquest C88, Ib). In all three countries the herbicides glyphosate (Roundup, U), diuron (U) and paraquat (II) are applied. In general defoliants are not used. In all three countries the crop is harvested by hand and cotton stalks are burnt on the fields or used as household fuels.
Cotton contributed 8.8% to the GDP of Benin (Fortucci, 2000) and 1.3% and 5% respectively to the GDP of Cameroon and Mali (Fortucci, 2000).

Turkey (3% of world production; 0.7 MHa)
The major areas of cotton cultivation are West (20%), South-West (60%) and South (20%) Turkey. Most of the 300,000 cotton farms are small scale and family-run averaging 5 hectares. Average production levels of 1350, 1600 and 1289 kg per hectare are reached respectively in West, South-west and South Turkey. With South Turkey having very low annual rainfall (189 mm), it is very much dependent on irrigation. West and South-west Turkey receive 600 - 1100 mm of rainfall annually and are consequently less dependent on irrigation. Irrigation is done via furrows (78%), flooding (9%) and sprinklers (5%). Only 8% of the area is not irrigated. In West and South-west Turkey cotton is cropped mainly on Entisola fluvent soils (60%) and Vertisols (40%), and in South Turkey on alluvial soils (70%) and vertisols (30%). Cotton stalks and weeds are usually burnt after the harvest. For the most part, locally developed hybrid varieties are used. The share of GM cotton is not known. Generally 1-year rotations are done with cereal crops (wheat, maize, barley) and sometimes a fallow year is included. Less commonly, multiple-year rotations with wheat and maize are done. The soil is prepared using machinery.
The most commonly applied pesticides in Turkey are diafenthiuron (Polo 50, II), carbosulfan (Marshall 25 EC, II), lambda cyhalothrin (Karate, II), chlorfluazuron (Atabron, U), thiodicarb (Larvin, II), nissorin, (n.I.), acetamiprid (Mosphilan, n.I.), Endosulfan (Thiodon, II), and imidacloprid (Gaucho, II). Popular herbicides are linuron (Match, U), trifluralin, (U), fluazifob butyl, (n.I.), and prometryne (U) (ICAC, 2005). In general no defoliants are used.
The share of cotton in the GDP is estimated to be approximately 4% (Gazanfer, 2004).

Australia (1% of world production; 0.2 Mha)
In Australia, 1100 farmers cultivate 198,000 hectares of cotton, with an average yield of 1760 kg per hectare (ranging from 300-3000 kg per hectare, depending mostly on water availability). The average farm size is 800 hectares, with 18% being more than 1000 hectares. In general the cotton fields receive 500 mm per year rainfall and the average temperature is 25°C. Mainly GM cotton is cultivated – as of 2005 GM is expected to be 80% of all production (Chandler, 2005).
Most commonly cotton is planted on the same plots every year, with a fallow period of a few months in between. All farming activities are mechanised. Nutrients are added via synthetic fertilisers (NPK, 200, 80, 75 kg per hectare). Most commonly applied pesticides are amitraz (Ovasyn, III), indoxacarb (Steward, n.I.), emamectin (Avermectin, n.I.), endosulfan (Thiodan, II), dimethoate (Rogor, II), spinosad (Tracer, U), fipronil (Regent, II), chlorpyrifos (Predator, II), and deltamethrin (II). Commonly used herbicides are glyphosate (Roundup, U), fluometuron (U), and pendamethalin, III (ICAC, 2005). On all fields defoliants are applied with thidizuron (n.I.) being by far the most widely applied.

Other regions
Egyptian cotton is famous for its long staple length combined with strong fibre that produces very fine cloth. In total Egypt cultivates 303,000 hectares, which are all flood irrigated.
Israel has the highest average production per hectare, with 1850 kg per hectare (ranging from 1500-3000 kg per hectare), with drip irrigation applied on all parcels. The 14,000 hectares that are cultivated are managed by 130 farmers.
Peru cultivates an interesting naturally coloured variety of cotton, with colours ranging from dark brown/black to green. The coloured cotton is limited to 300 hectares (ICAC, 2005) and is cultivated in Peru's dry zone (with 17 mm of rain per year).

(Kooistra. 2004)

Table 6. List of most commonly used pesticides in cotton (ICAC, 2005; PAN, 2005).

Active ingredient	WHO class[1]	Type[2]	China	India	USA	Pakistan	Brazil	Benin	Cameroon	Mali	Turkey	Australia
Toxicity class I												
parathion	Ia	i			x							
cypermethrin	Ib	i		x			x		x	x		
methyl-o-dematon	Ib	i		x								
methamidophos	Ib	i								x		
monocrotophos	Ib	i	x	x						x		
thiofanex	Ib	i								x		
triazophos/	Ib	i				x						
Toxicity class II												
bifenthrin	II	i				x						
carbosulfan	II	i					x				x	
chlorpyriphos	II	i		x		x		x				x
cyfluthrin	II	i	x				x	x				
deltamethrin	II	i				x	x					x
dimethoate	II	i		x								x
endosulfan	II	i		x			x	x	x	x	x	x
fenvalerate	II	i		x								
fipronil	II	i										x
imidacloprid	II	i	x	x		x	x				x	
lambdacyhalothrine	II	i					x	x			x	
organophosphates in general	II	i			x							
paraquat dichloride	II	h										
profenophos	II	i				x				x		
pyretroids in general	II				x							
quinalphos	II	i		x								
thiodicarb	II	i									x	
trichlorfon	II	i	x									
Toxicity class III												
alachlor	III	h	x									
amitraz	III	i										x
clomazone	III	h					x					
dicofol	III	i	x									
dimethipin	III	d										
fluchloralin	III	h		x								
malathion	III	i				x						

metolachlor	III	h				x						
MSMA	III	h/d	x				x					
organophosphates in general	III	I			x							
pendimethalin	III	h		x		x						x
pyretroids in general	III	i			x							
sodium chlorate	III	d										
Toxicity class U												
chlorfluazuron	U	i			x							
diafenthiuron	U	i									x	
diuron	U	h/d		x			x					
ferbam	U	i			x							
fluometuron	U	h	x									x
glyphosate, isopropylamine salt	U	h	x									x
linuron	U	h									x	
piperonyl butoxide	U	i	x									
prometryne	U	h	x								x	
spinosad	U	i		x		x						x
teflubenzuron	U	i					x					
trifluralin	U	h				x					x	
Toxicity class O												
chlordimeform	O	i	x									
EDTA, tetrasodium salt	O	i								x		
thidizuron	O	d			x							
profluralin	O	h			x							
Not listed by WHO												
acetamiprid	n.l.	i					x		x		x	
emamectin, benzoate	n.l.	i			x							x
fluazifop-butyl	n.l.	h									x	
Heliothis armigera	n.l.	o.i.										x
indoxacarb	n.l.	i				x						x
profluralin	n.l.	h			x							
sodium carbonate	n.l.	d								x		
thiamethoxam	n.l.	i				x						
trifloxysulfuron-sodium	n.l.	h					x					

[1] WHO toxicity classes. Ia = extremely hazardous, IB = highly hazardous, II = moderately hazardous, III = slightly hazardous, U = unlikely to present acute hazard in normal use, FM = fumigant, not classified, O = obsolete as pesticide, not listed, n.l.= not listed by WHO.

[2] i = Insecticide, h = herbicide, d = defoliant.

3.2 Organic systems

The European Community Council Regulation EC 2092/91 definition of organic farming states: 'Organic production systems are designed to produce optimum quantities of products of high quality by using management practices which aim to avoid the use of agro-chemical inputs and which minimise damage to the environment and wildlife' (EEC, 1993).

The International Federation for Organic Agricultural Movements (IFOAM), established in the early 1970s, represents over 600 members and associate institutions in over 100 countries. IFOAM (1996) defines the "organic" as referring to the particular farming system described in its Basic Standards. The "Principle Aims of Organic Agriculture and Processing" are based on the following equally important principles and ideas (Soil Association, 2005):

- to produce food of high nutritional quality in sufficient quantity;
- to interact in a constructive and life enhancing way with all natural systems and cycles;
- to encourage and enhance biological cycles within the farming system, involving micro organisms, soil flora and fauna, plants and animals;
- to maintain and increase long-term fertility of soils;
- to promote the healthy use and proper care of water, water resources and all life therein;
- to help in the conservation of soil and water;
- to use, as far as is possible, renewable resources in locally organised agricultural systems;
- to work, as far as possible, within a closed system with regard to organic matter and nutrient elements;
- to work, as far as possible, with materials and substances which can be reused or recycled, either on the farm or elsewhere;
- to give all livestock conditions of life which allow them to perform the basic aspects of their innate behaviour;
- to minimise all forms of pollution that may result from agricultural practices;
- to maintain the genetic diversity of the agricultural system and its surroundings, including the protection of plant and wildlife habitats;
- to allow everyone involved in organic production and processing a quality of life conforming to the UN Human Rights Charter, to cover their basic needs and obtain an adequate return and satisfaction from their work, including a safe working environment;
- to consider the wider social and ecological impact of the farming system;
- to produce non-food products from renewable resources, which are fully biodegradable;
- to encourage organic agriculture associations to function along democratic lines and the principle of division of powers;
- to progress towards an entire organic production chain, which is both socially just and ecologically responsible.

To be able to market products as 'organic' the farm must be certified by an organic certification body. Known organic cotton certifiers are the Swiss-based Bioswiss and IMO control, the UK-based Soil Association, and the Netherlands-based SKAL (Ministry of Agriculture, 2005), amongst others. Regulations in place that set the parameters for the organic production of cotton areRegulation (EEC) 2092/91 (EEC, 1993) or USDA National Organic Program, Standards and Guidelines (USDA NOP, 2005). These regulations outline a specific set of rules in place for organic cultivation, describing what must be certified, relevant exemptions and exclusions from certification, the use of the term "organic", and allowed and prohibited substances, methods and ingredients in organic production and processing.

Organic cultivation excludes the use of synthetic pesticides, synthetic fertilisers and genetically modified organisms. The organic certificate covers agricultural land only. Neither the origin of irrigation water nor the origin of agricultural soils (e.g. reclaimed land, natural forest etc.) are included. Recently, an organic crop cotton guide was published (Eyhorn et al., 2005).

Today certified organic cotton is grown in 10-15 countries. Production is concentrated in Turkey (1750 tonnes; 29% of total organically produced cotton, 2005) and the USA (1625 tonnes; 27%, 2005). Other important sites are found in India (1000 tonnes; 17%), Peru (550 tonnes; 9%), Uganda (275 tonnes; 5%), and in Egypt, Senegal, and Tanzania (200 tonnes each; 3%) (Table 7).

Table 7. Certified and traded organic cotton production worldwide in tonnes of fibre (Ton, 2003).[1]

Country	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01
Argentina	75	-	-	-	-	-
Australia	400	300	300	-	-	-
Brazil	1	1	1	5	10	20
Benin	-	1	5	20	20	30
Egypt	650	625	500	350	200	200
Greece	150	125	100	75	50	50
India	925	850	1000	825	1150	1000
Israel	50	50	20	-	-	-
Kenya	-	-	5	5	5	-
Mozambique	100	75	50	-	-	-
Nicaragua	20	20	20	-	-	-
Paraguay	50	50	50	-	-	-
Peru	900	600	650	650	500	550
Senegal	1	10	10	50	125	200
Tanzania	10	100	100	100	200	250
Turkey	725	850	1,000	1,200	2,000	1,750
Uganda	75	300	450	250	200	275
USA	3350	1550	1300	1900	2900	1625
Zimbabwe	-	-	1	5	5	-
Total	7482	5507	5562	5435	7365	5950
Change[2]	22	-16	1	-2	36	-29

[1] Recently organic production has sharply increased due to increased demand, but reliable figures were not yet available.
[2] In %, compared to previous year.

Organic cotton farms cover a wide range of farm sizes and their organisation depends on the country where they are located. A rough division can be made between the two types of farms: large–scale, mechanised farms and small-scale, animal traction driven farms. The first type is mostly found in the US and the second type is mostly found in Turkey, India and Peru.

Turkey (29% of world's organic cotton, 8000 hectares)
Presently there are around 350 organic cotton growers in Turkey with in total 7883 hectares under organic cotton cultivation (OE, 2005). The average farm size is 20 hectares, with a wide range from 2-1000 hectares. The average production per hectare is not known precisely, but is estimated to be 350 kg per hectare (OE, 2005). These data are, however, not certain. Ferrigno (personal communication 2005) estimates an average yield of 1500 kg per hectare. 40% of the farms are irrigated. More detailed information about organic cropping systems in Turkey is not yet available.

United States (27% of world's organic cotton, 3200 hectares)
Organic cotton farms in the US are situated in the cotton belt of the country and make up about 3200 hectares in total. In 1995 the area cropped to organic cotton was still 36,000 hectares, but due to low prices and unfavourable weather conditions many farmers have concluded organic cotton cultivation and returned to conventional. Cultivation was limited to Arizona, California, Missouri, New Mexico and Texas (OTA, 2004). Organic cotton was cultivated by 14 farmers and the average organic farm size was 500 hectares producing in total about 1200 kg cotton per

hectare. Data about irrigation practises or fertiliser use are not available, but it is likely that US organic farms are irrigated in a similar way to conventional or IPM farms in the US. All use tractors for field labour and cotton is harvested with machines. Currently no information is available about rotations and use of bio-control methods including pesticides of natural origin.
The organic farms are assisted by research institutes (California University) with site-specific information. All farms meet the requirements of the National Organic Program (USDA NOP, 2005).

India (18% of world's organic cotton, 8000 hectares)
In this country 4000 farmers cultivate organic cotton on 7500 hectares. Most of the fibre is grown in three major organic projects named Agrocel (Mandvi, Gujrat), Maikaal bioRe Ltd. (Central India), and Pratibha Syntex Limited (Vasudha) (North India). In general the organic cotton farmers belong to the middle and poor classes. Farm size is less than four hectares. Literacy levels are low, but are slowly on the rise. The level of knowledge concerning organic cultivation is still low. Rotations and strip cropping with millet, peppers, maize and cowpea are applied (personal communication Lanting, 2005 and personal communication Eyhorn, 2005). Organic manure is applied in quantities of 400-2000 kg per hectare and more than 20% of the organic cotton area is irrigated. All cotton is handpicked (Organic exchange, 2005). More information about organic cropping systems in India is not available.

Peru (8% of world's organic cotton, 300 hectares)
In 2004, 255 farmers were contracted to grow organic cotton over an area of 280 hectares. Peruvian cotton farmers have long-term experience with cotton production and some indigenous and traditional peasant farming technologies are still in use. Most organic cotton is grown in the Cañete valley, located on the desert coast 150 km south of Lima on private farms. Due to the lack of rainfall agriculture depends completely on (flood) irrigation coming from the Cañete River originating in the Andes Mountains. Cotton is often intercropped with maize and rotated with a limited number of winter crops like green beans or fodder maize. The only information about pest control is that to a limited degree pheromones are applied to control the Pink Bollworm and cotton plants are burned after picking to avoid pest transmission (Organic exchange, 2005). More information about organic cropping systems in Peru is not available.

Mali
In Mali, Helvetas (a Swiss NGO) started an organic cotton project in 2002; it is located in the Province of Bougouni, in the counties of Kolondieba and Yanfolila. The project started with 174 farmers, and has rapidly increased to 385 farmers. In 2003/2004 170 hectares were planted with organic cotton, averaging a yield of 475 kg of seed cotton per hectare. The average farm size is 5 hectares, with less than 10% cropped to cotton. The project plan foresees production of 50 tonnes of fibre per hectare in 2004/2005. Crops included in the rotation are groundnut, sesame and millet with shea butter trees in the fields. Some extension and micro-credit schemes for farm equipment are available. It is stated that there is a huge potential for further expansion.

Benin
In Benin, two organic cotton projects started in 1996/1997, one in Northern Benin and one in Central Benin. The Central Benin project (the OBEPAB; a Beninese NGO) works with 800 farmers (data 2003). The cotton is grown on small farms with an average of 2-8 hectares each. The project works with a guaranteed purchase price, which is set in advance of the season. Yields range from 270 - 562 kg per hectare. (OBEPAB a and b, 2002, in Ferrigno et al., 2005) (OE, 2005)

Senegal
The main production region is in the Central-East (project Koussanar). In 2005 there were approximately 1750 producers with an average farm size of 5 hectares in more than 50 villages. Another project in the Southeast project (Velingara) has not produced organic cotton due to management problems since 2001 (OE, 2005).

Egypt
In total 80 hectares was cultivated with organic cotton in the 2003/2004 season by Sekem, the largest grower of organic cotton in Egypt. Sekem manages an integrated supply chain from

the farm to the finished product. Besides this the company supports local community economic development and health and education projects in areas where they source their products (OE, 2005).

China

In China, organic cotton is only planted in Xinjiang due to the local low disease and insect pressure. Of the total of 1.0 Mha of cotton grown in Xinjiang, only 0.12% or 1300 hectares (2004) are grown organically and those farmers are organised into three producer groups: Of The Earth (OTE), Esquel and a third project whose name is unknown.
OTE's farms are located near Urumqi City. The Xingjian region has very good natural conditions for the development of organic cotton, and the local government can play an important role in promoting organic production by extension and the promotion of international trade (UNEP, 2002). Farms are about 45 hectares. Instead of synthetic fertiliser, the following sources of fertiliser are used: cotton seed residues, green manure crops, cotton stalks, leaves, and organic wastes. Methods that have been implemented to prevent pests and weeds include crop rotation, winter irrigation, planting of corn around the cotton field to distract the pest, manually pest and worm entrapment on the field, aspen traps to block and kill pests, and black light lamp traps (OE, 2003).

3.3 IPM systems

Integrated Pest Management (IPM) is characterised by the fact that it tries to keep a balance between pests and their natural enemies and to reduce the use of pesticides to a minimum level. It is defined by the Food and Agriculture Organisation as: 'A site-specific strategy for managing insect, weed, disease and other pests in the most cost effective, environmentally sound and socially acceptable way'. IPM is not a rigidly defined form of crop protection, but a dynamic system that adapts and makes sensible use of local resources and the latest research, technology, advice and experience' (FAO, 2004). The USA-based IPM-program of UC Davis/ California (Vargas, 2005) defines IPM an ecosystem-based strategy that 'focuses on the long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties'. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimises risks to human health, beneficial and non-target organisms, and the environment (Vargas, 2005). The Australian AAS (1999). IPM for cotton is defined as 'a system that integrates all available, practical means of managing pest populations with the aim of reducing insecticide use while maintaining or improving profitability, yield, fibre quality and crop maturity.' In practice this means that (cited from Bos et al., 2005):

- control measures are only considered when pests occur (no preventive pesticide spraying);
- the presence of pests does not automatically require (chemical) control because the infestation may be insignificant;
- when control measures are necessary, non-chemical control should be considered first (such as mechanical weeding);
- suitable control measures should be used in an integrated manner;
- pesticides should be used appropriately (no overdosing, avoid sensitive areas, wear protective clothing, etc.;
- pesticides and formulations used should be easily degradable and less toxic to man and the environment (aquatic organisms, key soil organisms, pollinators);
- pesticide use should be selective in order to minimise mortality of natural enemies of pests such as predators and parasites.

The wider term Integrated Crop Management (ICM) includes the reduction of synthetic fertilisers and energy to minimum levels. IPM and ICM are in practice often interchangeable terms, and here we use the term IPM when referring both systems. It is estimated that globally 20% of all cotton is grown on IPM-managed farms. Main contributors include the FAO-project 'IPM on cotton in Asia', including IPM projects in India, Vietnam, China, The Philippines, Pakistan and Bangladesh (FAO, 2004) and the IPM program of the United States Department of Agriculture (USDA) in

collaboration with state universities like UC Davis (2000) (Curtis, 1998). In the FAO-project, 90,000 small cotton producers have been trained in integrated pest management in China, India, Pakistan, Bangladesh, the Philippines, and Vietnam using the Farmer Field School technology (FAO, 2004).
Farmer access to IPM information and training relates to issues of who has the power to design a course or to select trainers and participants, and who holds the expert knowledge. Farmer education is also related to social structures, power relations and processes like the privatisation of farm services and literacy (Fliert and Proost, 1999).
In the USA, IPM is a widely accepted practise, applied on approximately 70% of the total cotton area. It should be stressed that the coverage however does not necessarily reflect the adoption of all IPM techniques (Zehnder, 2004). In China, pilot projects were financed by the Asian Development Bank and demonstrated that cotton farmers had reduced their use of pesticides and increased yields simultaneously (FAO-ADB, 1999). In Syria, the introduction of IPM has reduced pesticide application six-fold (FAO, 2004). In Egypt, IPM is being introduced slowly, but precise data are lacking (FAO, 2004). The UN (2000) estimates a 90% reduction in pesticide use in Egypt in the late 1990s due to the introduction of IPM (UN, 2000).

3.4 Other promising techniques

Conservation tillage is currently a method with potential to minimise soil erosion. Ploughing is usually reduced or even eliminated. Additional benefits are a reduction in weed populations and reduced tillage costs. According to a report by the Cotton foundation in the USA, 78% of US cotton farmers who have adopted conservation tillage practices since 1997 have done so specifically because herbicide-resistant cotton varieties had made it more feasible (Dinham, 2004).

3.5 Summary

The above paragraphs illustrate that there are important differences and similarities between conventional, IPM and organic systems. Two activities having major influence on the environment, irrigation water use and land clearing are not fundamentally different for the three farming systems (Table 8). In addition, production per unit of area very strongly differ for the different countries.

Table 8. Characteristics of organic, IPM, and conventional cotton farming systems.

	Organic	IPM	Conventional
synthetic/organic fertiliser use	org[1]	syn/org[1]	syn/org
synthetic/natural pesticide use	nat[2]	syn/nat[2]	syn/nat
irrigation water use	yes	yes	yes
average yields	rel. low[4]	rel. high	variable
monocultivation /mixed cropping systems	mo/mi[5]	mo/mi	mo/mi
continuous cultivation	no[6]	no/yes	no/yes
land clearing allowed	yes	yes	yes
burning organic material (weeds, plants, etc.)	no	yes	yes
mechanised labour	yes	yes	Yes
share of world production (%)	0.04	20.0	80

[1] org = organic fertiliser; syn/org = synthetic and/or organic fertiliser.
[2] nat. = natural pesticides allowed; only few natural pesticides are on the market and their use in cotton systems is very likely far less than the use of synthetic pesticides in IPM and conventional systems.
[3] syn/nat = synthetic and natural pesticides allowed; mainly synthetic pesticides are used.
[4] rel. = relatively.
[5] mo/mi = monoculture and/or mixed cropping systems. Mixed cropping systems are usually limited to the developing countries, more specifically to subsistence farming.
[6] continuous cultivation of cotton is not prohibited in organic systems, but most usually this is not done.

4 Environmental impact indicators

Naturally each agricultural activity has a certain impact on the environment. This impact is generally considered unsustainable if the environment is damaged to an extent that future generations cannot cultivate the same crop. The following sustainability problems have been reported in relation to cotton cultivation (IEEP, 2005):

- degraded land as a result of salinisation and erosion;
- water depletion by excessive use of soil and surface water;
- natural habitat conversion due to cutting of forests and dam constructions;
- eutrophication of surface water;
- wildlife contamination by pesticides (insects, fish, mammals, birds);
- human health due to direct pesticide intake primarily by farm workers but also by regional inhabitants through contamination of drinking water and food contamination.

The Department for Environment, Food and Rural Affairs (EU) has recently predicted two major environmental problems related to cotton cultivation (IEEP, 2005):

- intensification of pesticide use. Countries where this is expected to be the most severe are Australia, Brazil, Uzbekistan, Turkey, Pakistan, Mexico, India, China, and West and Central Africa (Benin, Burkina Faso, Chad and Mali), thus including the major cotton producing countries. The reason for intensification of pesticide use according to the IEEP (2005) is an increase in economic development leading to more opportunities to buy pesticides. If this does not goes hand-in-hand with the introduction of IPM-related techniques, it will lead to unwanted side-effects of pesticides on human health. Currently it is estimated that 15% of cotton farmers are not using any pesticides due to an inability to buy them (ICAC, 2005);
- increase in irrigation problems, leading to salinisation and unsustainable use of fresh water resources.

To be able to quantify the problems as mentioned above, the environmental impact can be divided into indicators, each representing an aspect of environmental impact. The relationship between agricultural practises and recognised environmental problems can be found in Table 9. The 'indicators' are derived from Life Cycle Assessment (LCA) methodology. The selection was done based on 17 different studies on the environmental impacts of cotton cultivation (Annex 1). In the following paragraphs the indicators and the differences between the three farming systems will be discussed.

Table 9. Recognised problems in cotton cultivation related to various agricultural practises and in relation to environmental impact indicators. Environmental impact indicators: 1: water use, 2: human toxicity, 3: environmental toxicity, 4: global warming, 5: eutrophication, 6: acidification, 7: erosion, 8: land-use, 9: biodiversity, 10: salinisation, 11: energy use.

	Organic fertilisers		Synthetic fertilisers		Pesticides	Land clearing	Irrigation	
recognized problems in cotton cultivation	production	use	production	use			dam construction	water withdrawal
degraded land				1	3	7		10
water depletion							1	1
human health effects		11	4, 11	11	2			11
natural habitat conversion	6	6	4, 5	3, 6	3	9	8	1
wildlife contamination by pesticides					3			1
eutrophication of surface water	4	5		5		7	1	1

4.1 Water use

As seen in Chapter 2.3.1, cotton consumes large amounts of fresh water. According to the World Resources Report 2005 (UNEP, 2005), 'The world's thirst for water is likely to become one of the most pressing resource issues of the 21st century'. Water use (expressed in litres per hectare of cotton or litre per kilogram of cotton yield) as an indicator for estimating the sustainability of cotton production has been recommended repeatedly (e.g. Tobler & Schaerer, 2001; Banuri, 1998; IERE, 2005; Hanssen, 2001; Clay, 2004) but currently it has not been applied in Life Cycle Analysis (LCA) studies on cotton cultivation, due to a lack of proper information. Bos et al. (2005) developed water use indicators for cotton cultivation, mainly based on water use efficiency. To date, methodologies have not taken sustainability of the source of irrigation water into account (groundwater versus surface water). However, without extensive field measurements, both on the farm and at the water source, water use is not easy to estimate at a farming systems level.
The potential water use indicator does not indicate significant differences between the three farming systems, as irrigation water application is allowed within all three farming systems, and mainly defined by local circumstances rather than by management characteristics. It is however important to note that irrigation water becomes relevant if conversion from one system to another would lead to a reduction in production, thus leading to more surface requirements for the same amount of product. Organic cotton is often regarded as a low yielding management system.
The actual water use indicator however, as shown in Chapter 3.2, does show a clear difference between farming systems as the main organic cotton producing areas (around 60%) are rain-fed. Expanding the organic cotton area in rain-fed regions by converting low-input conventional farms would therefore be unlikely to lead to increases in water consumption.

4.2 Human and environmental toxicity

The main impact of pesticides is on the environment, most notably on human beings. The most widely used pesticide risk indicator is the Environmental Index Quotient (EIQ), developed by Kovach et al. (1992) and used by the FAO as a monitoring tool for their IPM programs. The EIQ takes into account fish, bird, and bee toxicity, as well as toxicity to beneficial arthropods. Other pesticide risk indicators include PRIMET, which combines pesticide exposure assessment, effect assessment and risk assessment (Brink in Bos et al., 2005).
In Chapter 3.1 it was shown that in conventional cotton a large range of the most toxic pesticides are used. Since IPM aims to reduce pesticide use and to use necessary pesticides more safely, and organic abandons pesticide use altogether, this indicator clearly distinguishes the three management systems. Attention should also be paid to the use of natural pesticides in organic farming systems. Although currently there are no indications that the natural pesticides allowed in organic systems are widely used, it should be kept in mind that they are not necessarily less hazardous than synthetically produced pesticides. Pesticides were used as an LCA indicator by Clay (2004), Banuri (1998), and Slater (2003). A target value can not be set for this indicator because generally lower application levels are better (personal communication Kovach, 2005). Indirect costs (see Chapter 2.3.4) are currently not applied for any of the indicators. The way a pesticide is applied is crucial to the toxicity indicator (Chapter 2.3.4).

4.3 Global warming

The so-called 'greenhouse effect', the rise in the earth's temperature due to human activity, has become an important topic of debate and research over the past several years. Emissions of CH_4 and N_2O are also considered to be important contributors to climate change.
Cotton cultivation contributes to global warming primarily through energy use (including the costs of fertiliser transport and production of synthetic fertiliser-N), the burning of organic materials and to some extent the CH_4 produced from the use of animal labour.
The direct effects of global warming on cotton production are two-sided. On the one hand, increased concentrations of CO_2 may lead to increases in cotton yields and global warming may lengthen the growing season (Perkins, 2002). At the same time, global warming may lead to desertification e.g. in Central Asia.
The Kyoto Protocol provides for carbon sequestration in terrestrial sinks and carbon trading through 'Clean Development Mechanisms'. Terrestrial carbon sequestration can be realised through increasing soil organic matter content (Lal, 2004) by applying materials that have a

relatively large persistent carbon pool such as compost, and by cropping practices such as choice of rotation, tillage and cover cropping (Sainju et al., 2005).
In agricultural LCA studies, contribution to global warming is an important indicator (Tobler & Schaerer, 2001; Holme, 1993; Dettenkofer et al., 2001; Leffland, 1997; Weidema & Meeusen, 1992; Banuri, 1998; Dahllöf, 2004; Olson et al., 2001; Fryendal, 2001; Kooistra et al., 2005). Global warming is expressed in CO_2 equivalents. For example, the greenhouse gases CH_4 and N_2O contribute 21 and 243 times that of CO_2 (IPCC, 1999).
Factors influencing energy use are degree of mechanisation, irrigation techniques, amount of fertilisers used, and cultivation methods. According to Canakci et al. (2004), most energy needed for conventional cotton cultivation in Turkey is required for seedbed preparation and irrigation with shares of 14–65% and 26–40% respectively. Without irrigation the most significant energy inputs are fertiliser and diesel, contributing 40–54% and 17–43% respectively (Canakci et al., 2004; Gül et al., 2004).
In relation to the potential impact of Global Warming the degree of fertilisation with synthetic fertilisers, mechanisation and soil organic matter content are the most important factors. Therefore, systems with low or no synthetic fertiliser use, low or no mechanisation and high organic matter content are favoured, which refers to low input conventional, IPM and organic farms. Relative to fertiliser use, pesticide production and use contribute very little to the global warming indicator.

4.4 Eutrophication

Eutrophication causes algal bloom and subsequent oxygen shortages in surface water and affects natural vegetations. Phipps & Crosson (1986) and Nielsen & Lee (1987) estimated that 50-70% of all nutrients reaching surface waters, principally N and P, originate from fertilisers. Nitrates move with water and leach easily to surface and groundwater. P binds to sediments and contributes to eutrophication if soil is eroded (Smith et al., 1987). Eutrophication can have a devastating effect on aquatic ecosystems leading to, for example, algal growth, depletion of oxygen and a decline in aquatic plants and animals (Uri, 1998). This indicator is usually subdivided into terrestrial and aquatic eutrophication. To estimate the Eutrophication Potential, the emissions of NO_3, P, PO_4, NH_3 and NO_2 are taken into account. The emitted quantities are derived from the amounts of mineral fertiliser, diesel, farm yard manure and burnt organic material used as well as the estimated quantity of leaching. This indicator is considered to be relevant by multiple authors (Tobler & Schaerer, 2001; Clay, 2004; Kalliala, 1999; Dettenkofer et al., 2001; Leffland, 1997; Dahllöf, 2004; Fryendal, 2001; Home, 1993; Olson et al., 2001). Since limited research has been published on this subject it is not possible to give a clear conclusion as to the differences between the three systems based on this indicator.

4.5 Acidification

The effects of acidification mainly depend on the magnitude of deposition (wet or dry) and the sensitivity of soil and water. Main effects are found in soil (affecting soil communities), forests (vegetation damage) and surface and groundwater (shifts in aquatic species). Some health risks can be involved since acidification can lead to increased mobility of metals such as aluminium, copper and lead. This indicator represents the effects of cotton production on the acidification of natural ecosystems (Audsley et al., 1997). For an estimate of the acidification potential of SO_2 emissions, NH_3 and NO_2 are taken into account, and the emitted quantities are derived from the use of mineral fertiliser, diesel, pesticides, farm yard manure and the burning of organic material. Several studies consider acidification to be important (Tobler & Schaerer, 2001; Dettenkofer, 2000; Leffland 1997; Weidema & Meeusen, 1999; Banuri, 1998; Dahllöff 2004; Olson et al., 2001; Kooistra et al., 2005; Holme, 1993; Fryendal, 2001). As with eutrophication, almost no research is published on the indicator and it is therefore not possible to conclusively distinguish the three systems.

4.6 Erosion

The most important factors determining erosion are the percentage of soil covered with a crop, the angle of the field surface, type of irrigation and rainfall pattern, soil type, and measures taken

to prevent erosion. Since erosion is caused by factors that are not necessarily restricted to one farm management type, it is not possible to pin erosion problems on one type of management. However, conventional methods do not usually include erosion prevention, which can lead to major problems. Since organic management aims to maintain a high level of organic matter in the soil, cover crops and green manures are grown and erosion prevention measures are prescribed. Thus, organic farms will likely have less erosion compared to IPM and conventional farms within the same area (USDA-NOP, 2004). A common method for estimating soil erosion is done using the Revised Universal Soil Loss Equation (RUSLE, Nyakatawa, 2001), which expresses the amount of soil loss per surface unit.
Although the erosion may, as already stated, be an indicator that separates farms doing comprehensive soil organic matter management from those that do not, it seems impractical to include this indicator for estimating the sustainability of cotton production. Potential erosion depends to a large extent on topographical factors, and to simply state that cotton must be produced only on flat lands, for example, would be highly unrealistic. The measures a farmer takes to reduce erosion depend on the local situation, making a clear-cut erosion indicator for sustainable cotton production difficult. Clearly more work is needed on this important topic.

4.7 Land use

For agricultural production land is always used. The current distribution of crops over the earth's surface is mainly determined by climate, soil type, labour availability, price of product, distance to consumers, characteristics of varieties (quality, quantity, economic return), cultural aspects and the availability of planting material. Since land use for a cash crop like cotton competes with food and other cash crops, land use must be calculated in order to be able to compare the different crops. Also inputs into the system such as synthetic fertilisers (open mines, Chapter 2.3.2) and irrigation water (dams, watersheds, Chapter 2.3.1) have an impact on natural areas. Important aspects influencing land use are the productivity (yield) per hectare, and synthetic fertiliser and irrigation water use (and origin) and the value of additional land used. Several organic cotton projects report the incorporation of reafforestation programs (Senegal, Paraguay). Reafforestation is also included in some IPM programs. Further development of this LCA indicator is recommended.

4.8 Biodiversity

In addition to land use, agricultural practises affect biodiversity. The biodiversity lost from an area where original vegetation has been cleared, such as a forest (Chapter 2.3.4) as well as the biodiversity found in the cotton crop would need to be estimated. This indicator is now under development for the LCA methodology (Tobler & Schaerer, 2001). This indicator relates to differences in yield between farming systems and the associated land required in order to reach a certain yield. If more land is needed, which may be the case for many current unsustainable systems, biodiversity is negatively affected (see also Chapter 5, Discussion). Biodiversity is also negatively affected through the use of broad-spectrum pesticides. We conclude that for cotton production systems biodiversity is addressed via land use (including conversion of new habitats) and toxicity indicators. The only factor not addressed by these indicators is the effect on biodiversity of vast areas of monoculture cotton (e.g. in the USA). Although such monotonous land use clearly affects biodiversity (e.g. Panek, 1997; Liu et al., 2005), no recommendations are available on how landscape design can optimise biodiversity.

4.9 Salinisation

The effect of salinisation was introduced in Chapter 2.3.1. It mostly addressed the loss of agricultural land due to an accumulation of mineral salts. Compared to water use it is relatively independent of management type, because in a specific area water quality and the need to irrigate tends to be equal for all farms. It remains however an important effect of cotton cultivation. To date no LCA indicator has been developed for salinisation, which could be part of a water use indicator (Chapter 4.1).

4.10 Conclusions

Conventional and organic farming systems are not as different as expected (Table 9). For example, organic production does not take water use explicitly into account. When organic growers apply improper amounts of organic/natural fertilisers or apply them when the crop does not need fertiliser, they contribute to the same unsustainable elements as high-input conventional systems (Table 9). In other words, transforming a conventional system that has unsustainable water use to an organic system with the same degree of unsustainable water use has limited advantages. However, the majority of organic farming systems are rain-fed and these, according to Table 9 (see foot-notes), are considered to be 'low-input organic'.

Table 9. Relationship between farming systems and their corresponding environmental impact potential.

	Recognised problems in cotton cultivation							Expressed in LCA indicators										
farm management system[2]	degraded land	water depletion	human health effects	natural habitat conversion	wildlife contamination by pesticides	eutrophication of surface water		water use	human toxicity	environmental toxicity	global warming	eutrophication	acidification	erosion	land use	biodiversity	salinisation	energy use
conv-h	+	++	++	+	++	+		++	++	++	+	+	+	+	++	++	++	++
conv-l	-	- -	-	-	+	-		-	+	+	+	-	-	+	+	+	+	++
IPM-h	+	++	-	+	+/-	-		++	-	+	-	-	-	+/-	+	++	++	++
IPM-l	-	- -	-	-	+/-	-		-	-	+	-	-	-	+/-	+	+	+	-
org-h	+	++	+	+	-	+		++	-	-	+	+	+	-	++	++	++	+
org-l	- -	- -	- -	- -	- -	-		- -	- -	-	-	-	-	-	+	+	+	-

[1] + = moderately important impact potential,
++ = highly important impact potential,
- = slight impact potential,
- - = negligible impact potential.

[2] conv-h = high-input conventional, irrigation from non-sustainable source, high pesticide (quantity and toxicity) and fertiliser input;
conv-l = low input conventional, no irrigation, no excessive pesticide input and high fertiliser input;
IPM-h = low-input Integrated Pest Management (IPM) but with unsustainable water use. Inputs of pesticides and fertilisers are by definition low-input;
IPM-l = low input Integrated Pest Management (IPM) with sustainable water use. Inputs of pesticides and fertilisers are by definition low-input;
org-h = high-input organic management system, but using non-sustainable water sources, with relative low yields and/or unsophisticated fertiliser use;
org-l = low-input organic management system and using sustainable water sources, with optimum yields and sophisticated fertiliser use; in general, this type includes the majority of rain-fed organic cotton.

(Kooistra. 2004)

5 Social and trade related aspects of sustainable cotton production and processing

This chapter introduces key aspects to social sustainability – labour conditions, occupational health and safety, human rights and to a certain degree, trade issues. Social issues are an important aspect of sustainability for ideological reasons, but also for purely commercial or public relations ends. For example, consumers would likely be appalled if they were to learn that the organic or "sustainable" cotton t-shirt or jeans for which they had paid a premium, were produced in sweat shop conditions or using child labour. As such, there are pragmatic as well as ethical reasons for addressing social justice along the supply chain. It can be convincingly argued that in order for the cotton supply chain to be truly *sustainable* it must address social and economic issues, as well as environmental.

5.1 Introduction

Generally, three types of issues are distinguished in sustainability questions: social, environmental and trade-related issues (usually indicated as 'people, planet, profit'). It is important to note the difference between social and trade issues. The social issues are the labour conditions of the labourers in the production chain, whereas the trade issues are the economic conditions under which the companies in the production chain deal with each other. Social issues are about people (child labour, freedom of association, etc.); trade issues are about companies (premiums, guarantees, etc.). Some confusion may arise from the fact that the word social is also used in the expression 'social accountability', which is often used as a synonym for sustainability. In the expression 'social accountability', 'social' refers to the people one is accountable to (i.e. society), whereas 'social' in 'the social issues of sustainability' refers to issues one is accountable for. Hence, social accountability covers more than just social issues.
This chapter seeks to present key social issues to consider in the cotton chain, outline issues for which there are applicable standards, and present ideas as to how to coordinate along the supply chain so that consumers can buy an end product that is both socially and environmentally sustainable. IFOAM Basic Standards are described as a starting point and their relevance for the organic cotton sector is discussed. Then social issues addressed by stronger social standard-setting bodies are explored (i.e. *Social Accountability International, Sustainable Agriculture Network of the Rainforest Alliance*, and *Fair Trade Labelling Organisations International*). Finally the sustainable cotton supply chain is considered in terms of social and environmental sustainability and certification based primarily on a Ugandan organic fair trade cotton cooperative case. Areas demanding more research, coordination and consideration are presented in the conclusions.

5.2 Social issues addressed in organic cotton certification

Cotton and textiles is a new area for organic certification. The International Federation of Organic Agriculture Movements (IFOAM) is a membership-based organisation with 771 member organizations in 108 countries representing the organic sector. IFOAM is in a process of developing a set of Basic Standard for textiles and cotton. Some individual certification bodies (e.g. the Italian certification body ICEA (Instituto per la Certificazione Etica ed Ambiental) or the UK-based Soil Association) have developed and are already using organic cotton and textile standards. The standards generally cover organic cotton production. The dying process is also under discussion in terms of standard development.
As of January 2003 all *International Organic Accreditation System* (IOAS)-accredited organic certification bodies are compelled to include the social justice component in their own standards, and therefore all certified operations are obliged to comply with the social standards in addition to production and processing standards. As of October 31 2005[1] there were 32 IOAS Accredited Certification Bodies (ACBs) of more than 364 certification bodies internationally. (While this number appears quite small, it should be noted that many of the larger organic certification bodies are

[1] See IOAS website – http://www.ioas.org/WEBSITE/pdfs/051031_accred_List.pdf

IOAS-accredited and applications by others are pending.) Organic cotton operations also need to comply with these social standards in order to meet the requirements for certification if they are certified by an IOAS-accredited certification body (e.g. Soil Association Certification Ltd, ICEA). In this way organic cotton certification does address social issues.
In the past, all IFOAM Basic Standards were comprised of a general principle, recommendations and requirements. The general principle of the social justice chapter (8) stated: “Social justice and social rights are an integral part of organic agriculture and processing”. Over the past two years, IFOAM Basic Standards have been re-structured so that the principles are in a separate document from the recommendations and requirements. The re-structuring was voted on and accepted at the September 28 2005 General Assembly in Australia. The articulation of principles related to social justice now fall primarily under the recently developed ‘Principle of Fairness,’[2] which states:

- organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities;
- fairness is characterized by equity, respect, justice and stewardship of the shared world, both among people and in their relations to other living beings;
- this principle emphasizes that those involved in organic agriculture should conduct human relationships in a manner that ensures fairness at all levels and to all parties – farmers, workers, processors, distributors, traders and consumers. Organic agriculture should provide everyone involved with a good quality of life, and contribute to food sovereignty and reduction of poverty. It aims to supply a sufficient amount of good quality food and other products.

Some aspects of the so-called ‘Principle of Care’ in IFOAM’s new statement of principles can in part also be linked to social justice. Box 1 contains the requirements of the IFOAM Basic Standards pertaining to social justice. In addition, the recommendations state:

- operations should comply with all conventions of the International Labour Organization (ILO) relating to labour welfare and the UN Charter of Rights for Children;
- all employees and their families should have access to potable water, food, housing, education, transportation and health services;
- operators should provide for the basic social security needs of the employees, including benefits such as maternity, sickness and retirement benefits;
- all employees should have equal opportunity and adequate wages when performing the same level of work regardless of color, creed, and gender;
- workers should have adequate protection from noise, dust, light and exposure to chemicals that should be within acceptable limits in all production and processing operations;
- operators should respect the rights of indigenous peoples, and should not exploit land whose inhabitants or farmers have been or are being impoverished, dispossessed, colonized, expelled, exiled or killed, or which is currently in dispute regarding legal or customary local rights to its ownership;
- contracts should be fair, open to negotiation, and honoured in good faith.[3]

IFOAM social standards are non-comprehensive as compared to *Fair Trade Labelling Organisation* (FLO) or other social standards (SA8000, for example). However, they are based on *International Labour Organisation* (ILO) requirements and do represent a baseline of social concerns and a commitment to address social justice.
To summarize, for the purposes of exploring social sustainability, organic certification bodies can be divided into two sub-groups: IOAS-accredited or not. The 32 IOAS-accredited certification bodies must have social standards as part of their certification requirements. This ensures that some basic social justice concerns are addressed with organic production and processing certification. It is possible that organic certification bodies that are not IOAS-accredited may also have social standards, but there is no third-party verification system in place to check this.

[2] See IFOAM website: http://www.ifoam.org/organic_facts/principles/pdfs/Principles_Organic_Agriculture.pdf for details and for the elements of the “Principle of Care.”

[3] IFOAM (2002). IFOAM Basic Standards for Organic Production and Processing. Approved by the IFOAM General Assembly Victoria Canada August 2002.

Box 1 IFOAM Basic Standards (Chapter 8 on Social Justice)

Standards shall require that:

8.1 Operators shall have a policy on justice. Operators who hire fewer than ten (10) persons for labour and those who operate under a state system that enforces social laws may not be required to have such a policy.

8.2 In cases where production is based on violation of basic human rights and clear cases of social injustice, that product cannot be declared as organic.

8.3 Standards shall require that operators not use forced or involuntary labour.

8.4 Employees and contractors of organic operations have the freedom to associate, the right to organise and to bargain collectively.

8.5 Operators shall provide their employees equal opportunity and treatment, and shall not act in a discriminatory way.

8.6 Children employed by organic operators shall be provided with educational opportunities.

5.3 Issues addressed via more comprehensive social certification

The SASA (*Social Accountability in Sustainable Agriculture* – www.isealalliance.org/sasa) Project was a two year joint initiative of IFOAM, FLO, RA and SAI under the umbrella of the *International Social and Environmental Accreditation and Labeling* (ISEAL) *Alliance* that finished in April 2004. The Project was an innovative learning exercise that addressed key social issues in sustainable agriculture in terms of certification methodologies, compatibility of the social standards amongst the organisations involved, and key content issues such as the facilitation of small holder access to 'just' markets. The social auditing issues that were addressed in the SASA Project provide a clear indication of the kinds of concerns that need to be addressed in sustainable agriculture production and processing. The SASA Project covered the following social audit issues: (1) freedom of association and right to collective bargaining, (2) working hours, (3) seasonal workers, contracts and undocumented workers, (4) child labour, (5) health and safety, (6) wages/compensation, (7) discrimination, (8) basic treatment and disciplinary practices, and (9) forced labour. These represent the main social concerns that are currently part of the major social certification schemes. Although each organisation has different approaches and different requirements or priorities within this list, it provides a sound starting point for addressing social justice beyond the very basic social standards encapsulated within the organic requirements.
FLO's Fair trade criteria have a slightly broader focus than the social audit issues listed above that includes economic development in addition to labor conditions and human rights. The FLO Fair trade standards address the following concerns, amongst others:

- fair trade premium: the organisation has the commitment and capacity to administer the fair-trade premium in a way which is transparent for both the beneficiaries and FLO. Decisions are taken democratically;
- export ability: producers must have the logistical, administrative and technical means to bring a quality product to market;
- economic strengthening of the organisation: members will gradually take on more responsibility over the whole export process;
- price premium: producers receive a premium they can invest in the development of their co-operatives;
- long-term purchase guarantee: producer and buyer sign contracts that allow the producer and cooperative to make long-term plans;
- pre-financing/credit: producer is paid in advance at his request;
- producers receive a price for their product that covers the costs of sustainable production and living.

Fair trade standards are important to bear in mind in considering sustainable cotton as they often go hand-in-hand with organic certification (i.e. an operation may have both fair trade and organic certification), in developing country contexts However, Fair trade certification is not limited to organic production. The relevant FLO fair trade standards are those for cotton lint, and for cotton textiles and garments. Fair trade standards pertain particularly to small farmers cooperatives in 'developing countries' and, in some cases, to hired labor. For example, Max Havelaar Switzerland (a FLO member) certifies cotton from India, Pakistan, Mali and Senegal and Max Havelaar France certifies cotton grown in Mali, Senegal and Cameroon and in 2006 will also certify cotton from Burkina Faso. For 2005/2006, Max Havelaar France expects to certify approximately 20,000 cotton growers(Ratter 2005)[4].

Social concerns are also discussed more widely within the sustainable agriculture sector. For example, participants in a Social Justice Workshop held parallel to the IFOAM Organic Trade meeting in Bangkok (December 2003) compiled a list of social issues needing attention in sustainable agriculture[5] some of which are addressed through certification schemes, others not. They include the following:

- mechanisms needed for implementing social justice standards;
- no means for farmer price-setting outside market forces;
- no fair trade mechanisms in the North;
- limited capacity amongst farmers to set standards;
- no bottom-up strategies in place for evolving standards;
- no definition of child labor within the reality of the farmers;
- lack of food security mechanisms for small farmers;
- lack of standards for buyers – community/rights and responsibilities/pricing;
- lack of recognition for good practices among family/traditional farmers;
- assessing whether standards undercut traditional market models;
- no discussion of wild harvest products;
- no development element;
- undocumented workers must be more comprehensively addressed;
- better training for social justice needed (e.g. auditor training for social skills);
- chapter 8 in the IFOAM Basic Standards has no reference to price setting and subcontractor/operator relationships;
- land tenure of indigenous people needs to be addressed;
- lack of technical assistance for compliance to producers;
- IBS do not address farmers contracts with buyers;
- gender – standards address discrimination, but what about cultural values?
- uncertified organic or 'de facto' organic is not addressed in standards;
- regulations needed for the negotiation of fair contracts;
- farmers need access to government programs.

A significant step in assuring social sustainability for cotton would be to address the list of nine social issues addressed by the SASA Project (see above), while bearing in mind the larger context as reflected in some of the points raised at the Bangkok workshop. It must be noted that specific social issues needing attention in cotton production will vary by nation, region, and operation. That said, it is well-documented that occupational health and safety is a major concern in conventional cotton production (see also Mancini et al., 2005).

5.4 Potential socially and environmentally sustainable cotton supply chains

Cotton is a complex commodity in many ways. It combines social and environmental concerns at many points along the supply chain and will demand creative coordinated efforts in order to truly ensure and end product that is sustainable in both social and environmental realms. One of nine pilot audits for the SASA Project was in Uganda, looking at a large organic fair trade cotton cooperative and the parts of the supply chain that were within the country. The pilot audit experience covered the following steps in the chain: production (e.g. farmer fields and cooperative management); ginnery; spinning; dying; and cut-make-trim. The audit sought to consider how the social and environmental certification systems could coordinate in order to provide a fully certified end product for consumers. Gaps began to be understood and concerns about the

[4] Article entitled, "Textiles made of fair-traded cotton launched by Max Havelaar in several countries" 08.2005 by , Saro G. Ratter. Found on the PAN-Germany site on November 11 2005 http://www.pan-germany.org/info_db/gbr/news.html?id=56

[5] RAFI (2004). Social Justice Workshop Bangkok Thailand November 3-5 2003. Proceedings. Published, Pittsboro, NC.

cost distribution throughout the supply chain were raised as well as issues of traceability and cooperation amongst different certification schemes[6]. These issues remain pertinent and need further exploration.
Below is an illustration (figure 6) of some of the different steps in the processing/supply chain and certification options are provided as examples of how each level might be certified so as to ensure that social and environmental criteria are met. This is by no means a definitive guide but rather a tool to stimulate further thought on coordination for a more sustainable cotton end product.

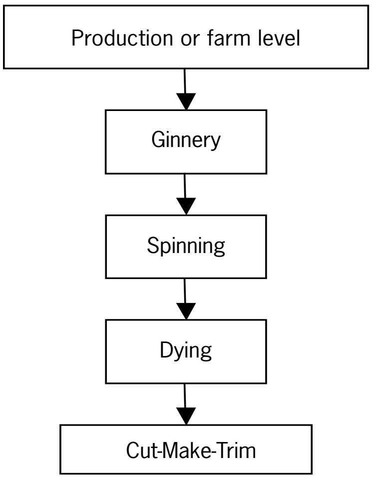

Figure 6: An example of a cotton processing/supply chain.

Production or farm level:
- organic certification of production and basic social standards for any size of operation;
- fair trade certification – social and economic standards with basic environmental, if it is a small producer cooperative.

Ginnery:
- fair trade certification as part of a small cooperative certification for social and economic standards;
- SA8000 certification of any size operation (though generally larger) of social criteria.

Spinning:
- SA8000 facility certification of social standards.

Dying:
- organic certification as to the dye recipes and toxicity levels (environmental sustainability;
- SA8000 certification of social criteria for the facility.

Cut-Make-Trim:
- fair trade for social criteria related to labor conditions (where linked to small producer organizations);
- SA8000 certification as to social criteria in the facility.

[6] From unpublished internal documents of the SASA Project and participation notes of the author of this section who was doing doctoral research through the SASA Project from February 2002-April 2004.

Pesticide shop in Amrawati, India. (Kooistra, 2004)

6 Discussion

The goal of this study was to compare the three major types of farming systems, conventional, IPM, and organic systems, in terms of environmental impact and which indicators would be useful for quantifying environmental impact. How these farming systems influence the subsequent cotton chain will also be discussed in this chapter.
A limited amount of data was available for analysis of the environmental impact of three types of cotton production systems. The reliability of sources is not always clear, or, alternatively, a reliable source is sometimes seriously criticised. An example of the latter is the publication in Science by Mäder et al. (2002), who concluded that energy use per unit of agricultural product was lower in organic than in conventional systems. This was extensively criticised by Trewavas (2004) and others. For the current study, time did not allow all potential uncertainties from the data provided to be traced and therefore, we concentrate on the clear-cut differences between farming systems. Clearly, more field-work must be done in order to evaluate the environmental effects of cotton systems.
It is interesting to speculate as to why so little has been published about the environmental impact of cotton systems, when cotton has likely the most impact on a global scale. Much cotton cultivation takes place in remote areas or in developing countries where it is difficult to obtain reliable information. Furthermore, agricultural LCA studies are quite rare. Another reason could be that environmental impact is not interesting for the processing and retail industry since it does not directly affect the production chain. In addition, the great heterogeneity among farm types hinders data extrapolation.

6.1 Environmental impact

Of the total cotton produced in 2004, an estimated 80% was produced under conventional farm management, 20% under IPM and 0.04% under organic management. Although in developed countries like the USA and Australia, regulations (including verification and monitoring) are such that most conventional farming can be regarded as IPM, pesticide and fertiliser use may still be high. Moreover, very large cotton fields existing in the USA and Australia may have significant impact on biodiversity (Chapter 4.8). In developing countries much conventional farming is far from sustainable, with demonstrated heavy pesticide impacts on the environment and on people. Pesticide use in cotton cultivation in developing countries is high: about 50% of pesticides are used in cotton cultivation and the types of pesticides used tend to be highly toxic (WHO classes I and II) and, although several developed countries have banned the most hazardous pesticides, they may still be in use illegally. With respect to environmental impact the main difference between the three systems is the amount of pesticides used, since aspects like water use, land clearing, and labour requirements are independent of the management system.
Average environmental impacts for a farming system are not good indicators of the environmental impact of a specific farm. Cotton practices especially within conventional systems vary greatly. For example, there is great diversity in farm size, degree of mechanisation, pesticide levels and fertiliser use, varying from no till, family-run farms of less than two hectares in Burkina Faso and India to highly mechanised 25,000 hectare farms in Brazil and the USA. Even within areas farm size and practices can vary enormously. For example, Kooistra et al. (2005) reported small conventional farms that did not use pesticides and other conventional farms of a similar size carrying out 12 pesticide applications per year. IPM projects in Asia and the United States have succeeded in reducing the amounts of pesticides used (Swezey et al., 2004). Small-scale organic farming systems in rain-fed areas show that it is possible to cultivate cotton without irrigation water and pesticides.

6.2 Indicators

To compare conventional, IPM and organic systems, or any other system, it is most relevant to take the effects of pesticides as a primary indicator as this indicator inflicts the greatest damage to people and the environment and is the most decisive factor distinguishing the three systems. To quantify pesticide use for a given farm, amounts and types of pesticides should be

known and it is crucial to have insight into the type of pesticide application (Chapter 2.3.4). The environmental impact could be assessed using the Environmental Impact Quotient (Kovach et al., 1992).
Pesticide use is however not the only factor expressing negative environmental impact. Notably water use and wide-spread negative consequences to cotton cultivation (Chapter 2.3.1) is a very significant factor, but as noted in Chapter 4.1, the sustainability of water use is not necessarily related to the type of farming system. Nevertheless, if current systems are compared in developing countries, then it should be noted that most organic cotton systems are rain-fed and the majority of conventional and IPM systems are irrigated, often unsustainably.
Water use implies more than simply monitoring the amount of irrigation water used per unit of agricultural surface, as water quality, probability of salinisation and vulnerability of the source to depletion are also important. To the best of our knowledge a comprehensive water use indicator has not yet been developed. Bos et al. (2005) provides an interesting proposal on water use efficiency in cotton fields, but this should be extended with sustainability of the water source. Because of the important environmental impact of water use related to cotton production systems, we recommend further research in this area. Since most cotton production is carried out in areas that are sensitive to salinisation and desertification, cotton production systems should be geared towards avoiding this, so that the land cropped to cotton can be used sustainably.
Global warming is strongly related to the amount of synthetic fertiliser and fuel used. Relatively fixed emission values are known for the production and use of both compounds. The same holds for eutrophication and acidification where also the burning of organic material is important. Burning of cotton residues is common practice in many conventional and IPM farms to reduce the build-up of pathogens such as *Verticillium dahliae*, which forms massive amounts of microsclerotia on the decaying shoot. Most likely the build-up of these pathogens is of lesser importance in systems where crop rotations are done.
The selection of the indicators will depend on the aim of the customer. If a specific company aims to lower its overall impact on the environment by buying more sustainably produced cotton, it would probably be a good choice to buy cotton from organic, low-input, rain-fed cotton farms in e.g. West Africa, India and Paraguay. It is, however, realistic to keep in mind that this would have significant additional cost implications to the company and hence the price of the end-product. If however the demand for this type of cotton would exceed the rain-fed area available (20% of the world cotton production), it could negatively affect land use. In that case, a balance needs to be found between an organic system with lower yields and a conventional system with higher yields. On the other hand, if the goal would be to decrease the environmental impact of the world's cotton production significantly, very likely large-scale support of IPM practices combined with more efficient irrigation systems would be the best option. Whether such an IPM system would then be environmentally better than an organic system depends of the quantity and types of pesticides allowed in the IPM system and the differences in yield between the two systems.
Clearly a significant step forwards can be made through farmer education as happens in IPM Farmer Field Schools and organic projects (often supported by Non-Governmental Organisations), given that the main practical problems (e.g. insect resistance to pesticides, uneconomic spraying and irrigation) are based in lack of knowledge vis a vis the agro-ecology of the cotton crop (FAO, 2004; personal communication Tobler, 2005). Further indicator development for water use, land use in terms of effects on wildlife, biodiversity, and destruction of natural habitats would be relevant in order to be able to quantify the environmental impact of cotton cultivation systems. A main research task is to generate information from cotton farms in tropical regions, so that environmental impacts can be quantified more precisely. Currently, all published LCA studies to date (Tobler & Schaerer, 2001; Laursen, 1997) and LCA software (Simapro, Ecoindicator, GaBi 4) rely on information from highly productive US cotton farms.

6.3 Choice of farming system

As illustrated above, the type of cotton production, conventional, IPM or organic, does not necessarily predict the environmental impact of a particular cotton farm. The difference between the three farming systems is less in developed countries and in places where subsistence conventional farming is applied without pesticides. In developed countries, conventional farming often approaches an IPM system because persistent and highly toxic pesticides are not allowed and the farmer is often aware that a sophisticated minimisation of pesticide use tends to be economically optimal. In terms of environmental impact, optimal IPM and organic systems converge to some extent in developed countries. In optimal systems, IPM scores well with respect to fertiliser use efficiency and the efficient use of narrow-range, low-persistence pesticides and in terms of higher yields. Organic farming scores well in terms of its wide rotations and lack of pesticide use. This, however, is not to say that the types of pesticides promoted by IPM are harmless. Still, more data are needed on yields of IPM and organic systems relative to the inputs required. Mäder et al. (2002) concluded for food rotations in Switzerland that organic production was more efficient in terms of inputs per unit of harvested products than IPM production. Although this is a widely different system than (sub)tropical cotton, it may indicate the potential of other organic systems.

Recently, Cherrett et al. (2005) calculated the ecological foot-print of different cotton systems on the basis of literature data. The ecological foot-print of cotton cultivation in Punjab was, irrespective whether it was organic or not, the highest (approx. 3.0 ha), while that of conventional and organic cotton cultivated in the USA was lower (approx. 2.6 and 1.8 ha respectively), which is due to the low yields per unit of area in Punjab. However, in this comparison the environmental effects of pesticide use have not been taken into account.

In less-developed countries, where most cotton farms are situated, differences between organic and conventional cotton production in terms of sustainability favour organic production of which the differences primarily lie in the unsustainable application of toxic pesticides in conventional systems. Thus, in future studies the usually higher yields in current conventional and IPM systems must be weighed against their levels of sustainability. Comparisons in yields between different farming types are lacking. Part of high yield levels in conventional systems is certainly due to an excessive use of pesticides. It should also be noted that conventional systems do not necessarily provide the highest yields (e.g., USA, Table 1).

The differences mentioned in potential yield between organic systems and conventional or IPM systems are largely due to the fact that in conventional systems crop growth can be better managed. Crop growth is managed through the use of artificial fertilisers, which can be directly taken up by plants, and by the application of synthetic pesticides, which can be used preventatively or curatively after a disease or pest has developed. By contrast, in organic systems, farmers have less flexibility as they rely primarily on organic manure that first needs to be mineralised by micro-organisms (which takes time) for plant nutrition, and on pesticides from natural origins which generally have a relatively low impact on selected pest and/or disease organisms.

An argument for prioritising organic rather than low impact conventional or IPM cotton production is that that organic cotton production is certified by independent third-parties. Although a consumer needs to be able to trust the certification body or label's claims, certified production systems offer a monitoring of farmer practices and farm-level evaluation of the system in place. Currently organic standards do not specifically address the origins of the land under cultivation (i.e. whether it was a natural area or agricultural land previously) nor do they address the origin and sustainability of the irrigation practises, despite general aims to promote an overall sustainable approach to production. For optimal, highly-technological conventional cotton production systems, standards and a verification system are necessary because without these elements, there is no way to differentiate clearly unsustainable conventional farming systems from more sustainable conventional farming systems. Having said this, the term 'conventional' (or IPM) may no longer be accurate for optimal systems. In conclusion, a clear description of a sustainable IPM system is needed as well as some form of system to verify that results are obtained with respect to the main impacts. Subsequently a label so that the consumer can identify end products as having come from that system.

6.4 Social and trade issues

Most verification and certification bodies mainly deal with one aspect of sustainability (social, environmental or economic) organic certificates mainly have environmental requirements, SA8000, FWF and ETI focus on social issues, and FLO (fair trade) concentrates on trade and development concerns. Some integration of the three aspects of sustainability is underway amongst standard-setters and certification bodies in recognition of the relevance of all three. For instance, IFOAM standards include six social requirements but these standards are only valid for production and do not address the whole supply chain for cotton.

6.5 Conclusions

- Water use (including the potential negative consequences of salinisation and water resource depletion) and pesticide use represent the greatest environmental problems in cotton systems. Water use and type of irrigation are not explicitly included in the standards for organic production at present. In principle, unsustainable water use may occur in all three farming types, although the majority of organic cotton systems are not irrigated. In developing countries most organic cotton is rain-fed while the majority of the IPM and conventional cotton is irrigated. The environmental impact of water use is considerably lower for rain-fed than for irrigated cotton, however the opportunities for yield gains by optimising water applications are also consequently lower.
- The widespread use of extremely and highly toxic pesticides in developing countries is a major concern both for the natural environment and for people who are exposed, especially workers applying these pesticides. Pesticide application methods strongly affect the potential impact on field workers and the environment; thus, the way field workers apply pesticides needs to be better understood.
- Biodiversity is negatively affected through the use of broad-spectrum pesticides, through conversion of natural habitats and through loss of land to degradation or shifting farming practices. For cotton production systems biodiversity is addressed through the land use and toxicity indicators. The effect on biodiversity of cropping vast areas of monoculture of cotton needs additional attention.
- Limited data on the environmental impact of cotton systems is available. In addition, the great heterogeneity of farm types hinders data extrapolation.
- Because of the great diversity in farming practises it is difficult to express the environmental impact of conventional, IPM and organic cotton farming on a systems level. The use of pesticides is highly problematic in several important cotton-producing countries and here the distinction between conventional and organic cotton production is evident.
- In developed countries conventional cotton production may to some extent approach IPM given that the most persistent and hazardous pesticides are not allowed and because inputs are increasingly optimised for cost reasons. However, the lack of clear-cut definitions for IPM and conventional systems also contributes to this conclusion.
- Organic farming is a certified type of production, while conventional is not, and IPM is generally not. With certified production it is easier for retailers and consumers to understand the history of the produce and thus make inferences about environmental impact. Although the general aims of organic farming are to promote an overall sustainable approach, the standards need improvement as they do not sufficiently address land and water use issues. For optimal, highly-technological conventional cotton production systems, a standards and verification system is necessary because otherwise there is no way to differentiate clearly unsustainable conventional farming systems from more sustainable conventional farming systems.
- Reflecting on the desirability of organic cotton production, water and land use issues should be kept in mind. Expanding the organic cotton area in rain-fed regions by converting low-input conventional farms to organic could be an optimal approach as yields can be as high as those in IPM and conventional cotton, water use can be generally sustainable, and no pesticides are used. This applies especially to countries that apply relatively hazardous pesticides. However, for conversion to organic cotton in irrigated areas it is necessary to address water and land use issues. Organic cotton production on eroded, pesticide-polluted and/or salinised soils would not be a viable option. Conversion to organic cotton production on large tracts of land that are mainly conventional can be a challenge if pest pressure is high.

6.6 Recommendations

- The current study could be extended by an analysis of each of the approaches against their characteristic visions and ultimate goals. Descriptions and definitions of optimal, most sustainable conventional and IPM cotton systems for both rain-fed and irrigated cotton are needed. Certification of such systems and labelling of products should be considered.
- Knowledge of what happens in the field is the basis for recommendations. Clearly for such an important crop as cotton more field work is needed to collect quantitative field data on environmental impact and yields in various developing and developed countries. This could lead to an extended Life Cycle Assessment comparing conventional/IPM and organic farms in several countries using the following indicators: Water use, Human and environmental toxicity, Global warming, Eutrophication, Acidification, Erosion, Land use, Biodiversity and Salinisation. Also the environmental impact of cotton production should be compared with the production of other fibres such as polyester, viscose, hemp, and linen (but see Cherrett et al., 2005 for first results on a comparison of cotton, polyester, and hemp).
- Further research is needed on how various stakeholders influence cultivation methods.
- Water and land use indicators need further development and implementation in LCA-cotton studies. The standard for organic production should also address these elements.
- The social, environmental, and trade-related issues that are particularly relevant for cotton production in different country contexts and at different points along the supply chain merit further research in order to build a comprehensive picture of sustainable cotton beyond just environmental indicators.
- Organic certification done by an IOAS-accredited certification body assures that a baseline level of social justice is maintained at the production level. To address more than these minimal social concerns, to address trade-related concerns and to address the other parts of the supply chain, other means are necessary. For example, Fair Trade Labelling Organisations (for small producer organisations) or Social Accountability International (for larger operations and other steps along the supply chain) are possible certification partners.
- Certification packages need to be constructed that address environmental, social, and trade-related concerns throughout the whole supply chain. Costing and traceability for such a system clearly needs attention.
- Verification and certification bodies in the three sustainability areas (social, environment, trade) should study how they can co-operate.

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Annex 1. Indicator used in cottan studies.

Indicator	Tobler, 2001	Clay, 2004	Slater, 2003	Kalliala, 1999	Blackburn, 2003	Dettenkofer, 2000	Leffland, 1997	Winkle, 1978	Weidema, 1999	Franklin, 1992	Laursen, 1997	Banuri, 1998	Aumonier, 2005	Dahllof, 2004	Olson ,2001
barren land (salinisation, soil life, erosion)		x										x			
water depletion soil and surfacewater		x													
human health, direct pesticide intake farm workers and regional inhabitants		x													
natural habitat conversion/forest cutting + dam construction		x													
wildlife contamination (insects, fish, mammals, birds)	x	x							x						
eutrophication of surface water	x	x		x		x	x		x				x	x	x
water consumption				x		x					x	x		x	
salinisation soil			x									x			
pesticides			x									x			
erosion			x									x			
pesticides in final cloth															
irrigation with surface water (m^3 ha^{-1} cotton)	x											x			
irrigation with groundwater (m^3 ha^{-1} cotton)	x											x			
rainfall (m^3 ha^{-1} cotton)	x														
el energy (gwp, kwk ha^{-1} cotton)	x			x	x			x		x	x				x
fossil fuel (gwp,kwh ha^{-1} cotton)	x										x			x	x
pesticides (g ha^{-1})	x										x	x			
defoliant, maturing agent (HM, g ha^{-1})	x														
artificial fertilizer (eutropohication, g ha^{-1})	x											x			
organic matter (eutrophication, g ha^{-1})	x														
non renewable resources				x											
global warming	x			x		x	x		x				x	x	x
acidification	x			x		x	x		x				x	x	x
oxidant formation				x									x	x	
human health impacts (CO, NO_x, SO_2,CH)	x			x		x	x		x				x		
total polluted air m^3				x											
nature occupation									x						
ozone formation									x						
ozone depletion	x								x				x		
solid waste	x									x	x				x
abiotic resource depletion													x		
freshwater toxicity													x		
terrestrial ecotox													x		