UNIVERSITY OF CAMBRIDGE
INSTITUTE FOR SUSTAINABILITY LEADERSHIP

Threading natural capital into cotton

Technical report

@CambridgeNatCap

The University of Cambridge Institute for Sustainability Leadership

For 800 years, the University of Cambridge has fostered leadership, ideas and innovations that have benefited and transformed societies. The University now has a critical role to play to help the world respond to a singular challenge: how to provide for as many as nine billion people by 2050 within a finite envelope of land, water and natural resources, whilst adapting to a warmer, less predictable climate.

The University of Cambridge Institute for Sustainability Leadership (CISL) empowers business and policy leaders to make the necessary adjustments to their organisations, industries and economic systems in light of this challenge. By bringing together multidisciplinary researchers with influential business and policy practitioners across the globe, we foster an exchange of ideas across traditional boundaries to generate new, solutions-oriented thinking. His Royal Highness The Prince of Wales is the Patron of CISL and plays an active role in its work. A particular strength of CISL is its ability to engage actors across business, finance and government. With deep policy connections across the EU and internationally, dedicated platforms for the banking, investment and insurance industries, and executive development programmes for senior decision-makers, it is well-placed to support leadership in both the real and financial economies.

Rewiring the Economy

Rewiring the Economy is our ten-year plan to lay the foundations for a sustainable economy. The plan is built on ten interdependent tasks, delivered by business, government and finance leaders co-operatively over the next decade to create an economy that encourages sustainable business practices and delivers positive outcomes for people and societies.

CISL is particularly focused on setting a bold ambition for business and innovating to deliver greater value (Task seven). CISL's Natural Capital Leaders Platform has focused on commodity-specific Action Research Collaboratories (ARCs) to consider how value can be created while having a neutral or positive impact on the natural world.

Publication details

Disclaimer
The opinions expressed here are those of the authors and do not represent an official position of CISL or any of its individual business partners or clients.

Authors and acknowledgments
The principal investigators and authors of this report and the Summary report are: Dr Gemma Cranston, Dr Jonathan Green and Hannah Tranter of CISL.

This document is part of a series of 'Doing business with nature' publications; these identify challenges and opportunities for companies whose future growth depends on a healthy and sustained supply of nature's goods and its services, known as 'natural capital'. The rationale for investing in sustainable natural capital management is set out in Doing business with nature: Opportunities from natural capital and has been further developed through commodity-specific Action Research Collaboratories (ARCs) for Dairy in the UK and Ireland and for Cotton (described here). This work forms the basis of the Cotton Tool.

The authors would like to thank all members involved in this Action Research Collaboratory (ARC) for their input and Steve Strebl who led the evidence review which underpins this work.

As well as the seven industry leaders who participated CISL would like to thank the Advisory Committee to this Collaboratory: At Stake Advisors (Sean Ansett), Better Cotton Initiative (Damien Sanfilippo), CottonConnect (Alison Ward, Deeti Vyas and Anna Karlsson Ellison), Cotton Incorporated (Kater Hake and Michele Wallace), Cotton made in Africa (Alexandra Perschau), Fairtrade (Subindu Garkhel), Textile Exchange (Liesl Truscott), Richard Sidebottom (University of Cambridge) and Simon Ferrigno (independent consultant).

Reference
Please refer to this paper as CISL. (2016).*Threading natural capital into cotton: Technical report.* Report by the Natural Capital Leaders Platform. Cambridge, UK: CISL.

Copies
This full document can be downloaded from CISL's website: www.cisl.cam.ac.uk

Contact
To obtain more information on the report, please contact Dr Gemma Cranston:
E: gemma.cranston@cisl.cam.ac.uk
T: +44 (0)1223 761711

February 2016

Collaboratory Members:

Contents

The Cotton Action Research Collaboratory

Cotton is a natural fibre worn throughout the world across socio-economic boundaries and is one of the world's most important crops; in 2014-15 it was grown across an estimated 34 million hectares (~2.5 per cent of the world's agricultural land) an area comparable to the size of Finland.

Seven businesses came together to spearhead this Cotton Action Research Collaboratory (ARC) with the ambition of ensuring that producers are able to meet future demand for high quality, ethically sourced and sustainably grown cotton.

This ARC explored 15 different interventions and the evidence of positive natural capital impacts for each. This assessment can support business decisions to guarantee that the natural capital underpinning the industry is used and managed more sustainably. The ARC focused on water, biodiversity and soil particularly at the growing stage of the supply chain where natural capital challenges are most prevalent.

The cotton industry is dependent upon natural capital. Sustainable cotton production requires healthy soils and biodiversity as well as access to sufficient water to provide for the crop's needs. These influence the quantity and quality of cotton yields as well as the crop's ability to cope with stresses such as drought or pest infestation. If poorly managed, these factors can combine to threaten cotton supply chains, influence prices and impact farmer livelihoods. There are some excellent examples of progress. By revealing the evidence of positive natural capital impacts from different management practices businesses can go further in securing sustainable supplies of cotton.

Making informed decisions about safeguarding the natural resources that cotton production depends upon is vital to ensure the long-term security of cotton supply chains. This project has identified the natural capital challenges to cotton production and evaluated evidence on how 15 different interventions impact on natural capital. It is clear that there are opportunities to reduce negative natural capital impacts and thus reduce business vulnerabilities and risk. The study focused upon natural capital but acknowledges the broader sustainability issues, such as poverty, labour issues, and socio-economic resilience within which it sits.

This work is a first step towards assembling the appropriate evidence for best practice around sustaining natural capital. It will help businesses to have informed discussions with their supply chains and farmers so these are secured for the future.

The ARC has produced several pieces of work:

• The Threading natural capital into cotton: Doing business with nature report presents the case for natural capital and cotton and calls on the industry, cotton initiatives and researchers to take some of its findings forward into action.

• This technical report explores 15 different interventions, including drip irrigation and pesticide use optimisation, and analyses the scientific evidence regarding the impacts of these practices upon natural capital.

• The Cotton Tool equips users with some in-depth knowledge of fifteen different cotton management interventions so that they can then engage on these key areas with supply chain partners.

Setting the scene

There are a variety of management interventions that are adopted to improve cotton yields, address environmental issues, or secure natural capital at the growing stage of the cotton supply chain. Fifteen key interventions that are commonly considered to be beneficial for natural capital were selected to be investigated. These were determined by members of the Collaboratory and expert advisors and fall into four categories:

1. Water consumption	Drip irrigation	Deficit irrigation	Irrigation with brackish or saline water		
2. Soil fertilisation	Recycling cotton gin waste	Fertilisation using plant waste	Animal manure		
3. Pest management	Organic pesticide	Pesticide use optimisation	Habitat management for predators	Promoting biocontrol through genetic modification	
4. Land and diversity management	Crop rotation	Habitat diversity	Keeping a tidy farm	Removing volunteer cotton	Limiting cotton expansion

Water, soil and biodiversity are all fundamental for growing cotton, and it is often assumed that the above interventions can help to secure these elements; however, this is not fully substantiated. Without evidence for positive impact upon these natural capital elements it is difficult for businesses to have meaningful discussions with their supply chains about possible improvements.

This Technical Report describes the finding from a systematic review of the scientific evidence for the effectiveness of these interventions in delivering positive outcomes for water, biodiversity and soil. Businesses can use this resource to have confident discussions with their cotton producers to secure sustainable cotton within their supply chains.

A total of 160 academically and peer reviewed published studies were critically reviewed. The evidence highlighted whether those interventions had previously been successful in providing positive impacts on natural capital. The review exposed a geographical imbalance with limited scientific data available in certain regions.

Many of the interventions, and their sub-elements, are referred to in widely endorsed programmes and standards that consider Integrated Pest Management (IPM), Good Agricultural Practices (GAP) core agro-ecological principles, fair prices, decent work, local resource inputs, and natural habitat conservation.

The systematic review of evidence revealed two messages:
1. There are several evidence based options for cotton farmers and the supply chains to better manage their natural capital impacts and reduce their vulnerability to its degradation
2. For many of the selected interventions there is poor understanding of how they impact natural capital within specific contexts

How to use this document

The 15 key interventions were researched through a systematic review, based on the Conservation Evidence process[a] and using a search and filtering framework (Figure 1, page 8). This document synthesises the 160 different studies that were reviewed to provide evidence on how the 15 interventions impact natural capital. Each chapter represents an intervention and outlines the underpinning evidence for the impacts of this cotton management intervention on natural capital.

The following 15 chapters include the following sub sections:

Section	***Purpose***
1 Description	• To introduce the intervention
2 Quick facts	• To briefly explain the definition and purpose of the intervention • To introduce the key benefits delivered by the intervention
3 Synthesis 3.1 Impact summary of the intervention 3.2 Soil 3.3 Water 3.4 Biodiversity	• To present the key messages from the individual studies • To outline the impacts on soil, water and biodiversity
4 Evidence review	• To detail the individual studies, present their geographical regions of experimentation • To categorise the evidence according to its quality (Table 1) • To highlight the impacts on a key areas of interest to business (Table 2-6)
5 Bibliography	• To identify the studies that were critically reviewed

Not all interventions are applicable to all production systems and considerations such as size (small-scale/large-scale), system (organic/non-organic) and conditions (non-irrigated/irrigated) are considered within **the Cotton tool**.

Quality of Evidence	
CRR	controlled, randomised, replicated
C	controlled
RR	randomised, replicated
C Rep	controlled, replicated
C Ran	controlled, randomised
Rep	replicated
Ran	randomised

Table 1: The quality of the evidence and studies was categorised.

[a]The Conservation Evidence process summarises evidence from the scientific literature about the effects of conservation interventions, such as methods of habitat or species management. It is designed to support decisions about how to maintain and restore global biodiversity.
More information at: http://www.conservationevidence.com/

	Water:	Including water quality and/or quantity
	Biodiversity:	Including diversity and/or abundance
	Soil:	Including structure and/or fertility

Table 2: Natural capital classification

Positive	Proven positive impact derived from abundance of scientific evidence.
No evidence	This outcome does not change the status quo or direct causal relationship has not been established. If current common practice is abandoned in favour of this intervention, this indicator will not be influenced.
Negative	Proven negative impact derived from abundance of scientific evidence.
Limited evidence	There is limited evidence to report on impacts.

Table 3: Impact on natural capital elements

$	**Low:** Affordable solution for the majority of farmers in developing as well as developed countries. Knowledge, risk management or other non-financial factors could be the only obstacles preventing implementation.
$$	**Medium:** The solution faces some capital requirements, imposing some constraints on implementation, which may be amplified in a developing country environment. However, the solution would produce a reasonable return on investment if implemented.
$$$	**High:** Capital intensive solution, which could be highly problematic for developing as well as developed countries to implement due to financial requirements. The solution may not be viable from a supply chain perspective.

Table 4: Relative values of costs

	Increases: Evidence shows that the intervention increases yields
	Decreases: Evidence shows that the intervention decreases yields
	Is not affected: Yield has not changed as a result of the intervention
	Limited evidence: There is limited or mixed evidence on the impacts of the intervention on yields and no conclusion can be drawn

Table 5: Impacts on yield

	Increases: Evidence shows that the intervention generally improves the spinnability of cotton fibre
	Decreases: Evidence shows that the intervention frequently lowers the spinnability of cotton fibre
	Is not affected: There is no evidence that the intervention consistently impacts the spinnability of cotton fibre

Table 6: Impact on fibre quality

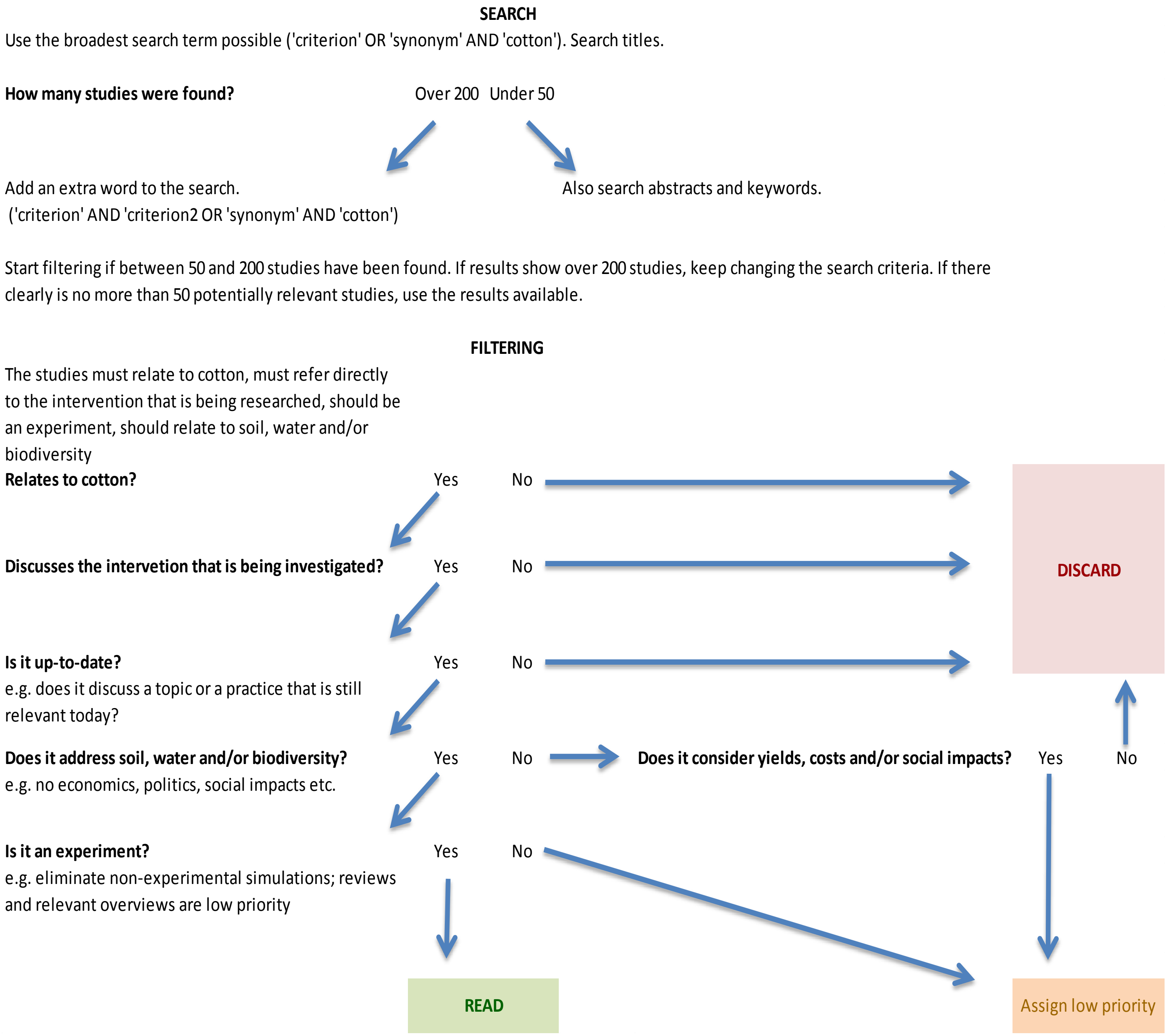


Figure 1: The evidence was reviewed and assessed according to a systematic search and filtering process.

Water consumption

Section Overview

Cotton production consumes water in the form of either green, blue or grey[a] water. Production systems in certain parts of the world, including those of smallholders in Africa, depend upon green water (rainwater that is stored within soils); rainfed cotton can therefore be considered to be the most efficient in terms of water use. Three interventions were identified that were relevant for cotton production systems that depend on blue water (surface and ground water). These were then evaluated by using particular search criteria (See Appendix 1.1: Primary Search and Appendix 1.2: Secondary Search).

Section Chapters

Chapter 1: Drip Irrigation

Evidence			Yield	Cost	Quality
Positive	Positive	Limited	Increases	High	Increases

Definition and purpose: Installing surface or sub-surface irrigation systems to provide water directly to plant roots and reduce evaporative water losses
Benefits: Maximises water use efficiency; minimises losses to evaporation; and reduces weed growth

Chapter 2: Deficit Irrigation

Evidence			Yield	Cost	Quality
None	Positive	Limited	Decreases	Low	Is not affected

Definition and purpose: Implementing irrigation schedules that maximise water use efficiency rather than yield per unit area as a means of reducing water consumption
Benefits: Maximises water use efficiency; relieves pressure on water supplies; and minimises negative impacts to yield or quality

Chapter 3: Irrigation with Brackish or Saline Water

Evidence			Yield	Cost	Quality
Negative	Positive	None	Decreases	Low	Decreases

Definition and purpose: Using water with high salt concentration to irrigate crops and to reduce freshwater consumption for cotton production in water scarce areas
Benefits: Reduces reliance on scarce freshwater supplies; and increases cotton production in water scarce areas while potentially damaging soil structure and causing soil aggregates to disperse (deflocculation)

[a]Green water is water stored within the soils and replenished by rainfall, blue water is surface or ground water and the water that is polluted in the course of cotton production is referred to as grey water.

1 Drip irrigation

1.1 Description

Cotton can be grown under irrigated or rainfed ('dry') conditions. Drip irrigation is generally considered the most water-efficient way of irrigating a field, as it applies water in precise quantities directly to the plant's roots, thereby minimising waste. There are two types of drip irrigation systems – surface and subsurface. Surface systems apply water through a set of pipes laid on the surface, whereas subsurface systems moisturise the roots directly through a system of buried tubes, thus reducing losses due to evaporation and preventing weed growth.

1.2 Quick facts

Definition and purpose: Installing surface or sub-surface irrigation systems to provide water directly to plant roots and reduce evaporative water losses

Benefits: Maximises water use efficiency; minimises losses to evaporation; and reduces weed growth

1.3 Synthesis

Drip irrigation has profound impacts on water, moderate impacts on soil and minor impacts on biodiversity. All conclusions below are based solely on studies examining data from and relating directly to cotton production.

Six studies (of which two were controlled, randomised and replicated, and two were controlled and replicated) conclude that drip irrigation **increases yield**[1-6]. Three studies (including one controlled, randomised, replicated in Australia) find no effect[7-9].

1.3.1 Impact summary of the intervention

In total, 15 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
Limited evidence	Positive	Limited evidence	Positive	Limited evidence	Limited evidence	Increases	High	Increases

1.3.2 Soil

One study (controlled, randomised, replicated) concludes that subsurface drip irrigation **nearly eliminates erosion and runoff**, as opposed to furrow irrigation[10].

The evidence on **how drip irrigation affects soil salinity** remains inconclusive. A controlled, randomised, replicated study from China asserts that drip irrigation increases soil salinity more than flood irrigation[11], whereas an experiment from India associates drip irrigation with lower soil salinity levels than furrow irrigation methods[3]. Different types of soil and initial salinity in China and India likely caused the contradictory conclusions.

1.3.3 Water

Ten studies (of which two are controlled, randomised and replicated, two that are controlled and replicated and one which is replicated) indicate **higher water-use efficiency** with drip irrigation compared to other methods (e.g. furrow)[1-8,12,13]. One study (controlled, randomised, replicated from Australia) finds no effect on water savings[9]. The study notes that its results refer to a specific type of heavy clay soil (Vertisol) with high water retention capabilities for which drip irrigation does not yield extra water use efficiency benefits; in light soils that lose water faster due to gravity however, drip irrigation has been found more beneficial. One study finds increased water-use efficiency of drip irrigation only under water-stressed conditions[8].

One study (controlled, randomised, replicated) suggests that **aerated water applied** through drip irrigation in heavy soils improves yields and achieves higher water efficiency[6]. The field study confirmed earlier small-scale experiments with aerated water that had arrived at the same conclusion.

1.3.4 Biodiversity

Studies tend not to refer to biodiversity. Two studies (both randomised and replicated) show that furrow irrigation and water-stress are associated with **higher incidences of whitefly infestations**[14,15], suggesting that implementing drip irrigation may lower these incidences. Some studies suggest that sprinkler irrigation may act to depress whitefly populations on cotton but do not compare this to the effectiveness of drip irrigation methods[16] and were therefore not assessed as part of the review.

1.4 Evidence review

1.4.1 Asia

1.4.1.1 Water use efficiency of irrigated cotton in Uzbekistan under drip and furrow irrigation[4]

Key message: Drip irrigation increases water-efficiency and yields, compared to furrow irrigation.

Location: Tashkent, Uzbekistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				CRR			CRR

A controlled, replicated, randomised experiment conducted in Tashkent, Uzbekistan on deep silt loam (Calcic Xerosol) aimed to establish cotton water use, yield, and water-use efficiency under full and deficit irrigation, compare these variables for drip and furrow irrigation, and determine the best settings for irrigation in order to maximize yield and achieve the best water-use efficiency. Two irrigation scheduling treatments with drip irrigation and one with furrow irrigation as a control were used. Irrigation was scheduled when water in the root zone was depleted to 70% of the field capacity (default value 0.30 m^3 $m-^3$). Water-use efficiency for drip irrigation significantly exceeded water-use efficiency of furrow irrigation (0.82-1.12 kg/m3 compared to 0.55-0.62 kg/m3). Drip irrigation consumed 18-42% less water and produced 10-19% higher yield, compared to furrow irrigation.

1.4.1.2 *Localized salt accumulation: the main reason for cotton root length decrease during advanced growth stages under drip irrigation with mulch film in a saline soil*[11]

Key message: Drip irrigation increases soil salinity more than flood irrigation.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Negative					
Quality		CRR					

A controlled, randomised, replicated experiment conducted on sandy loam in Xinjiang, China examined cotton root length and soil salt accumulation in drip irrigation under plastic mulch, using flood irrigation under plastic mulch as a control. The root length under drip irrigation decreased during both years of the study. By contrast, it remained unchanged under flood irrigation. The authors attributed the reduction in length to salt accumulation, as the areas with shorter root length coincided with areas of higher salt concentration (shorter length was observed when electrical conductivity exceeded 2.8 mS/cm). Both drip and flood irrigation marked an increase in soil salinity concentration, but the increase was higher for drip irrigation. Soil salinity increases were also more localized for drip irrigation, as opposed to flood irrigation with more even distribution.

1.4.1.3 *Cotton use and water use efficiency at various levels of water and N through drip irrigation under two methods of planting*[1]

Key message: Drip irrigation saves water, increases yield.

Location: Punjab, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				C Rep			C Rep

A controlled, replicated experiment in Punjab, India on loamy sand revealed that the same quantity of water applied through drip irrigation, as opposed to check-basin irrigation, increased yields by 32% (2144kg/ha to 1624kg/ha). The experiment was performed on an experimental farm with three drip irrigated plots (treatment) and one check-basin (surface flooding) plot as a control. Additionally, each treatment was applied on two different methods of sowing – paired rows and conventional (normal) rows. When the quantity of water was reduced to 75%, the yields were still 12% higher than the control's yields at 100% water. When the quantity dropped to 50%, yields were only 2% lower than the check-basin. Also, paired sowing used half the water than what was required for normal sowing (due to half the number of laterals required for irrigation), but produced only 16% less yield (1949kg/ha compared to 2144kg/ha both at 100% water). Drip irrigated paired rows planting still resulted in 20% higher yield than the check-basin method (1949kg/ha to 1624kg/ha). The study presented evidence that paired rows planting (as opposed to normal rows) in combination with drip irrigation offered a cost-effective solution to arid regions, such as Punjab, to conserve water without sacrificing yield.

1.4.1.4 Effect of drip and furrow irrigation methods on Bemisia tabaci populations in cotton fields[14]

Key message: Furrow irrigation and water stress are associated with higher whitefly populations.

Location: Aydin, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive*	Positive*	
Quality					RR	RR	

*Inferred positive impact on biodiversity based on assumed lower use of insecticide.

A replicated, randomised experiment in Aydin, Turkey explored effects of furrow and drip irrigation on trends in populations of whiteflies (*Bemisia tabaci*) – a cotton pest. Both drip and furrow irrigated plots were subjected to different rates of irrigation, specifically 100% (full irrigation), 66% and 33%. The experiment revealed that populations tended to be higher for furrow than for drip irrigated plots and then for the 33% treatment in either plots. Nevertheless, the population never reached the economic injury level in any plot. The study suggested reducing water-stress to reduce populations of whiteflies, regardless of the method of irrigation.

1.4.1.5 Drip vs. surface irrigation: A comparison focusing on water saving and economic returns using multicriteria analysis applied to cotton[12]

Key message: Drip irrigation is more water-efficient, but not economically viable for farmers.

Location: north-eastern Syria

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			
Quality				Simulation			

A simulation based on data collected in north-eastern Syria compared different irrigation systems in terms of water efficiency and economic returns. The study pointed out that a drip irrigation system, albeit more water-efficient, would require an upfront investment equal to 24-53% of a local farmer's annual income. Variable costs of running different irrigation systems were similar.

1.4.1.6 Comparative effects of drip and furrow irrigation on the yield and water productivity of cotton in a saline and waterlogged vertisol[3]

Key message: Drip irrigation saves water, increases yields and is associated with lower soil salinity.

Location: Karnataka, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive		Positive			Positive
Quality							

An experiment in Karnataka, India examined the differences between furrow and drip irrigation and four quantities of irrigation water based on evapotranspiration (0.8, 1.0, 1.2 and 1.4 times the evapotranspiration rate) in regards to water use, yields and soil salinity. Drip irrigated plots produced 38% higher yields. At the same time, they consumed 21.5% (0.8 evapotranspiration), 16.3% (1.0), 12.3% (1.2) and 9.1% (1.4) of water. Both irrigation methods marked approximately quadratic increases in yields with increasing quantity of water (11%, 33% and 15% increase as opposed to 0.8 evapotranspiration rate for drip and 17%, 65% and 30% for furrow). Also, higher soil salinity occurred in furrow irrigated plots.

1.4.1.7 Effects of different irrigation methods on shedding and yield of cotton[2]

Key message: Drip irrigation saves water, increases yields.

Location: Anatolia, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				4 years			4 years

A four year experiment on clay (cracking, and thus with high infiltration rate 15 mm/h) in Anatolia, Turkey compared furrow, sprinkler and drip irrigation at different quantities of water. The authors found that drip irrigation produced the highest yields (2070-4900 kg/ha), followed by furrow irrigation (2610-3640 kg/ha) and sprinkler irrigation (850-3380 kg/ha). On average, the drip irrigated plot produced 21% more seed-cotton than the furrow plot and 30% more than the sprinkler system. The study discovered a quadratic relationship between amount of water applied and yields. In terms of water-use efficiency, the drip irrigation method achieved the highest with 4.87 kg/ha/mm, followed by furrow (3.87 kg/ha/mm) and sprinkler (2.36 kg/ha/mm).

1.4.1.8 Deficit irrigation and nitrogen effects on seed cotton yield, water productivity and yield response factor in shallow soils of semi-arid environment[5]

Key message: Drip irrigation saves water, increases yields. Deficit irrigation has little to no effect on water-use efficiency.

Location: Pali-Marwar, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				C Rep			C Rep

A controlled, replicated experiment on a fine loamy soil in Pali-Marwar, India looked at the interaction of six levels of deficit irrigation applied through and four levels of nitrogen application. The authors used drip irrigation to carry out the experiment and a furrow irrigated plot as a control. The deficit irrigation levels were based on evapotranspiration ratio (1.0 or full irrigation, 0.9, 0.8, 0.7, 0.6 and 0.5). The fertiliser rates were 80, 120, 160 and 200 kg/ha. Lastly, the authors tested the response to a plant growth mineral spray that either was or was not applied. The furrow irrigated plot was only tested for full irrigation and 0.5 evapotranspiration and received 140 kg/ha of N fertiliser. In all comparable cases (that is, full and 0.5 irrigation), the drip irrigation system saved water and produced superior yields. The fully irrigated drip system used 23% and 28% less water (14% and 19% for 0.5) and produced 36.5% and 50.1% higher yield than the fully irrigated furrow plot in the first and the second year, respectively. Yield declined proportionally with decreasing quantity of irrigation water. The effectiveness of the plant growth mineral spray also dropped with decreasing quantity of water (yield increased 16-18% for 1.0-0.8 irrigation, but only 10-12% for lower irrigation levels).

Water-use efficiency did not vary significantly with different deficit irrigation levels. Still, water-use efficiency was numerically slightly higher at 0.9-0.7 irrigation than at any other level. Increasing the level of nitrogen, however, did increase water-use efficiency.

1.4.2 Australia and Oceania

1.4.2.1 Benefits of oxygation of subsurface drip-irrigation water for cotton in a Vertosol[6]

Key message: Aerated water applied through subsurface drip irrigation on heavy clay soils improves yields and water-efficiency.

Location: central Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				CRR			CRR

A controlled, randomised, replicated study on a Vertosol in Australia investigated the impact of aerated water applied through subsurface drip irrigation on cotton growth. The treatment was water with 12% air by volume and the control was normal water with no air added. The authors chose twelve plots and randomly assigned them to six replications of two irrigation treatments over seven years. The study found that on average cotton lint yields were 7% higher and gross production water-use index was 10% higher compared to the control field.[10]

1.4.2.2 Effects of subsurface drip irrigation rates and furrow irrigation for cotton grown on a vertisol on off-site movement of sediments, nutrients and pesticides[10]

Key message: Subsurface drip irrigation minimizes erosion, runoff.

Location: central Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive	Positive				
Quality	CRR	CRR	CRR				

A controlled, randomised, replicated experiment on a Vertisol in central Queensland, Australia examined impacts of different types of irrigation on erosion and runoff. The study compared subsurface drip irrigated plots at different water regimes and furrow plots as controls. Four irrigation treatments were tested based on crop evapotranspiration rate: 50%, 75%, 90%, 120% (later reduced to 105%). The study found that furrow irrigation eroded more soil, carrying away 5.97 t/ha, as opposed to subsurface drip irrigation (2.53 t/ha) and deficit drip irrigation, which did not erode soil at all. Though subsurface drip irrigation reduces erosion, it can also cause erosion even on heavy clay soils if more water is applied than required by daily crop evapotranspiration demand. In regards to runoff, furrow irrigation caused a higher outflow of nutrients off the field. Nitrogen was removed at 15.1 kg/ha compared to 2.9 kg/ha for drip irrigation. Furrow irrigation also moved 778 g/ha of phosphorus compared to none for drip irrigation. Deficit drip irrigation did not remove any nitrogen or phosphorus. Lastly, furrow irrigation and subsurface drip irrigation at 120% removed several herbicides applied in prior seasons. Overall, however, furrow irrigation removed more herbicides than drip irrigation. Deficit irrigations removed none (with one exception for drip at 90%).

1.4.2.3 The response of cotton to subsurface drip and furrow irrigation in a Vertisol[9]

Key message: Drip irrigation does not affect yields or water-use efficiency on Vertisols.

Location: central Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				No effect			No effect
Quality				CRR			CRR

A controlled, randomised, replicated experiment on a Vertisol in central Queensland, Australia examined impacts of different types of irrigation on cotton yields and quality. The study compared subsurface drip irrigated plots at different water regimes and furrow plots as controls. Four irrigation treatments were tested based on crop evapotranspiration rate: 50%, 75%, 90%, 120% (later reduced to 105%). The experiment confirmed that irrigation above field capacity caused waterlogging, thus reducing yield. Overall, yields were higher with furrow irrigation, especially in the second year of the two year study. Nevertheless, the difference between the 75% treatment and furrow irrigation was negligible in the first year. In terms of water use, drip irrigation demonstrated higher irrigation efficiencies (crop water use to applied irrigation water) with 80% for the 120% treatment plot and 93% for the 105% treatment plot compared to 65-67% for furrow irrigation. However, water-use efficiency did not show a clear pattern, as it was higher for drip irrigation in the first year and lower in the second. The authors suggested that heavy clays such as vertisols retain water better than light soils, where drip irrigation may prevent loss of water due to gravitation. Also, water-stressed cotton matured earlier, in particular by 25 days for the 50% treatment group. Lower yields associated with water-stress, however, could be justified if the introduction of another crop produced water and pesticide savings. Lastly, lint quality did not show any consistent pattern.

1.4.3 Europe

1.4.3.1 A comparison between drip and furrow irrigation in cotton at two levels of water supply[8]

Key message: Drip irrigation performs better than furrow irrigation under water-stressed conditions.

Location: Cordoba, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			No effect
Quality							

An experiment performed on sandy loam in Cordoba, Spain compared two irrigation systems (drip and furrow), three cultivars (Coker, Jaen, Tabladilla) and two quantities of water (full and deficit irrigation). Deficit irrigation applied 75% of the calculated optimum amount of water. Under both full and deficit conditions, drip irrigation yielded less than furrow irrigation in the first year and more in the second year. The study found similar water-use efficiencies for both irrigation methods (6.3-6.5 kg $ha^{-1}mm^{-1}$ for drip and 6.2 for kg $ha^{-1}mm^{-1}$ for furrow). However, drip irrigation performed better under deficit conditions (7.2-7.3 kg $ha^{-1}mm^{-1}$ versus 6.0-6.3 kg $ha^{-1}mm^{-1}$).

1.4.3.2 Effect of subsurface drip irrigation on cotton plantations[13]

Key message: Subsurface drip irrigation is better for dry conditions than surface drip irrigation.

Location: Larissa, Greece

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			
Quality				Rep			

A replicated experiment on clay (calcic chromoxerert) in Greece compared surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) systems in terms of yields and water use efficiency. The authors divided the experimental field in two with one half under SDI and the other under SSDI. Additionally, four irrigation treatments were used with different quantitites of water based on crop evapotranspiration (120%, 100%, 80% and 60%). The advantages of SSDI were prominent especially during dry conditions and in deficit irrigation when its water-use efficiency exceeded that of SDI by more than 20%. The experiment showed little difference between the two under full and excessive irrigation or in wetter conditions. Also, SSDI exhibited weaker weed growth.

1.4.4 North America

1.4.4.1 The effects of drip or furrow irrigation of cotton on Bemisia argentifolii[15]

Key message: Furrow irrigation and water stress are associated with higher incidence of *Bemisia argentifolii*.

Location: Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive*	Positive*	
Quality					RR	RR	

*Inferred positive impact on biodiversity based on assumed lower use of insecticide.

A randomised, replicated experiment on sandy loam in Arizona, USA investigated the effects of drip and furrow irrigation and three irrigation levels (aimed at inducing low, intermediate and high water stress) on populations of *Bemisia argentifolii* (sweetpotato whiteflies – common pest). The study suggested that nymphs and eggs tended to occur in greater number on water-stressed cotton and on furrow irrigated plots, although this was not the case every year of the study. The authors also changed cultivars during the study and concluded that Deltapine 77 exhibited greater resistance to whiteflies than Deltapine 50.

1.4.4.2 Evaluation a of drip vs. furrow irrigated cotton production system[7]

Key message: Drip irrigation is more water-efficient, does not affect yields.

Location: Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			No effect
Quality				Low			Low

An experiment in Arizona, USA compared the performance of drip and furrow irrigated systems. The furrow field consisted of Pima silty clay loam and the drip field was 2/3 Gila loam and 1/3 Vinton-Anthony sandy loam. The study determined that the drip irrigated cotton grew higher and retained more fruit. The drip irrigated field also maintained stable soil moisture, as opposed to fluctuations noticed in the furrow field. In terms of water usage, 20-25 acre-inches of water was applied to the drip irrigated plot, compared to 60 acre-inches for the furrow irrigated one. Yields were similar for both irrigation methods. However, water-use efficiency was 25 lbs. of lint per acre-inch of water for furrow and 70-80 lbs. of lint of acre-inch of water for the drip method. It should be noted that the study lacked controls, randomization or replication and both fields grew different cultivars, thus hampering somewhat the validity of the study.

1.5 Bibliography

[1]Aujla, M. S., Thind, H. S., & Buttar, G. S. (2005). Cotton yield and water use efficiency at various levels of water and N through drip irrigation under two methods of planting. *Agricultural Water Management, 71*(2), 167-179. doi: 10.1016/j.agwat.2004.06.010

[2]Cetin, O., & Bilgel, L. (2002). Effects of different irrigation methods on shedding and yield of cotton. *Agricultural Water Management, 54*(1), 1-15.

[3]Rajak, D., Manjunatha, M. V., Rajkumar, G. R., Hebbara, M., & Minhas, P. S. (2006). Comparative effects of drip and furrow irrigation on the yield and water productivity of cotton (Gossypium hirsutum L.) in a saline and waterlogged vertisol. *Agricultural Water Management, 83*(1-2), 30-36. doi: 10.1016/j.agwat.2005.11.005

[4]Ibragimov, N., Evett, S. R., Esanbekov, Y., Kamilov, B. S., Mirzaev, L., & Lamers, J. P. A. (2007). Water use efficiency of irrigated cotton in Uzbekistan under drip and furrow irrigation. *Agricultural Water Management, 90*(1-2), 112-120. doi: 10.1016/j.agwat.2007.01.016

[5]Singh, Y., Rao, S. S., & Regar, P. L. (2010). Deficit irrigation and nitrogen effects on seed cotton yield, water productivity and yield response factor in shallow soils of semi-arid environment. *Agricultural Water Management, 97*(7), 965-970. doi: 10.1016/j.agwat.2010.01.028

[6]Pendergast, L., Bhattarai, S. P., & Midmore, D. J. (2013). Benefits of oxygation of subsurface drip-irrigation water for cotton in a Vertosol. *Crop & Pasture Science, 64*(11-12), 1171-1181. doi: 10.1071/Cp13348

[7]Norton, E., & Silvertooth, J. (2001). Evaluation of a drip vs. furrow irrigated cotton production system. *Cotton: A College of Agriculture Report*.

[8]Mateos, L., Berengena, J., Orgaz, F., Diz, J., & Fereres, E. (1991). A Comparison between Drip and Furrow Irrigation in Cotton at 2 Levels of Water-Supply. *Agricultural Water Management, 19*(4), 313-324. doi: 10.1016/0378-3774(91)90024-D

[9]Bhattarai, S. P., Mchugh, A. D., Lotz, G., & Midmore, D. J. (2006). The response of cotton to subsurface drip and furrow irrigation in a vertisol. *Experimental Agriculture, 42*(1), 29-49. doi: 10.1017/S0014479705003029

[10]Mchugh, A. D., Bhattarai, S., Lotz, G., & Midmore, D. J. (2008). Effects of subsurface drip irrigation rates and furrow irrigation for cotton grown on a vertisol on off-site movement of sediments, nutrients and pesticides. *Agronomy for Sustainable Development, 28*(4), 507-519. doi: 10.1051/Agro:2008034

[11]Mai, W. X., Tian, C. Y., & Li, L. (2014). Localized salt accumulation: the main reason for cotton root length decrease during advanced growth stages under drip irrigation with mulch film in a saline soil. *Journal of Arid Land, 6*(3), 361-370. doi: 10.1007/s40333-014-0001-0

[12]Darouich, H. M., Pedras, C. M. G., Goncalves, J. M., & Pereira, L. S. (2014). Drip vs. surface irrigation: A comparison focussing on water saving and economic returns using multicriteria analysis applied to cotton. *Biosystems Engineering, 122*, 74-90. doi: 10.1016/j.biosystemseng.2014.03.010

[13]Kalfountzos, D., Alexiou, I., Kotsopoulos, S., Zavakos, G., & Vyrlas, P. (2007). Effect of subsurface drip irrigation on cotton plantations. *Water Resources Management, 21*(8), 1341-1351. doi: 10.1007/s11269-006-9085-4

[14]Gencsoylu, I., Horowitz, A. R., Sezgin, F., & Oncuer, C. (2003). Effect of drip and furrow irrigation methods on Bemisia tabaci populations in cotton fields. *Phytoparasitica, 31*(2), 139-143. doi: 10.1007/Bf02980783

[15]Flint, H. M., Radin, J. W., Parks, N. J., & Reaves, L. L. (1995). The Effects of Drip or Furrow Irrigation of Cotton on Bemisia-Argentifolii (Homoptera, Aleyrodidae). *Journal of Agricultural Entomology, 12*(1), 25-32.

[16]Castle, S.J., Henneberry, T.J., & Toscano, N.C. (1996). Suppression of *Bemisia tabaci* (Homoptera: Aleyrodidae) infestations in cataloupe and cotton with sprinkler irrigation. *Crop Protection, 15(7),* 657-663.

2 Deficit irrigation

2.1 Description

Deficit irrigation maximises water efficiency, rather than yields per unit area. In practice, this means watering the crop less than would be optimal. Whilst, deficit irrigation reduces water consumption enormously per unit area (by approximately 25%), there is only a relatively minor drop in yields (5-15%). In water-stressed regions, this strategy may relieve pressure on water supplies, whist minimising yield losses.

2.2 Quick facts

Definition and purpose: Implementing irrigation schedules that maximise water use efficiency rather than yield per unit area as a means of reducing water consumption

Benefits: Maximises water use efficiency; relieves pressure on water supplies; and minimises negative impacts to yield or quality

2.3 Synthesis

Deficit irrigation primarily affects water consumption with most studies devoted to measuring efficiency of water use under water-stressed conditions. Two studies relate plant water-stress to biodiversity. No studies linking deficit irrigation to effects on soils were found. Four studies from the same author and based on the same experiment with the same conclusions were counted as one in the total impact counts below[1-4].

2.3.1 Impact summary of the intervention

In total, 26 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
			Positive	Limited evidence	Limited evidence	Decreases	Low	Is not affected

2.3.2 Soil

No effects on soil have been identified.

2.3.3 Water

Fifteen studies (ten randomised and replicated, of which six are also controlled) highlight **superior water-use efficiency** of deficit irrigation, especially under mild water-stress[1,5-18]. Five studies (four replicated, of which one is randomised and one controlled) find no effect[19-23]. Deficit irrigation represents a typical Pareto 80:20 case: reduced supply of water may decrease yields slightly, but will maximise water-use efficiency. **Deficit irrigation within drip irrigation systems generally finds highest water-use efficiency -** around 70-80% of ‘optimum’ or ‘full irrigation’ level. Thus, for arid regions experiencing frequent water shortages implementing deficit irrigation using a drip irrigation system would be worth considering.

Additionally, one replicated study compares surface and subsurface drip systems. The study recommends subsurface drip irrigation for arid conditions, stressing its superior performance under water-stress (with no difference found between the two under regular conditions)[15].

As for scheduling optimisation, one study reveals a quadratic relationship between yields and water quantity, suggesting that under- as well as over-irrigation decrease yields. The same study also suggests using canopy temperature to schedule irrigation[14]. One study (randomised, replicated) recommends using thermal imagery to measure canopy temperature for irrigation scheduling purposes[16]. One study shows that cotton reacts differently to water stress during different growing stages[17]. A different study, however, indicates that different irrigation intervals do not affect yield or quality of cotton[23].

2.3.4 Biodiversity

In regards to biodiversity, two studies (both randomised, replicated) associate **plant water-stress with higher incidence of whitefly infestations**[24,25].

2.4 Evidence review

2.4.1 Asia

2.4.1.1 Evaluation of mulched drip irrigation for cotton in arid Northwest China[18]

Key message: Cotton exhibits different sensitivity to water stress and saline water during different stages of its life.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				CRR			CRR

A controlled, randomised, replicated experiment in Xinjiang, China showed that cotton exhibits different sensitivities to water salinity and water stress during different parts of the growing season. Based on numerical simulations and modelling, the study suggested that drip irrigation alternating fresh and brackish water and subsequent flood irrigation with freshwater (that allows for leaching of salt accumulated in the soil) would constitute a sustainable irrigation practice.

2.4.1.2 Assessment of yield and water use efficiency of drip-irrigated cotton as affected by deficit irrigation[2]

Key message: Deficit irrigation increases water-efficiency.

Location: Damascus, Syria

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				RR			RR

A randomised, replicated study conducted in Damascus, Syria on sandy clay loam compared water-use efficiency on plots irrigated with different quantity of water: fully irrigated, 80%, 65% and 50% of the full irrigation level. Although the fully irrigated plots produced higher seed cotton yield, the highest water-use use efficiency was found for the 80% deficit irrigation level, which increased water-use efficiency by 8-14% and produced only marginally lower yield. Therefore, deficit irrigation was found to be more suitable for areas experiencing water shortages. The study also found that irrigation had little to no effect on fibre quality.

2.4.1.3 Yield and water use efficiency of drip irrigated cotton at different irrigation intervals and watering regimes[7]

Key message: Deficit irrigation increases water-efficiency.

Location: The Aegean, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality							

A study conducted in the Aegean region of Turkey examined effects of different irrigation levels on yields and water use efficiency. The study looked at two irrigation intervals (4 days and 8 days) and three watering regimes for each interval: 100% (full irrigation), 67% and 33% of full irrigation. Full irrigation at 8 day interval produced the highest yield, but 67% treatment at 8 day interval achieved the highest water-use efficiency, saving 33% of water, while sacrificing only 6% of the yield.

2.4.1.4 Different drip irrigation regimes affect cotton yield, water use efficiency and fibre quality in western Turkey[8]

Key message: Deficit irrigation increases water-efficiency.

Location: Aydin, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				CRR			CRR

A controlled, randomised, replicated experiment in Western Turkey on Entisols and Fluvisols-Regosols measured the impacts of different amounts of water applied through drip irrigation. The control and treatments were based on soil water depletion and were determined as 100% (full irrigation), 75%, 50%, and 25%. The study discovered a linear relationship between seed-cotton yield and water use. The 25% treatment achieved the highest water use efficiency and produced the lowest yield, whereas 100% control resulted in the exact opposite. The study recommended 75% deficit irrigation as the best option for water stressed arid regions, as this treatment saved 25% of water, while reducing yield by 17.1%. Looking at fibre quality, the results were inconsistent, but the scholars claimed that the highest quality was achieved with deficit irrigation.

2.4.1.5 Effects of deficit drip irrigation on ratios on cotton yield and fibre quality[9]

Key message: Deficit irrigation increases water-efficiency.

Location: Aydin, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				CRR			CRR

A controlled, randomised, replicated experiment in Western Turkey on loam and sandy loam measured the impacts of different irrigation water quantities on yield, water use efficiency and fibre quality. Application of water was determined according to soil water depletion, which was given as the difference between the depth of water held in the root zone at field capacity and the depth of water actually held. Four treatment levels (0%, 25%, 50%, 75%) were compared to full irrigation (100%) used as a control. Water use efficiency was increasing, as the amount of water was decreasing. However, the study found that reduction of water by 25% led to only a 7.5% drop in yield, whereas a reduction by 50% decreased yields by 20%. Also, deficit irrigation always decreased seed-cotton yield, but the difference between full irrigation and the 75% treatment was not significant. Therefore, 75% irrigation level was found to be the most appropriate solution for situations of water shortage. The study also indicated that deficit irrigation might have negatively affected the quality of fibre in some respects (fibre length). However, the difference in the quality of fibre was significant for only one of the two years of the experiment and response to other determinants of quality such as fibre strength was inconsistent.

2.4.1.6 Lint yield and seed quality response of drip irrigated cotton under various levels of water[10]

Key message: Deficit irrigation greatly increases water-use efficiency, decreases yields slightly.

Location: Northern Iran

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				RR			RR

A randomised, replicated study in northern Iran compared the performance of cotton crop under four irrigation regimes: full irrigation (100% of class A pan evaporation), 70%, 40% and 0%). The authors identified a quadratic relationship between lint yield and irrigation regime. Lint yield decreased 4% for the 70% treatment and 14% for the 40% treatment. These two treatments also produced the highest seed quality.

2.4.1.7 *Effect of drip and furrow irrigation methods on Bemisia tabaci populations in cotton fields*[24]

Key message: Furrow irrigation and water stress are associated with higher whitefly populations.

Location: Aydin, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	**Fertility**	**Quality**	**Quantity**	**Diversity**	**Abundance**	
Impacts					Negative*	Negative*	
Quality					RR	RR	

* Inferred negative impact on biodiversity based on assumed higher use of insecticide under deficit irrigation conditions.

A replicated, randomised experiment in Aydin, Turkey explored effects of furrow and drip irrigation on trends in populations of whiteflies (*Bemisia tabaci*) – a cotton pest. Both drip and furrow irrigated plots were subjected to different rates of irrigation, specifically 100% (full irrigation), 66% and 33%. The experiment revealed that populations tended to be higher for furrow than for drip irrigated plots and then for the 33% treatment in either plots. Nevertheless, the population never reached the economic injury level in any plot. The study suggested reducing water-stress to reduce populations of whiteflies, regardless of the method of irrigation.

2.4.1.8 *Applicability of micro irrigation system on cotton yield and water use efficiency*[19]

Key message: More water leads to higher yields, water-use efficiency data do not display a clear pattern.

Location: Kerman province, Iran

	Soil		Water		Biodiversity		Yield
	Structure	**Fertility**	**Quality**	**Quantity**	**Diversity**	**Abundance**	
Impacts				No effect			No effect
Quality				RR			RR

A randomised, replicated study in Kerman province, Iran tested cotton's response to three different irrigation regimes (125%, 100% and 75% of plant water requirement) and two ways of arranging the irrigation pipes (conventional and alternative). The 125% treatment produced the highest yield (2610 kg/ha), followed by the 100% treatment (2231 kg/ha) and 75% treatment (1406 kg/ha). According to the authors, however, the difference between the two most water-intensive treatments was insignificant. Also, conventional pipe arrangement yielded 16% more raw cotton than alternative arrangement. Conventional arrangement also achieved more favourable water-use efficiency with the 100% treatment ranking at the top (0.223 kg/m^3) followed by the 125% treatment (0.210 kg/m^3). Nevertheless, the authors recommended the alternative system at 100% irrigation level as the most suitable for places facing similar climatic conditions as the study area, because it cost 20% less to implement and produced only 377 kg/m^3 less yield.

2.4.1.9 *Physiological response and water-saving effect of regulated deficit irrigation in cotton*[11]

Key message: Deficit irrigation increases water-use efficiency.

Location: north-western China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality							

An experiment on light loamy soil in north-western China subjected pot-grown cotton to three soil water content levels at late seedling, budding stage or both. Fully watered plants produced the highest yield, but water-stressed plants performed better in terms of water-use efficiency. The highest water-use efficiency (0.462 kg m^{-3}) was achieved with roughly 77% of the water used to irrigate the most watered plant. Additionally, the study showed that deficit irrigation could reduce excessive vegetative growth, thus improving canopy conditions and yield efficiency.

2.4.1.10 *Deficit irrigation and nitrogen effects on seed cotton yield, water productivity and yield response factor in shallow soils of semi-arid environment*[21]

Key message: Drip irrigation saves water, increases yields. Deficit irrigation has little to no effect on water-use efficiency.

Location: Pali-Marwar, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				No effect			Negative
Quality				C Rep			C Rep

A controlled, replicated experiment on fine loamy soil in Pali-Marwar, India looked at the interaction of six levels of deficit irrigation applied through and four levels of nitrogen application. The authors used drip irrigation to carry out the experiment and a furrow irrigated plot as a control. The deficit irrigation levels were based on an evapotranspiration ratio (1.0 or full irrigation, 0.9, 0.8, 0.7, 0.6 and 0.5). The fertiliser rates were 80, 120, 160 and 200 kg/ha. Lastly, the authors tested the response to a plant growth mineral spray that either was or was not applied. The furrow irrigated plot was only tested for full irrigation and 0.5 evapotranspiration and received 140 kg/ha of N fertiliser. In all comparable cases (that is, full and 0.5 irrigation), the drip irrigation system saved water and produced superior yields. The fully irrigated drip system used 23% and 28% less water (14% and 19% for 0.5) and produced 36.5% and 50.1% higher yield than the fully irrigated furrow plot in the first and the second year, respectively. Yield declined proportionally with decreasing quantity of irrigation water. The effectiveness of the plant growth mineral spray also dropped with decreasing quantity of water (yield increased 16-18% for 1.0-0.8 irrigation, but only 10-12% for lower irrigation levels). Water-use efficiency did not vary significantly with different deficit irrigation levels. Still, water-use efficiency was numerically slightly higher at 0.9-0.7 irrigation than at any other level. Increasing the level of nitrogen, however, did increase water-use efficiency.

2.4.1.11 Simulating cotton yield response to deficit irrigation with the FAO AquaCrop model[12]

Key message: Deficit irrigation saves water, decreases yield, increases water-use efficiency slightly at 80% of the full irrigation level, but has no effect at other levels.

Location: Damascus, Syria

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				RR			RR

A randomised, replicated experiment on sandy clay loam in Damascus, Syria examined full irrigation (irrigated at 100% of soil water depletion) and deficit irrigation at 80%, 65% and 50%, aiming to calibrate the FAO AquaCrop model for the eastern Mediterranean. Yields increased linearly with additional water. The highest water-use efficiency was for the 80% treatment every year, ranging between 0.7 and 0.72 kg/m^3 compared to 0.62 and 0.67 kg/m^3 for the other treatments. The AquaCrop model, however, did not predict any visible pattern in water-use efficiency.

2.4.1.12 Evapotranspiration and water use of full and deficit irrigated cotton in the Mediterranean environment in northern Syria[22]

Key message: Deficit irrigation does not affect water-use efficiency.

Location: near Aleppo, Syria

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				No effect			Negative
Quality				Rep			Rep

A replicated experiment on fine clay 35km from Aleppo, Syria tested cotton yield and water efficiency performance under four irrigation levels (40%, 60%, 80% and 100% or full irrigation) and three nitrogen fertilisation levels (100, 150 and 200 kg/ha) using drip irrigation. The study found linear relationships between yields and nitrogen, yields and water quantity, and water quantity and water-use efficiency. Water-use efficiency values oscillated between 0.23kg/m^3 at the 40% treatment with the lowest nitrogen level to 0.51 kg/m^3 at full irrigation with the highest nitrogen level. Therefore, the study concluded that deficit irrigation did not improve water-use efficiency in cotton production.

2.4.1.13 Effects of deficit irrigation on the yield and yield components of drip irrigated cotton in a Mediterranean environment[11]

Key message: Deficit irrigation increases water-use efficiency, optimum irrigation level is 70%.

Location: Adana, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				CRR			CRR

A controlled, randomised, replicated experiment on heavy clay in Adana, Turkey examined the response of cotton to full irrigation (100% of water) and deficit irrigation at 70%, 50% and 0% (or dryland) water based on crop evapotranspiration. The study identified a quadratic relationship between irrigation water amount and seed-cotton yield and a near-linear relationship between evapotranspiration and yield. On average, the 70% treatment saved 26% of water and produced only 6% less yield than full irrigation. The 50% treatment saved 51% of water and produced 23% less yield than full irrigation. Water-use efficiency values decreased with increasing amounts of water in all four years of the study. The authors concluded that deficit irrigation significantly affected seed-cotton yield and recommended 70% deficit irrigation to be used under water-stressed conditions.

2.4.1.14 Yield and water relations of cotton-maize cropping sequence under deficit irrigation using drip system[5]

Key message: Deficit irrigation increases water-efficiency.

Location: Coimbatore, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				CRR			CRR

A controlled, randomised, replicated study in Coimbatore, India performed on sandy clay examined deficit irrigation and its relation to yields. The experiment involved cotton and maize grown in sequence on a no-till field. Six plots on which different amounts of water were applied were investigated and one surface furrow irrigated plot was used as a control. The study found a second degree polynomial relationship between water use and yields (for both cotton and maize), which was in contrast to cited previous experiments describing a linear relationship. The authors concluded that mild water stress induced by alternate deficit irrigation (corresponding to 100% evapotranspiration coefficient once in every three days) achieved the best ratio between yields and water-use efficiency.

2.4.1.15 Soil moisture distribution and root characters as influenced by deficit irrigation through drip system in cotton-maize cropping sequence[2]

Key message: More water stress produced lengthier roots.

Location: Coimbatore, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality	Based on the same experiment as #7						

A controlled, randomised, replicated experiment on sandy clay in Coimbatore, India studied the effect of deficit irrigation on soil moisture distribution and root growth in cotton-maize cropping sequence. The study was designed to test six treatments based on evapotranspiration: conventional irrigation at 100 %(full irrigation), 100% and 50% in first and second irrigation cycle (mild deficit), alternate deficit irrigation at 100% (50% conventional once in six days), conventional drip at 80%, 80% and 40% in first and second irrigation cycle and 80% in alternate cycle (conventional of 40% once in six days). Furrow irrigation was used as a control. The results revealed that water stress influenced root systems of cotton and maize. Water-stressed cotton tended to grow deeper, as its roots searched for water. Under alternate deficit irrigation, water stress at first reduced the dry weight, but the plants then recovered quickly and the dry mass of their root systems exceeded the fully watered plants.

2.4.1.16 Influence of deficit irrigation on growth, yield and yield parameters of cotton-maize cropping sequence[3]

Key message: Deficit irrigation increases water-use efficiency, mild water deficit achieves the highest water-use efficiency.

Location: Coimbatore, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality	Based on the same experiment as #7						

A controlled, randomised, replicated experiment on sandy clay in Coimbatore, India studied the effect of deficit irrigation on yield and yield parameters in cotton-maize cropping sequence. The study was designed to test six treatments based on evapotranspiration: conventional irrigation at 100 %(full irrigation), 100% and 50% in first and second irrigation cycle (mild deficit), alternate deficit irrigation at 100% (50% conventional once in six days), conventional drip at 80%, 80% and 40% in first and second irrigation cycle and 80% in alternate cycle (conventional of 40% once in six days). Furrow irrigation was used as a control. Full irrigation produced the highest yields and the best yield parameters such as the most sympodial branches and bolls per plant. Deficit irrigation significantly influenced all characteristics, but the study concluded that water-use efficiency increased as water use decreased for both cotton and maize. The mild deficit treatments produced better results in terms of water efficiency than other treatments (9.0 kg ha^{-1} mm^{-1} in both years of the study for 100% and 50% alternate treatment and 9.2 and 8.9 kg ha^{-1} mm^{-1} for 80% and 40% alternate treatment).

2.4.1.17 Effect of deficit irrigation on yield, relative leaf water content, leaf proline accumulation and chlorophyll stability index of cotton-maize cropping sequence[4]

Key message: Cotton physiology parameters react to water stress.

Location: Coimbatore, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality	Based on the same experiment as #7						

A controlled, randomised, replicated experiment on sandy clay in Coimbatore, India studied the effect of deficit irrigation on relative leaf water content, chlorophyll stability index and leaf proline content in cotton-maize cropping sequence. The study was designed to test six treatments based on evapotranspiration: conventional irrigation at 100 %(full irrigation), 100% and 50% in first and second irrigation cycle (mild deficit), alternate deficit irrigation at 100% (50% conventional once in six days), conventional drip at 80%, 80% and 40% in first and second irrigation cycle and 80% in alternate cycle (conventional of 40% once in six days). Furrow irrigation was used as a control. The results indicated that relative leaf water content and chlorophyll stability index were highest and leaf proline content was lowest in mildly water stressed plants.

2.4.2 Australia and Oceania

2.4.2.1 Estimation of soil water deficit in an irrigated cotton field with infrared thermography[16]

Key message: Thermal imagery accurately indicates plant water stress and could be used to schedule irrigation.

Location: near Toowoomba, Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				RR			RR

A randomised, replicated experiment on Vertosol (heavy cracking clay) 20 km west of Toowoomba, Queensland, Australia investigated the possibility of using thermal imagery (photos of plant canopy made with infrared cameras) to discover plant water stress and use it to help schedule irrigation. Four irrigation treatments were examined based on 50%, 60%, 70% and 85% of plant available water capacity. The study concluded that thermal imagery could be used as an accurate indicator of plant water stress.

2.4.3 Europe

2.4.3.1 Effect of limited drip irrigation regime on yield, yield components, and fiber quality of cotton under Mediterranean conditions[1]

Key message: Deficit irrigation increases water-efficiency.

Location: Athens, Greece

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				RR			RR

A randomised, replicated experiment conducted on clay loam in Athens, Greece compared the yields, growth characteristics and fibre quality for cotton under full irrigation (100% of evapotranspiration) and deficit irrigation (50%) using a surface drip irrigation system. Two cultivars commonly grown in Greece were tested: Julia and Zoi. Full irrigation produced the highest yields, but the reduction in yield under deficit irrigation was only 16% for Julia and 28% for Zoi. The study did not find any statistically significant impact of deficit irrigation on quality characteristics, except for fibre length, which was 3% shorter for Julia and 3.7% shorter for Zoi.

2.4.3.2 Effect of subsurface drip irrigation on cotton plantations[15]

Key message: Subsurface drip irrigation is better for dry conditions than surface drip irrigation.

Location: Larissa, Greece

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				Rep*			Rep*

*No difference between surface and subsurface systems under full irrigation.

A replicated experiment on clay (calcic chromoxerert) in Greece compared surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) systems in terms of yields and water use efficiency. The authors divided the experimental field in two with one half under SDI and the other under SSDI. Additionally, four irrigation treatments were used with different quantity of water based on crop evapotranspiration (120%, 100%, 80% and 60%). The advantages of SSDI were prominent especially during dry conditions and in deficit irrigation when its water-use efficiency exceeded that of SDI by more than 20%. The experiment showed little difference between the two under full and excessive irrigation or in wetter conditions. Also, SSDI exhibited weaker weed growth.

2.4.4 North America

2.4.4.1 Cotton yield and applied water relationships under drip irrigation[18]

Key message: Canopy temperature performed better for drip irrigation scheduling than soil water replacement methods. There is a quadratic relationship between yields and water quantity.

Location: Lubbock, Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality				meta-analysis			meta-analysis

A meta-analysis of data gathered between 1988 and 1999 in experimental, controlled, replicated surface drip irrigation scheduling studies performed on Olton clay loam in Texas, USA concluded that canopy temperature of 28°C was ideal for scheduling drip irrigation, as it produced higher yields compared to soil water replacement method. Water was applied to cotton in quantities ranging from deficit to excessive amounts. The results indicated that yields were positively correlated with heat. They were also positively correlated with water quantity up to a point. The highest yields were estimated at 74cm of water applied between planting and crop maturity or at irrigation input of 58cm (the difference was rain).

2.4.4.2 Cotton response to subsurface drip irrigation frequency under deficit irrigation[23]

Key message: Different irrigation intervals do not affect yield or quality.

Location: St. Lawrence region, Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				No effect			No effect
Quality				Rep			Rep

A replicated experiment on silty clay loam in St. Lawrence region in Texas investigated the impact of different deficit irrigation frequencies on cotton lint yield and quality over two seasons. Using subsurface drip irrigation, the study tested irrigating at 4 and 16 day intervals in the first year and 2 and 8 day intervals in the second year. The same total amount of water was applied each year for each irrigation frequency. No significant differences were found in yields or quality in either year. The study concluded that irrigation intervals of 16 days or less with subsurface drip irrigation did not influence cotton response, provided the soil had adequate water holding capacity. Thus, farmers in water-stressed regions could use more flexibility in managing their water resources.

2.4.4.3 Evapotranspiration of full-, deficit-irrigated, and dryland cotton on the Northern Texas High Plains[20]

Key message: There is a linear relationship between yields and water quantity. Impact of irrigation on water-use efficiency is inconclusive.

Location: Bushland, Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				No effect			No effect
Quality				Low			Low

An experiment on clay loam in Northern Texas High Plains compared growth performance, water use and yields in fully irrigated, deficit irrigated and dryland cotton. The fully irrigated field achieved better growth parameters, but the growth pattern of dryland and deficit-irrigated cotton was similar (even though deficit-irrigated cotton grew somewhat more). In terms of water-use efficiency, the authors found a linear relationship indicating that more water resulted in higher water use efficiency. Water-use efficiency values in the two years of the study were 0.092 and 0.103 kg m^{-3} for dryland, 0.144 kg and 0.219 kg m^{-3} for deficit-irrigated and 0.194 and 0.151 kg m^{-3} for fully irrigated cotton. Therefore, it seems that additional water increased water-use efficiency, but the data did not reveal any clear pattern. On average, deficit irrigation achieved slightly higher water-use efficiency than full irrigation. Dryland cultivation was the worst performer in terms of water-use efficiency.

2.4.4.4 Evaluation of FAO-56 crop coefficient procedures for deficit irrigation management of cotton in a humid climate[26]

Key message: FAO-56 can be used to estimate crop water needs under deficit irrigation in humid climates.

Location: Griffin, Georgia, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							Positive
Quality							

An experiment on high sand content (92%) soil in Griffin, Georgia, USA examined the usefulness of FAO-56 tool (guidelines for computing crop water requirements from the Food and Agriculture Organization of the United Nations) in humid climates. Cotton was planted in three rainout shelters and irrigated at different rates (triggered at 40%, 60% and 90% of the available water content). The paper confirmed that FAO-56 procedure was a reliable method for estimating cotton evapotranspiration under deficit irrigation in humid climates.

2.4.4.5 Deficit irrigation for enhancing sustainable water use: Comparison of cotton nitrogen uptake and prediction of lint yield in a multivariate autoregressive state-space model[13]

Key message: Deficit irrigation increases water-use efficiency, maximising it at 75% of full irrigation.

Location: Southern High Plains, Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Negative
Quality							

An experiment on sandy loam in the southern High Plains in Texas, USA examined the performance of cotton under deficit irrigation. Two irrigation treatments (50% and 75% of the optimum water quantity based on expected evapotranspiration) were tested. The study did not include a fully irrigated plot, opting to compare the results against data from earlier studies instead. The results showed that irrigation at 50% evapotranspiration reduced lint yield by 25% and saved 33% of water, compared to full irrigation. Irrigating at 75% caused only a 7.8% loss in lint yield, but saved 25% of water. The authors concluded that the 75% irrigation level offered the best option for water conservation.

2.4.4.6 The effects of drip or furrow irrigation of cotton on Bemisia argentifolii[25]

Key message: Furrow irrigation and water stress are associated with higher *Bemisia argentifolii* population.

Location: Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Negative*	Negative*	
Quality					RR	RR	

* Inferred negative impact on biodiversity based on assumed higher use of insecticide under deficit irrigation conditions.

A randomised, replicated experiment on sandy loam in Arizona, USA investigated the effects of drip and furrow irrigation and three irrigation levels (aimed at inducing low, intermediate and high water stress) on populations of *Bemisia argentifolii* (sweetpotato whiteflies – common pest). The study suggested that nymphs and eggs tended to occur in greater number on water-stressed cotton and on furrow irrigated plots, although this was not the case every year of the study. The authors also changed cultivars during the study and concluded that Deltapine 77 exhibited greater resistance to whiteflies than Deltapine 50.

2.5 Bibliography

[1]Papastylianou, P. T., & Argyrokastritis, I. G. (2014). Effect of limited drip irrigation regime on yield, yield components, and fiber quality of cotton under Mediterranean conditions. *Agricultural Water Management, 142*, 127-134. doi: 10.1016/j.agwat.2014.05.005

[2]Sampathkumar, T., Pandian, B. J., & Mahimairaja, S. (2012). Soil moisture distribution and root characters as influenced by deficit irrigation through drip system in cotton-maize cropping sequence. *Agricultural Water Management, 103*, 43-53. doi: 10.1016/j.agwat.2011.10.016

[3]Sampathkumar, T., Pandian, B. J., Rangaswamy, M. V., Manickasundaram, P., & Jeyakumar, P. (2013). Influence of deficit irrigation on growth, yield and yield parameters of cotton-maize cropping sequence. *Agricultural Water Management, 130*, 90-102. doi: 10.1016/j.agwat.2013.08.018

[4]Sampathkumar, T., Pandian, B. J., Jeyakumar, P., & Manickasundaram, P. (2014). Effect of Deficit irrigation on Yield, Relative Leaf Water Content, Leaf Proline Accumulation and Chlorophyll Stability Index of Cotton-Maize Cropping Sequence. *Experimental Agriculture, 50*(3), 407-425. doi: 10.1017/S0014479713000598

[5]Sampathkumar, T., Pandian, B. J., Ranghaswamy, M. V., & Manickasundaram, P. (2012). Yield and Water Relations of Cotton-Maize Cropping Sequence under Deficit irrigation Using Drip System. *Irrigation and Drainage, 61*(2), 208-219. doi: 10.1002/Ird.6446.

[6]Hussein, F., Janat, M., & Yakoub, A. (2011). Assessment of yield and water use efficiency of drip-irrigated cotton (Gossypium hirsutum L.) as affected by deficit irrigation. *Turkish Journal of Agriculture and Forestry, 35*(6), 611-621. doi: 10.3906/tar-1008-1138

[7]Dagdelen, N., Sezgin, F., Gurbuz, T., Yilmaz, E., Akcay, S., & Yesilirmak, E. (2009). Yield and Water Use Efficiency of Drip Irrigated Cotton (Gossypium hirsutum L.) at Different Irrigation Intervals and Watering Regimes. *Philippine Agricultural Scientist, 92*(2), 193-200.

[8]Dagdelen, N., Basal, H., Yilmaz, E., Gurbuz, T., & Akcay, S. (2009). Different drip irrigation regimes affect cotton yield, water use efficiency and fiber quality in western Turkey. *Agricultural Water Management, 96*(1), 111-120. doi: 10.1016/j.agwat.2008.07.003

[9]Basal, H., Dagdelen, N., Unay, A., & Yilmaz, E. (2009). Effects of Deficit Drip irrigation Ratios on Cotton (Gossypium hirsutum L.) Yield and Fibre Quality. *Journal of Agronomy and Crop Science, 195*(1), 19-29. doi: 10.1111/j.1439-037X.2008.00340.x

[10]Ghaderi-Far, F., Khavari, F., & Sohrabi, B. (2012). Lint yield and seed quality response of drip irrigated cotton under various levels of water. *International Journal of Plant Production, 6*(1), 115-128.

[11]Shi, W. J., Kang, S. Z., & Song, X. Y. (2004). Physiological response and water-saving effect of regulated deficit irrigation in cotton. *Water-Saving Agriculture and Sustainable Use of Water and Land Resources, Vols 1 and 2, Proceedings*, 117-121.

[12]Hussein, F., Janat, M., & Yakoub, A. (2011). Simulating cotton yield response to deficit irrigation with the FAO AquaCrop model. *Spanish Journal of Agricultural Research, 9*(4), 1319-1330. doi: 10.5424/sjar/20110904-358-10

[13]Li, H., & Lascano, R. J. (2011). Deficit irrigation for enhancing sustainable water use: Comparison of cotton nitrogen uptake and prediction of lint yield in a multivariate autoregressive state-space model. *Environmental and Experimental Botany, 71*(2), 224-231. doi: 10.1016/j.envexpbot.2010.12.007

[14]Unlu, M., Kanber, R., Koc, D. L., Tekin, S., & Kapur, B. (2011). Effects of deficit irrigation on the yield and yield components of drip irrigated cotton in a mediterranean environment. *Agricultural Water Management, 98*(4), 597-605. doi: 10.1016/j.agwat.2010.10.020

[15]Kalfountzos, D., Alexiou, I., Kotsopoulos, S., Zavakos, G., & Vyrlas, P. (2007). Effect of subsurface drip irrigation on cotton plantations. *Water Resources Management, 21*(8), 1341-1351. doi: 10.1007/s11269-006-9085-4

[16]Padhi, J., Misra, R. K., & Payero, J. O. (2012). Estimation of soil water deficit in an irrigated cotton field with infrared thermography. *Field Crops Research, 126*, 45-55. doi: 10.1016/j.fcr.2011.09.015

[17]Wang, Z. M., Jin, M. G., Simunek, J., & van Genuchten, M. T. (2014). Evaluation of mulched drip irrigation for cotton in arid Northwest China. *Irrigation Science, 32*(1), 15-27. doi: 10.1007/s00271-013-0409-x

[18]Wanjura, D. F., Upchurch, D. R., Mahan, J. R., & Burke, J. J. (2002). Cotton yield and applied water relationships under drip irrigation. *Agricultural Water Management, 55*(3), 217-237. doi: Pii S0378-3774(01)00175-5

[19]Asadi, R., Kouhi, N., & Yazdanpanah, N. (2012). Applicability of micro irrigation system on cotton yield and water use efficiency. *Journal of Food Agriculture & Environment, 10*(1), 302-306.

[20]Howell, T. A., Evett, S. R., Tolk, J. A., & Schneider, A. D. (2004). Evapotranspiration of full-, deficit-irrigated, and dryland cotton on the northern Texas high plains. *Journal of Irrigation and Drainage Engineering-Asce, 130*(4), 277-285. doi: 10.1061/(Asce)0733-9437(2004)130:4(277)

[21]Singh, Y., Rao, S. S., & Regar, P. L. (2010). Deficit irrigation and nitrogen effects on seed cotton yield, water productivity and yield response factor in shallow soils of semi-arid environment. *Agricultural Water Management, 97*(7), 965-970. doi: 10.1016/j.agwat.2010.01.028

[22]Oweis, T. Y., Farahani, H. J., & Hachum, A. Y. (2011). Evapotranspiration and water use of full and deficit irrigated cotton in the Mediterranean environment in northern Syria. *Agricultural Water Management, 98*(8), 1239-1248. doi: 10.1016/j.agwat.2011.02.009

[23]Enciso, J. M., Unruh, B. L., Colaizzi, P. D., & Multer, W. L. (2003). Cotton response to subsurface drip irrigation frequency under deficit irrigation. *Applied Engineering in Agriculture, 19*(5), 555-558.

[24]Gencsoylu, I., Horowitz, A. R., Sezgin, F., & Oncuer, C. (2003). Effect of drip and furrow irrigation methods on Bemisia tabaci populations in cotton fields. *Phytoparasitica, 31*(2), 139-143. doi: 10.1007/Bf02980783

[25]Flint, H. M., Radin, J. W., Parks, N. J., & Reaves, L. L. (1995). The Effects of Drip or Furrow Irrigation of Cotton on Bemisia-Argentifolii (Homoptera, Aleyrodidae). *Journal of Agricultural Entomology, 12*(1), 25-32.

[26]Suleiman, A. A., Soler, C. M. T., & Hoogenboom, G. (2007). Evaluation of FAO-56 crop coefficient procedures for deficit irrigation management of cotton in a humid climate. *Agricultural Water Management, 91*(1-3), 33-42. doi: 10.1016/j.agwat.2007.03.006

3 Irrigation with brackish or saline water

3.1 Description

As cotton is often grown in arid regions where water is scarce, farmers sometimes have to resort to lower quality water to irrigate the crop. As a salt-tolerant plant, cotton can withstand relatively high salt concentrations in the irrigation water. However, using saline or brackish water comes with serious side-effects such as salt build-up in the soil or lower yields.

3.2 Quick facts

Definition and purpose: Using water with high salt concentration to irrigate crops and to reduce freshwater consumption for cotton production in water scarce areas

Benefits: Reduces reliance on scarce freshwater supplies; and increases cotton production in water scarce areas while potentially damaging soil structure and causing soil aggregates to disperse (deflocculation)

3.3 Synthesis

Irrigation with brackish or saline water affects soil quality through salt build-up within the soil profile. Minimal impacts on water were found and no effects on biodiversity were identified, although some could be deduced because negatively impacted soil fertility can be detrimental to biodiversity.

Two studies (of which one was controlled, both were randomised and replicated) suggest **decreasing spaces between plants to increase yields** under saline conditions[1,2].

It is important to note that saline water can delay or reduce germination significantly but has even worse effects on subsequent seedling growth by inhibiting influxes of potassium and calcium; these adverse effects can be alleviated and root growth can be protected through an increased supply of calcium within the growth medium[3,4].

3.3.1 Impact summary of the intervention

In total, 16 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
	Negative	Limited evidence	Positive			Decreases	Low	Decreases

3.3.2 Soil

A majority of studies agree that **the use of saline and brackish water increases soil salinity** with slightly fewer studies also pointing out **negative effects on yield** (some show no effect, but there is no study claiming a positive impact on yield)[1,2,5-12].

Four studies (three replicated, of which two are also randomised and one also controlled) recommend using **alternate irrigation or irrigating with freshwater to leach salt**[5,6,12,13]. Implicitly, cotton production in arid regions with saline soils (such as Xinjiang, China) will still put pressure on scarce water resources even if efficient drip irrigation systems are adopted and brackish or saline water is used for irrigation. Also, extra water will still be required for leaching the excess salt. These issues put into question the viability of cotton production in these water stressed regions.

3.3.3 Water

One study from Australia recommends using subsurface drip irrigation to apply **aerated water to increase yields** under saline conditions[14].

Lastly, one study (randomised and replicated) warns that irrigation with brackish or saline water reduces water and fertiliser uptake efficiency and **increases drainage, thus risking groundwater contamination**[9].

3.3.4 Biodiversity

No effects on biodiversity have been identified.

3.4 Evidence review

3.4.1 Asia

3.4.1.1 Plant spacing effect on yield of cotton irrigated with saline waters[2]

Key message: Narrower spacing will yield more cotton under irrigation with saline water.

Location: Negev, Israel

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Negative						Negative*
Quality	RR						RR

* Yield will be lower under saline conditions, but narrower spaces will mitigate the loss.

A randomised, replicated experiment on deep silt loam in the Negev, Israel aimed to determine the effect of plant density on cotton yield under irrigation with saline water. The authors examined two inter-row spacing widths (75cm and 96.5cm), two intra-row spacing widths (12.5cm and 9cm) and two salinity levels (5.5 dS/m and 18dS/m). Plants irrigated with saline water grew smaller (71.6cm and 82.6cm versus 120cm expected in the region). The study concluded that plant density's effect on plant height was insignificant. Inter-row spacing could also be reduced because the authors did not observe any significant competition between plants at narrower spaces between rows. Cotton yield also increased with narrower spacing. Consequently, row widths narrower than 96.5cm could be used for the salinity levels tested to increase yield.

3.4.1.2 Drip irrigation of cotton with saline-sodic water[8]

Key message: Saline water does not affect yields, causes salt accumulation in the soil.

Location: Negev, Israel

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Negative						No effect
Quality	C						C

A controlled experiment on a sandy loam soil in the Negev, Israel water investigated effects of irrigation at different salinities (measured by electrical conductivity) and with different soil amendments. A cotton field was irrigated with waster at electrical conductivities 1.0, 3.2, 5.4, and 7.3 dS/m. Each of these plots was also tested for three different soil amendments (gypsum, sulphuric acid, control). The study showed that salinity levels did not reduce yields, despite salt accumulation, the fact that salinity slightly depressed plant height, and deeper roots in more saline water. The water at 3.2 dS/m produced the highest yield (6.2 t/ha) – significantly higher in both years of the study than all other salinity levels. The authors observed significant accumulation of exchangeable sodium in the soil profile. Gypsum and sulphuric acid did not reduce the amount of adsorbed sodium in the root zone, but only moved it from the emitter to underneath the plant row. The authors recommended applying amendments before the winter rains to prevent this phenomenon.

3.4.1.3 Effect of continuous irrigation with sodic and saline-sodic waters on soil properties and crop yields under cotton-wheat rotation in northwestern India[7]

Key message: Use of saline and sodic waters increases soil salinity, decreases yields.

Location: Punjab, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Negative			Positive*			Negative
Quality	RR long-term (8 years)			-			RR long-term (8 years)

* Positive impact on water quantity assumed, as using saline water implies saving fresh water.

A randomised, replicated, long-term experiment (8 years in duration) on a sandy loam soil in Punjab, India investigated what would happen to the exchangeable sodium percentage (the amount of sodium in soil) and yields if sodic and saline-sodic water were continuously used for irrigation. The experiment tested eight waters containing various concentrations of $NaHCO_3$ and NaCl: good quality canal water (electrical conductivity, or EC, 0.25 dS/m), three sodic waters (EC 0.56, 0.92, 1.16 dS/m), and four saline-sodic waters (EC 2.85, 2.76, 2.83, and 2.69 dS/m). Saline and saline-sodic irrigation water increased soil pH, electrical conductivity, and exchangeable sodium percentage. They also decreased yields. The increase was higher under saline-sodic than saline treatments.

3.4.1.4 Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation[5]

Key message: Alternate irrigation with freshwater and saline water or soil amendments will eliminate negative effects of saline water on soil quality and crop yields.

Location: Faisalabad, Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	No effect			Positive*			No effect
Quality	RR			-			RR

* Positive impact on water quantity assumed, as using saline water implies saving fresh water.

A randomised, replicated experiment on a sandy loam soil in Faisalabad, Pakistan evaluated different irrigation and soil management strategies for growing cotton. The study examined irrigation at various salinities with and without soil amendments. Five treatments were tested: irrigation with freshwater, irrigation with saline-sodic water (EC 3.32 dS/m) only, alternate irrigation with freshwater and saline-sodic water, irrigation with saline-sodic water and farm manure applied before sowing at 25 Mg ha^{-1} $year^{-1}$, and irrigation with saline-sodic water and gypsum. The latter treatment managed to keep the soil pH lower than alternate irrigation or farm manure. The yields were lower for the saline-sodic water only treatment than for other treatments. Also, treatments including saline-sodic water increased soil salinity, but the increase was significant exclusively in saline-sodic water only treatment. Maximum benefit was achieved the alternate irrigation treatment.

3.4.1.5 An alternative water source and combined agronomic practices for cotton irrigation in coastal saline soils[15]

Key message: Apply mineral fertiliser, gypsum, and polyacrylamide to increase yields, reduce salinity in the soil. There is no difference between well water and desalinized sea water.

Location: Huanghua city, Hebei province, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	No effect			Positive*			No effect
Quality	RR			-			RR

* Positive impact on water quantity assumed, as using saline water implies saving fresh water.

A randomised, replicated experiment on a loamy clay soil in Hebei province, China examined the effects of different waters, irrigation methods and fertilisation choices. The two main treatments were local well water and desalinized sea-ice water. Second, the study tested irrigation with and without polyacrylamide added to the water (PAM – a substance that increases soil infiltration and prevents erosion by encouraging soil molecules to adhere to one another and form bigger chunks). Third, the study looked at four fertiliser treatments: a mineral fertiliser, a mineral fertiliser in combination with an organic one, a mineral fertiliser with gypsum, and a non-fertilized plot. The authors did not discover any major difference between the two waters used in terms of yields or salt leaching. PAM-treated water significantly reduced salinity in the topsoil (2.3-3.9 g/kg versus 4.6-8.6 g/kg in untreated). The PAM-treated water also increased yields (compared to the non-fertilized plot) by 50% for the mineral fertiliser treatment, 49% for the combination of mineral and organic fertiliser, and 70% with mineral fertiliser combined with gypsum. Therefore, the authors recommended gypsum fertilisation as the best practice.

3.4.1.6 Effects of saline water drip irrigation on soil salinity and cotton growth in an Oasis Field[12]

Key message: Salt accumulates in the root zone, irrigate with freshwater before sowing next year's crop.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Negative			Positive*			
Quality	Rep			-			

* Positive impact on water quantity assumed, as using saline water implies saving fresh water.

A replicated experiment in Xinjiang, China tested water of different salinities in cotton over two seasons. The authors irrigated cotton with water of different salinity levels during the flowering stage and bud stage. Each year, the authors tested six salinity levels based on the degree of mineralization. In the first year, the treatments were 0.45 (freshwater), 1.95, 2.40, 2.82, 2.91, and 3.27 (saline groundwater) g/l. In the second year, the treatments were 0.46, 2.24, 3.81, 6.58, and 11.05 g/l. Salt in the region where the study was conducted was not leached naturally by rainwater. The authors found that if they used water with mineralization greater than 2.24 g/l, the field had to be irrigated with freshwater before sowing next year's crop to leach the salt.

3.4.1.7 Effects of different drip irrigation regimes on saline-sodic soil nutrients and cotton yield in an arid region of Northwest China[16]

Key message: More water applied to a soil being reclaimed results in greater increases of soil nutrients and greater decreases in salinity and sodicity of soil.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive			Negative			Positive
Quality	Rep			Rep			Rep

A replicated experiment in Xinjiang, China showed that there was a linear relationship between the amount of water applied through irrigation and soil matric potential. The author explained the relationship by reductions in salinity and sodicity of the soil due to increased leaching. Significant reductions in soil salinity and sodicity – a problem common to arid regions – were achieved at higher water use that allowed proper leaching (460-666mm). Soil organic carbon content also increased significantly due to three years of plant growth.

3.4.1.8 Evaluation of mulched drip irrigation for cotton in arid Northwest China[13]

Key message: Cotton exhibits different sensitivity to water stress and saline water during its life.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				CRR			CRR

A controlled, randomised, replicated experiment in Xinjiang, China showed that cotton exhibits different sensitivities to water salinity and water stress during different parts of the growing season. Based on numerical simulations and modelling, the study suggested that drip irrigation alternating fresh and brackish water and subsequent flood irrigation with freshwater (that allows for leaching of salt accumulated in the soil) would constitute a sustainable irrigation practice.

3.4.1.9 Root distribution and growth of cotton as affected by drip irrigation with saline water[11]

Key message: Excessive use of fertiliser exacerbates the negative effects of irrigation with saline water.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive*			Negative
Quality				-			CRR

* Positive impact on water quantity assumed, as using saline water implies saving fresh water.

A controlled, randomised, replicated experiment in Xinjiang, China examined root growth of cotton under fertilized and unfertilized conditions when irrigated with water of different salinity levels. The experiment was conducted on six plots, three of which received fertiliser treatment. One plot of each (fertilized and non-fertilized) underwent fresh water, brackish water or saline water treatment. The authors discovered that nitrogen fertiliser generally increased root biomass, irrigation with saline water decreased root biomass, but there was no significant difference between irrigation with freshwater or brackish water. Also, water salinity did not affect average root length density, root diameter and root volume, but these variables decreased as nitrogen rates increased. Saline water seemed to negatively affect nitrogen uptake, yields and water-use efficiency, and the use of nitrogen fertiliser exacerbated these effects.

3.4.1.10 Change characteristic of soil salinity on long-term drip irrigation under plastic film in Xinjiang cotton field[17]

Key message: Drip irrigation under plastic mulch decreases soil salinity.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive						
Quality	-						

A three year experiment conducted on saline arid soil in Xinjiang, China measured change in soil salinity over several years of drip irrigation treatment. The authors chose eight plots where cotton had been grown and which had been drip irrigated for different number of years before the experiment. The study concluded that after several years of drip irrigating under plastic mulch, soil salinity would decrease exponentially. Salinity of root growth zone dropped to acceptable levels after 4 years. Overall, it took 5.7 years to reduce salinity levels in the upper soil layer to 0.5% (down from a default level of 2.5-7%) and 6.9 years to reduce salinity in the lower layer to 0.5% (from 1.8-4.2%). Thus, controlling for salinity and water was necessary for over 7 years.

3.4.1.11 Influence of different amounts of irrigation water on salt leaching and cotton growth under drip irrigation in an arid and saline area[18]

Key message: The more water is used to leach salt in saline soils, the higher the yields will likely be.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive			Negative			Positive
Quality	RR			RR			RR

A replicated, randomised study in Xinjiang, China on saline soil attempted to explain the impact of irrigation on salt leaching. The authors prepared five water treatments with different amounts of water based on the soil matric potential (water capacity of the soil). All plots received a dose of compound fertiliser upfront, plus a nitrogen-based fertiliser dissolved in the irrigation water. Weather events and other adverse circumstances resulted in no yield in the first of the three years of the experiment, but yields were obtained during subsequent years. The authors arrived at the conclusion that as soil matric potential decreased, yield also decreased. The reduction in soil salinity (measured through electrical conductivity) was greatest in the upper soil layer and was getting progressively smaller with soil depth. Reductions in electrical conductivity between 0cm and 80cm depth also decreased with decreasing soil matric potential.

3.4.1.12 The soil-water flow system beneath a cotton field in arid north-west China, serviced by mulched drip irrigation using brackish water[10]

Key message: Drip irrigation with brackish water increases soil salinity.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Negative			Positive*			
Quality	-			-			

* Positive impact on water quantity assumed, as using saline water implies saving fresh water.

An experiment in Xinjiang, China attempted to map soil water and salinity distribution under irrigation with brackish water using 29 plastic mulches. Irrigation events created a ‘curved surface of zero flux’ – a boundary within the soil determining a hydraulic gradient – that controlled the water movement. Water above this boundary moved upward, whereas water below it moved downward. Hydrogeology, irrigation regime, climate, plant growth, and mulching would all affect sources and sinks and boundaries of the soil water flow system. The roots consumed water and nutrients selectively, leaving salt behind and increasing salt concentration in the root zone. Salinity increased 1.9 times between the beginning and the end of the season.

3.4.1.13 Effects of water salinity and N application rate on water- and N-use efficiency of cotton under drip irrigation[9]

Key message: Drip irrigation with brackish and saline water increases soil salinity, reduces yields. Lower soil salinity and higher nitrogen application rates increase water-use efficiency. Irrigation with saline water increases the risk of groundwater contamination.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Negative		Negative	Positive			Negative
Quality	RR		RR	RR			RR

A randomised, replicated experiment on alluvial grey desert soil in Xinjiang, China compared the performance of cotton crop grown under different irrigation water salinity levels and different nitrogen fertilisation levels. The experiment used freshwater, brackish water and saline water and four nitrogen application rates, including one treatment without any nitrogen added. The study showed that soil water content was higher for brackish and saline (38% higher than fresh and 10% higher than brackish) water and for non-fertilized plots. The differences in soil water content were more prominent closer to the surface, whereas in 0.8-1.0m depth the difference was negligible. Soil salinity increased under brackish and saline water treatments, whereas freshwater treatment saw only a negligible change. Increases in soil salinity associated with nitrogen application were not statistically significant. The authors did not observe any significant difference between the two highest nitrogen application rates (360 kg/hm^2 and 460 kg/hm^2) in treatments irrigated with brackish or saline water, implying that higher nitrogen application rates did not affect cotton growth under high irrigation water salinity levels.

In terms of yields, brackish water reduced seed cotton yields by 10% in the first year and 16% in the second year compared to the freshwater treatment. Saline water treatment reduced yields by 23% and 29% in the first and second year, respectively. For freshwater and brackish water, yield increased significantly with increasing nitrogen application rate. By contrast, saline water treatment did not reveal any significant difference in yields between different nitrogen application rate treatments.

Lastly, both water salinity and nitrogen application rates affected water-use efficiency. Fresh and brackish water exhibited similar water-use efficiency, which was some 11% higher than that of saline water. Also, water-use efficiency increased with increasing nitrogen application rates. Nitrogen uptake was also 16% and 20% higher in brackish water and freshwater, respectively, compared to saline water. Drainage was 55% higher in the brackish water treatment and 103% higher in the saline water treatment compared to freshwater, increasing the risk of groundwater contamination.

3.4.2 Australia and Oceania

3.4.2.1 Oxygation enhances growth, gas exchange and salt tolerance of vegetable soybean and cotton in a saline Vertisol[14]

Key message: Aerated water minimizes impact of soil salinity, increases yields.

Location: Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Positive
Quality				CRR			CRR

A controlled, randomised, replicated pot experiment on a cracking clay soil (Vertisol) in Queensland, Australia examined if aerated water (12% air by volume) could minimize the impact of salinity on plants under oxygen-limiting soil environments. The soil was salinized to electrical conductivities of 2, 8, 14, and 20 dS/m. Each pot with different salinity was assessed with and without the addition of aerated water. Aerated water increased cotton lint yield by 18% and water-use efficiency by 16%, compared with the control. Other plant characteristics such as plant height or relative water leaf content also performed better under oxygation.

3.4.3 Europe

3.4.3.1 Irrigation with saline water in the reclaimed marsh soils of south-west Spain: impact on soil properties and cotton and sugar beet crops[6]

Key message: Use saline water for supplementary irrigation does not bring about any major repercussions.

Location: south-west Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	No effect			Positive			No effect
Quality	-			-			-

An experiment near Lebrija, south-west Spain examined the effects of irrigation with saline water on soil characteristics and yields of cotton and sugar beet. Two fields were used. The first was irrigated with fresh water (1.7 dS/m) all the time, while the other received two irrigations with saline water (5.9 and 7.0 dS/m). The study showed that there were no differences in drainage behaviour between the two plots, leading the authors to conclude that saline water did not affect water retention characteristics of the soil. Though soil salinity (electrical conductivity and exchangeable sodium percentage) increased immediately after the application of saline water to a maximum of 7.5dS/m, it decreased gradually after irrigation with fresh water, eventually reaching levels similar to the fresh water field. Irrigation with saline water did not affect yield. Thanks to irrigation with saline water, 25% less fresh water was consumed.

3.4.4 North America

3.4.4.1 Narrow row cotton under saline conditions[1]

Key message: Yield decreases with increasing salinization, but can be partially compensated for with narrower spaces between plants.

Location: California, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Negative						Negative*
Quality	C						C

* Yield will be lower under saline conditions, but narrower spaces will mitigate the loss.

A controlled experiment in California, USA on fine sandy loam investigated if increasing the density of cotton plants could increase yields under irrigation with water of different salinity levels. The rationale was that cotton grows smaller when irrigated with saline water, and so more cotton could be grown in the same area. The study tested four salinity levels: 0.6, 6, 12, and 18 dS/m. Plants on salinized plots grew smaller, their leaves were also smaller and thicker. Canopy did not close on salinized plots, whereas the low salinity plots closed their canopy nearly as much as the control. Although yields of individual plants decreased with narrower rows, this effect became less prominent at higher salinity levels. Yield per plant decreased with denser planting, but the total yield increased because of larger number of plants per unit area. The study concluded that optimum plant density for attaining maximum yield may differ with different salinity levels.

3.5 Bibliography

[1]Francois, L. E. (1982). Narrow Row Cotton (Gossypium-Hirsutum-L) under Saline Conditions. *Irrigation Science, 3*(3), 149-156. doi: Doi 10.1007/Bf00446003

[2]Keren, R., Meiri, A., & Kalo, Y. (1983). Plant Spacing Effect on Yield of Cotton Irrigated with Saline Waters. *Plant and Soil, 74*(3), 461-465. doi: Doi 10.1007/Bf02181364

[3]Kent, L.M., Läuchli, A. (1985). Germination and seedling growth of cotton: salinity-calcium interactions. *Plant, Cell and Environment, 8,* 155-159. Doi: 10.1111/j.1365-3040.1985.tb01223.x

[4]Cramer, G.R., Lynch, J., Läuchli, A., Epstein, E. (1986). Influc of Na+, K+, and Ca2+ into Roots of Salt-Stressed Cotton Seedlings. *Plant Physiology 83(3),* 510-516. Doi: 10.1104/pp.83.3.510.

[5]Murtaza, G., Ghafoor, A., & Qadir, M. (2006). Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation. *Agricultural Water Management, 81*(1-2), 98-114. doi: DOI 10.1016/j.agwat.2005.03.003

[6]Moreno, F., Cabrera, F., Fernandez-Boy, E., Giron, I. F., Fernandez, J. E., & Bellido, B. (2001). Irrigation with saline water in the reclaimed marsh soils of south-west Spain: impact on soil properties and cotton and sugar beet crops. *Agricultural Water Management, 48*(2), 133-150. doi: Doi 10.1016/S0378-3774(00)00120-7

[7]Bajwa, M. S., Choudhary, O. P., & Josan, A. S. (1992). Effect of Continuous Irrigation with Sodic and Saline-Sodic Waters on Soil Properties and Crop Yields under Cotton-Wheat Rotation in Northwestern India. *Agricultural Water Management, 22*(4), 345-356. doi: Doi 10.1016/0378-3774(92)90042-U

[8]Mantell, A., Frenkel, H., & Meiri, A. (1985). Drip irrigation of Cotton with Saline-Sodic Water. *Irrigation Science, 6*(2), 95-106. doi: Doi 10.1007/Bf00251558

[9]Min, W., Hou, Z. A., Ma, L. J., Zhang, W., Ru, S. B., & Ye, J. (2014). Effects of water salinity and N application rate on water- and N-use efficiency of cotton under drip irrigation. *Journal of Arid Land, 6*(4), 454-467. doi: DOI 10.1007/s40333-013-0250-3

[10]Li, X. W., Jin, M. G., Huang, J. O., & Yuan, J. J. (2015). The soil-water flow system beneath a cotton field in arid north-west China, serviced by mulched drip irrigation using brackish water. *Hydrogeology Journal, 23*(1), 35-46. doi: DOI 10.1007/s10040-014-1210-5

[11]Min, W., Guo, H. J., Zhou, G. W., Zhang, W., Ma, L. J., Ye, J., & Hou, Z. N. (2014). Root distribution and growth of cotton as affected by drip irrigation with saline water. *Field Crops Research, 169*, 1-10. doi: DOI 10.1016/j.fcr.2014.09.002

[12]Hu, S. J., Shen, Y. J., Chen, X. L., Gan, Y. D., & Wang, X. F. (2013). Effects of saline water drip irrigation on soil salinity and cotton growth in an Oasis Field. *Ecohydrology, 6*(6), 1021-1030. doi: Doi 10.1002/Eco.1336

[13]Wang, Z. M., Jin, M. G., Simunek, J., & van Genuchten, M. T. (2014). Evaluation of mulched drip irrigation for cotton in arid Northwest China. *Irrigation Science, 32*(1), 15-27. doi: DOI 10.1007/s00271-013-0409-x

[14]Bhattarai, S. P., & Midmore, D. J. (2009). Oxygation Enhances Growth, Gas Exchange and Salt Tolerance of Vegetable Soybean and Cotton in a Saline Vertisol. *Journal of Integrative Plant Biology, 51*(7), 675-688. doi: DOI 10.1111/j.1744-7909.2009.00837.x

[15]Wang, X. B., Zhao, Q. S., Hu, Y. J., Zheng, Y., Wu, X. P., Wu, H. J., . . . Manzur, C. L. (2012). An alternative water source and combined agronomic practices for cotton irrigation in coastal saline soils. *Irrigation Science, 30*(3), 221-232. doi: DOI 10.1007/s00271-011-0277-1

[16]Wang, R. S., Kang, Y. H., & Wan, S. Q. (2015). Effects of different drip irrigation regimes on saline-sodic soil nutrients and cotton yield in an arid region of Northwest China. *Agricultural Water Management, 153*, 1-8. doi: DOI 10.1016/j.agwat.2015.01.025

[17]Wang, Z. H., Yang, P. L., & Zheng, X. R. (2013). Change characteristic of soil salinity on long-term drip irrigation under plastic film in Xinjiang cotton field. *Journal of Food Agriculture & Environment, 11*(2), 1017-1020.

[18]Wang, R. S., Kang, Y. H., Wan, S. Q., Hu, W., Liu, S. P., Jiang, S. F., & Liu, S. H. (2012). Influence of different amounts of irrigation water on salt leaching and cotton growth under drip irrigation in an arid and saline area. *Agricultural Water Management, 110*, 109-117. doi: DOI 10.1016/j.agwat.2012.04.005

Soil fertilisation

Section Overview

Cotton production depends on fertile soil. Production systems often rely on synthetic or mineral fertilisers to improve soil nutrients for crop growth; these inputs however can be costly and their manufacture contributes both directly and indirectly to greenhouse gas emissions. There are a number of alternatives to such fertilisers, three of which were identified and researched using a number of terms (See Appendix 2.1: Primary Search and Appendix 2.2: Secondary Search).

Section Chapters

Chapter 4: Recycling Cotton Gin Waste

Evidence			Yield	Cost	Quality
Positive	Positive	None	Increases	Low	Increases

Definition and purpose: Post-processing use of cotton gin waste (a by-product of separating cotton fibre from seeds) as, for example, compost as a means of creating value from a by-product and reduce reliance on other inputs to cotton production

Benefits: Improves soil physical, chemical and biological characteristics; reduces reliance on inorganic fertilisers; and improves water quality

Chapter 5: Fertilisation using Plant Waste

Evidence			Yield	Cost	Quality
Positive	None	Positive	Increases	Low	Increases

Definition and purpose: Using organic matter (plant waste or compost) to fertilise fields and composting these leftover plant residues to improve soil properties

Benefits: Benefits long term soil health; builds more resilient systems; increases yields; and reduces usage of synthetic fertilisers

Chapter 6: Animal Manure

Evidence			Yield	Cost	Quality
Positive	None	None	Increases	Low	Is not affected

Definition and purpose: Incorporating animal manure into cotton crop fertilisation nutrient management plans as a means of fertilising crops using an organic waste product

Benefits: Improves soil health; and reduces reliance on synthetic fertiliser

4 Recycling cotton gin waste

4.1 Description

Cotton gin waste is a by-product of cotton processing. It consists of husks, stalks, remnants of cotton bolls and other organic waste. It is often burned or allowed to rot near ginning facilities, because it is, in certain cases, assumed to have no practical use. However, cotton gin waste can be composted or otherwise modified and further utilized for improving soil on cotton fields themselves or for other on farm purposes.

4.2 Quick facts

Definition and purpose: Post-processing use of cotton gin waste (a by-product of separating cotton fibre from seeds) as, for example, compost as a means of creating value from a by-product and reduce reliance on other inputs to cotton production

Benefits: Improves soil physical, chemical and biological characteristics; reduces reliance on inorganic fertilisers; and improves water quality

4.3 Synthesis

Cotton gin waste mostly affects soil, as it can be used in various modifications and combinations with other substances to improve soil fertility and structure. Cotton gin waste can also affect water quality through its potential use in water treatment processes. No studies document any effects on biodiversity.

Only one study referred to recycling cotton gin waste for the production of cotton while others referred more generally to on farm use for increasing soil fertility on other crop fields or for improving water quality[1].

4.3.1 Impact summary of the intervention

In total, 15 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance	Increases	Low	Increases
Positive	Positive	Positive						

4.3.2 Soil

Seven studies (four randomised, replicated, of which two are also controlled, and one controlled and randomised) stress the **benefits of cotton gin waste for soil structure**, especially for soil organic matter[2-8]. Seven studies (three randomised, replicated, two of which were also controlled, and two controlled, of which one was randomised and one replicated) **cotton gin waste improves or sustains soil fertility**[3-5,6-9]**.** Four studies (all randomised, replicated, three also controlled) also claim that **cotton gin waste increases yields** of various crops[1,5,6,8].

Cotton gin waste has a high concentration of organic matter; however, if often contains a number of pathogens and weed seeds. While recycling cotton gin waste is recommended for soil fertility and conditioning, it does not guarantee complete sterilization of the compost media[10].

4.3.3 Water

Four experiments (one replicated, one controlled) suggest **using cotton gin waste to treat polluted water**[11-14].

4.3.4 Biodiversity

No effects on biodiversity have been identified.

4.4 Evidence review

4.4.1 Asia

4.4.1.1 Changes of organic carbon content in two soils by cotton gin waste amendment, a by-product of agricultural industry[2]

Key message: Cotton gin waste increases soil organic matter.

Location: Antalya region, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive						
Quality	RR						

A randomised, replicated experiment measured changes in organic carbon content in clay and sandy loam after the addition of cotton gin trash. The experiment was carried out in pots in a greenhouse with four levels of organic fertiliser (cotton gin trash): 0, 10, 20 and 40 t/ha. An analysis of cotton gin trash found basic pH (5.96) and high content of organic matter as well as available potassium and nitrogen. Organic carbon increased in both soils with increasing amounts of cotton gin trash, the highest occurring in the 40 t/ha treatment. Overall, the increase was higher for clay than for sandy loam.

4.4.2 Australia and Oceania

4.4.2.1 Changes in Vertisol properties as affected by organic amendments application rates[3]

Key message: Cotton gin trash improves soil.

Location: New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					
Quality	C Ran	C Ran					

A controlled, randomised study on a cracking clay soil (Vertisol) in New South Wales, Australia tried to find the optimal rate for application of organic amendments. Five organic fertilisers applied at six different rates (cotton gin trash, cattle manure, biosolids, composted chicken manure and liquefied vermicast) were compared with an unamended control. The treatments were observed for six weeks at 30°C in a growth cabinet. The study concluded that all fertilisers changed the soil's chemical, physical and biological properties. As for cotton gin trash, microbiological properties were not significantly affected, except for the highest application rate of 120 t/ha. Mean weight diameter of the soil was not significantly affected, but increases were observed up to 30 t/ha. The light fraction of organic matter increased significantly, except for the lowest application rate (7.5 t/ha). A significant increase in nitrate-N (NO3-N) content was observed with the highest increase occurring at 60 t/ha. Similarly, phosphate-P (PO4-P) increased the most at 30 t/ha. No significant changes were observed for Na concentration, but exchangeable K content increased significantly for all rates, except 7.5 t/ha. The authors determined that cotton gin trash optimal application rate was 30 t/ha.

4.4.2.2 Organic amendments influence nutrient availability and cotton productivity in irrigated Vertosols[15]

Key message: Organic fertiliser does not affect soil structure, fertility, yields on a Vertosol.

Location: Narrabri, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	No effect	No effect					No effect
Quality	CRR	CRR					CRR

A controlled, randomised, replicated experiment on a Vertosol (cracking clay soil) in Narrabri, New South Wales, Australia examined the influence of organic fertiliser on soil health. Three treatments based on common local practice were tested: cattle manure (10 t/ha), composted cotton gin trash (7.5 t/ha), commercial vermicompost liquid (50 L/ha). The results were compared to a control plot that did not receive any organic fertiliser. All plots were also fertilized with a mineral fertiliser – urea (60 kg N/ha). The study did not find any significant differences in soil characteristics between treatments. Microbial biomass, respiration and nutrient uptake were not affected. The data on exchangeable K and Na concentrations did not display a clear pattern, but except for two occasions neither differed significantly. The phosphate-P concentration differed significantly only 12 months after first application (111% for cattle manure and 55% increase for cotton gin trash compared to the control). Also, vermicompost seemed to increase Zn, Fe, Cu and Mn concentrations. However, the authors warned that rapid mineralisation of soil organic matter could lead to a long-term decline in soil carbon stocks. Changes in the soil characteristics were only observed from one year to another regardless of treatment. Yield did not vary significantly, either. The study concluded that application of organic fertiliser at the rates used in the experiment did not have any major short-term effects on soil quality. The authors pointed out that the result was valid for alkaline, swelling soils typical for Australia’s cotton growing regions. Most similar studies showing positive results of organic fertiliser application were conducted on acidic, non-swelling soils.

4.4.2.3 Sorption and desorption of endosulfan sulfate and diuron to composted cotton gin trash[11]

Key message: Composted cotton gin trash sorbs pesticides, reduces contamination of pesticide-laden water.

Location: Narrabri, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive				
Quality			C				

A controlled experiment in Narrabri, New South Wales, Australia examined the potential use of composted cotton gin trash to remedy water contaminated with pesticides. The authors hypothesized that composted cotton gin trash could sorb diuron and endosulfan sulfate owing to the high proportion of organic matter, which helps bind pesticides. The study concluded that composted cotton gin trash could effectively sorb concentrations of diuron and endosulfan sulfate commonly found in farm runoff (5-500 µgL-1 and 1-100 µgL-1, respectively).

4.4.3 Europe

4.4.3.1 Degradation and adsorption of terbuthylazine and chloropyrifos in biobed biomixtures from composted cotton crop residues[12]

Key message: Composted cotton residues in biobeds reduce runoff, improve pesticide degradation.

Location: Volos, Greece

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive				
Quality			Rep				

A replicated experiment on sandy loam in Volos, Greece investigated the effect of cotton gin trash on decomposition of common pesticides – terbuthylazine and chlorpyrifos. The authors used biobeds – a bioremediation system common in Northern Europe (holes in the ground in their simplest form) that collects pesticide-laden runoff, thus preventing it from spilling off the field. The biobed contains substances that promote rapid degradation of pesticides. In this study, degradation was assessed on five substrates: sterilised soil, non-sterilised soil, soil and compost (3:1 ratio), soil and compost (1:1), and soil and compost and straw (2:1:1). Adsorption was measured in two treatments: soil, and soil and compost 1:1. The study found out that degradation of terbuthylazine was slower compared with chlorpyrifos in all substrates studied. Compost biomixtures degraded terbuthylazine better because organic matter and greater microbial activity destroyed the pesticide faster. By contrast, degradation of the more lipophilic (that is, soluble in fats, oils, lipids) chlorpyrifos proceeded slower in compost biomixtures because the organic matter in the compost acted as a surface of adsorption (K_d = 746 mLg^{-1} compared to K_d = 17 mLg^{-1} for soil). Additionally, the more alkaline conditions in soil (pH 8.5) compared to compost biomixtures (pH 6.6) might also have contributed to faster dissolution of chlorpyrifos in that particular medium. The authors concluded that composted cotton residues could be used in biobeds, as they promoted degradation of hydrophilic pesticides (terbuthylazine) and the adsorption of hydrophobic pesticides (chlorpyrifos).

4.4.3.2 Study of composting of cotton residues[4]

Key message: Crushed cotton waste composts better than uncrushed waste.

Location: Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					
Quality	-	-					

A study in Spain compared the composting processes of uncrushed and crushed cotton residue. The residues contained mainly seeds and husks of the flowers. The composting process took 191 days, after which both crushed and uncrushed composts similarly increased their organic matter contents. Both treatments also similarly increased the soil pH. The soil nitrogen content also increased in both treatments, but the increase was much more substantial in the crushed treatment (N-Kjeldahl rose from 1.34 to 2.96, as opposed to 1.83 to 2.05 for the uncrushed treatment). Overall, the crushed treatment displayed the highest values of macronutrients and micronutrients.

4.4.3.3 Crushed cotton gin compost on soil biological properties and rice yield[5]

Key message: Cotton gin waste increases soil organic matter, yields, improves soil structure, but achieves better performance when combined with mineral fertiliser.

Location: Sevilla, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					Positive
Quality	CRR	CRR					CRR

A controlled, randomised, replicated experiment on an Aquic Xerofluvent in Sevilla, Spain applied cotton gin waste on rice fields at different rates. The study tested for 10, 15 and 20 t/ha of cotton gin waste with and without the addition of mineral fertiliser, comparing the results with a non-fertilized control. The study concluded that the cotton gin compost was the main cause behind carbon biomass increase in the soil. All treatment plots exhibited better values in terms of yield, microbial activity, soil respiration, C/N ratio, other soil biological properties and nutrition than the control plot. However, the plots that received mineral fertiliser as well performed even better than the plots with cotton waste only. The authors pointed out that cotton waste contained very little nitrogen, which was the reason for high C/N ratios in the soil fertilized with organic fertiliser only.

4.4.3.4 Cotton fertilisation with composts of (sugarbeet) vinasse and agricultural residues[1]

Key message: Vinasse combined with organic waste increase cotton yields, do not affect quality.

Location: Sevilla, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							Positive
Quality							CRR

A controlled, randomised, replicated study in Sevilla, Spain tested mixtures of beet vinasse combined with different organic wastes. Beet vinasse is a biochemically desugarized remnant of sugarbeet rich in N, K and organic matter, but due to high salt content, low P content and high density it is not ideal as a standalone fertiliser. For that reason, it is mixed with other substances. The authors composted vinasse for seven months with ten different organic wastes: olive-pressed cake, olive-pressed cake and leonardite, cotton gin trash, cotton gin trash and leonardite, municipal solid waste, tobacco dust, composted olive-oil-mill effluents, olive-oil-mill sludge, grape marc, and rice husk. The results of this study were compared against a plot that received mineral fertiliser. A non-fertilized plot was used as a control. The authors did not observe any differences in quality between the treatments and control. All treatments produced higher yields than the control. Mineral fertiliser, rice husk, municipal solid waste and the non-fertilized plot all yielded less than the mean yield commonly obtained the locality, whereas all the other treatments produced more than the mean.

4.4.3.5 Effects of a compost made from the solid by-product (“alperujo”) of the two-phase centrifugation system for olive oil extraction and cotton gin waste on growth and nutrient content of ryegrass[9]

Key message: Cotton gin waste and alperujo mixture improves soil productivity, but works better in combination with mineral fertiliser.

Location: Murcia, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					No effect
Quality		C Rep					C Rep

A controlled, replicated laboratory experiment on calcareous clay loam tested three compost application rates (0, 40 and 80 t/ha) and two nitrogen fertilisation rates (0 kg N/ha and 60 kg N/ha) on ryegrass. The compost mixture consisted of cotton gin waste and ‘alperujo’ – a by-product of olive oil extraction. The mixture had basic pH, high C/N ratio, was rich in organic matter, and had high potassium and nitrogen content, albeit not bioavailable. It was also low in other nutrients compared to manure and other composts. The compost slightly stimulated plant growth and increased yields despite its poor quality; additional nitrogen fertilisation improved soil productivity considerably more. The authors recommended using compost in combination with mineral fertiliser to enhance soil productivity.

4.4.3.6 *Effects of the application of a compost originating from crushed cotton gin residues on wheat yield under dryland conditions*[6]

Key message: Cotton gin waste compost improves soil structure, fertility, increases wheat yield.

Location: Sevilla, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					Positive
Quality	RR	RR					RR

A randomised, replicated study on calcareous Fluvisol in Sevilla, Spain examined the impact of cotton gin waste compost on soil fertility. The design tested four treatments: no compost, 20, 40, 60 and 90 t/ha of compost. All treatments also received NH_4NO_3 at 150 kg N/ha. The study revealed that owing to its organic matter content cotton gin waste compost improved soil microbial activity, structural stability and porosity as well as yields.

4.4.3.7 *Chemical changes during vermicomposting of sheep manure mixed with cotton industrial wastes (vermicompost)*[7]

Key message: Vermicomposting reduces salinity, increases mineralization of organic matter.

Location: Barcelona, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					
Quality							

A study in Barcelona, Spain examined the variations in chemical composition of sheep manure alone and in combination with cotton gin waste during 12 weeks of vermicomposting. The authors also compared the results with treatments without earthworms. The presence of earthworms was associated with lower salinity. The increase in P, Na and K also indicated that vermicomposting accelerated mineralization of organic matter. The authors concluded that vermicomposting could be an alternative method for recovery of industrial wastes as well as a low-cost fertiliser.

4.4.4 North America

4.4.4.1 Removal of added nitrate in the single, binary and ternary systems of cotton burr compost, zerovalent iron, and sediment: Implications for groundwater nitrate remediation using permeable reactive barriers[13]

Key message: Cotton burr compost is effective at removing nitrate from contaminated groundwater.

Location: USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive				
Quality							

An experiment in the U.S. tested the potential of cotton burr compost as a material for remediation of groundwater nitrogen – a nutrient normally added through mineral fertilisation and a common water contaminant. The study tested several materials: cotton burr compost by itself, Peerless Fe^0 (iron) by itself, aquifer sediment from Elizabeth City, North Carolina by itself, cotton burr compost and Peerless Fe^0 1:1 (weight ratio), cotton burr compost and Peerless Fe^0 1:5, iron and sediment 1:1, cotton burr compost and sediment 1:1, cotton burr compost, iron and sediment 1:1:1, and cotton burr compost, iron and sediment 1:5:1. The study found that cotton burr compost by itself effectively removed nitrate from groundwater. It was not advantageous to mix it with any other substance because cotton burr compost degraded nitrate more efficiently than any of the other combinations.

4.4.4.2 Composting gin trash reduces waste disposal and pollution problems[16]

Key message: Chicken manure mixed with cotton gin waste at 1:3 ratio produce quality compost.

Location: Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

An experiment in Arizona, USA tried to optimize cotton gin trash compost composition in order to reduce pollution from burning cotton gin trash and provide compost rich in nitrogen. The study tested different quantities of cotton gin trash mixed with the same quantity of chicken manure (a nitrogen-rich source), composting the mixture over for days. The ratios of gin trash to chicken manure (both dry weight) were 1:1, 3:1 and 5:1. The 3:1 ratio produced the most desirable compost with the most uniform material and the finest particles.

4.4.4.3 Use of cotton gin trash (CGT) to form a biological lagoon sealant[14]

Key message: Cotton gin trash can be used as a waste lagoon sealant.

Location: Georgia, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive				
Quality							

A study in Georgia, USA looked into the possibility of utilizing cotton gin trash to treat industrial discharge. The authors constructed soil columns with sandy loam at the top and the bottom and cotton gin trash of different thickness in the middle. The columns were compacted twice during 15 days that water was allowed to percolate through them. The study found that compacted cotton gin trash had the potential to be used to seal waste lagoons; ideal layer of cotton gin trash was less than 10cm.

4.4.5 South America

4.4.5.1 Yield of bean plant and changes in pH and soil organic matter as a function of doses of compost cotton waste[8]

Key message: Cotton gin waste increases soil organic matter, fertility.

Location: Lavras, Brazil

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					Positive
Quality	CRR	CRR					CRR

A controlled, randomised, replicated study conducted on an Acrisol in Brazil examined the effects of cotton waste compost on soil and plant growth. The study tested five treatments: 0, 20, 40, 60 and 80 t/ha of cotton waste compost. The cotton waste compost increased growth and improved productive characteristics in beans. It also caused an increase in soil pH and added soil organic matter.

4.5 Bibliography

[1]Madejon, E., Diaz, M. J., Lopez, R., Lozano, C., & Cabrera, F. (1996). Cotton fertilisation with composts of (sugarbeet) vinasse and agricultural residues. *Fertiliser Research, 43*(1-3), 179-182. doi: 10.1007/Bf00747699

[2]Alagoz, Z., & Yilmaz, E. (2011). Changes of organic carbon content in two soils by cotton gin waste amendment, a by-product of agricultural industry. *Journal of Food Agriculture & Environment, 9*(2), 250-252.

[3]Ghosh, S., Lockwood, P., Daniel, H., Hulugalle, N., King, K., & Kristiansen, P. (2011). Changes in Vertisol properties as affected by organic amendments application rates. *Soil Use and Management, 27*(2), 195-204. doi: 10.1111/j.1475-2743.2011.00333.x

[4]Tejada, M., Dobao, M. M., Benitez, C., & Gonzalez, J. L. (2001). Study of composting of cotton residues. *Bioresource Technology, 79*(2), 199-202. doi: 10.1016/S0960-8524(01)00059-1

[5]Tejada, M., & Gonzalez, J. L. (2006). Crushed cotton gin compost on soil biological properties and rice yield. *European Journal of Agronomy, 25*(1), 22-29. doi: 10.1016/j.eja.2006.01.007

[6]Tejada, M., & Gonzalez, J. L. (2003). Effects of the application of a compost originating from crushed cotton gin residues on wheat yield under dryland conditions. *European Journal of Agronomy, 19*(2), 357-368. doi: Pii S1161-0301(02)00089-8

[7]Albanell, E., Plaixats, J., & Cabrero, T. (1988). Chemical-Changes during Vermicomposting (Eisenia-Fetida) of Sheep Manure Mixed with Cotton Industrial-Wastes. *Biology and Fertility of Soils, 6*(3), 266-269.

[8]Ramos, S. J., Alves, D. S., Fernandes, L. A., & da Costa, C. A. (2009). Yield of bean plant and changes in pH and soil organic matter as a function of doses of compost cotton waste. *Ciencia Rural, 39*(5), 1572-1576. doi: 10.1590/S0103-84782009005000064

[9]Alburquerque, J. A., Gonzalvez, J., Garcia, D., & Cegarra, J. (2007). Effects of a compost made from the solid by-product ("alperujo") of the two-phase centrifugation system for olive oil extraction and cotton gin waste on growth and nutrient content of ryegrass (Lolium perenne L.). *Bioresource Technology, 98*(4), 940-945. doi: 10.1016/j.biortech.2006.04.014

[10]Barton, B.M. (1976). Cotton gin wastes, fertiliser. *U.S. Patent No. 3,953,191*.

[11]Burns, M., Crossan, A. N., Kennedy, I. R., & Rose, M. T. (2008). Sorption and desorption of endosulfan sulfate and diuron to composted cotton gin trash. *Journal of Agricultural and Food Chemistry, 56*(13), 5260-5265. doi: 10.1021/Jf703631j

[12]Kravvariti, K., Tsiropoulos, N. G., & Karpouzas, D. G. (2010). Degradation and adsorption of terbuthylazine and chlorpyrifos in biobed biomixtures from composted cotton crop residues. *Pest management Science, 66*(10), 1122-1128. doi: 10.1002/Ps.1990

[13]Su, C. M., & Puls, R. W. (2007). Removal of added nitrate in the single, binary, and ternary systems of cotton burr compost, zerovalent iron, and sediment: Implications for groundwater nitrate remediation using permeable reactive barriers. *Chemosphere, 67*(8), 1653-1662. doi: 10.1016/j.chemosphere.2006.09.059

[14]Smith, J. W., & Tollner, E. W. (1999). Use of cotton gin trash (CGT) to form a biological lagoon sealant. *Bioresource Technology, 69*(3), 207-213. doi: Doi 10.1016/S0960-8524(98)00197-7

[15]Ghosh, S., Hulugalle, N., Lockwood, P., King, K., Kristiansen, P., & Daniel, H. (2008). Organic amendments influence nutrient availability and cotton productivity in irrigated Vertosols. *Australian Journal of Agricultural Research, 59*(11), 1068-1074. doi: 10.1071/Ar08141

[16]Pessarakli, M. (1990). Composting Gin Trash Reduces Waste-Disposal and Pollution Problems. *Journal of Environmental Science and Health Part a-Environmental Science and Engineering & Toxic and Hazardous Substance Control, 25*(8), 1037-1047.

5 Fertilisation using plant waste

5.1 Description

Organic amendments are thought to provide benefits for long-term soil health. Fertilisation using plant waste implies applying either plant waste or compost to improve soil properties, rather than synthetic mineral fertiliser. Composting is a form of recycling and allows the creation of value from a waste product: organic matter left over from previous crop is decomposed and used as organic fertiliser the next season.

5.2 Quick facts

Definition and purpose: Using organic matter (plant waste or compost) to fertilise fields and composting these leftover plant residues to improve soil properties

Benefits: Benefits long term soil health; builds more resilient systems; increases yields; and reduces usage of synthetic fertilisers

5.3 Synthesis

All studies on the use of organic amendments in cotton associate composting or plant wastes with at least some benefits to soil structure or fertility. There are no studies linking fertilisation of plant waste and organic fertilisers to effects on water. Although studies provide ample material for general conclusions to be drawn, one should note that composition of fertiliser mixtures as well as experimental designs vary across studies.

Four studies (all controlled, randomised and replicated) indicate that **compost increases yields equally or more than mineral fertiliser**[1-4].

5.3.1 Impact summary of the intervention

In total, ten studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance	Increases	Low	Increases
Positive	Positive			Positive	Positive			

5.3.2 Soil

Eight studies (all of which were replicated, five of which were also controlled and randomised and one which was also controlled) examining effects of plant waste fertilisation on soil highlight **benefits to soil health**[1,2,4,5,6-9].

Three studies (all of which were replicated, two were also controlled and one was also randomised) advocate **applying organic fertiliser in combination with mineral fertiliser** in order to reduce the amount of mineral fertiliser necessary as well as to improve soil structure and fertility[5,6,9]. One study from Australia (controlled, randomised and replicated) finds little benefit from this treatment[10].

One replicated study indicates that **compost prevents runoff and erosion**[7].

5.3.3 Water
No effects on water have been identified.

5.3.4 Biodiversity
Two studies (both controlled, randomised and replicated) associate some **organic substances with pesticidal properties**[1,8].

5.4 Evidence review

5.4.1 Africa

5.4.1.1 Effects of ploughing frequency and compost on soil aggregate stability in a cotton-maize rotation in Burkina Faso[6]
Key message: Organic fertiliser and reduced tillage improve soil structure, prevent erosion.

Location: Bondoukouy, Burkina Faso

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive						
Quality	Rep						

A replicated experiment on loam (Luvisol) and sandy loam (Lixisol) in Bondoukouy, Burkina Faso examined the impacts of mineral and organic fertiliser (compost) in combination with different tillage frequencies in a cotton-maize sequence. The authors tested annual tillage (ox-ploughing) and reduced tillage (ox-ploughing in the first year and hand-hoe scarifying in the second year) on eight fields with four for each type of tillage. The fields were further split into subplots that tested for any additional benefits from compost (mineral fertiliser was applied to all plots, compost consisting of crop residues and cow dung only to some). The study concluded that reduced tillage significantly improved the soil macroaggregate stability in the year of hand hoeing in both types of soil. Added compost further limited the negative effects of ploughing on soil stability by increasing the mass of water-stable macroaggregates. The study recommended adding organic fertiliser and reducing tillage to improve the standard local practice of annual tillage and only applying mineral fertiliser.

5.4.1.2 Ploughing frequency and compost application effects on soil infiltrability in a cotton-maize rotation system on a Ferric Luvisol and a Ferric Lixisol in Burkina Faso[7]
Key message: Compost increases water infiltrability, thus reducing runoff and erosion.

Location: Bondoukouy, Burkina Faso

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive						
Quality	Rep						

A replicated experiment on loam (Luvisol) and sandy loam (Lixisol) in Bondoukouy, Burkina Faso examined water infiltration parameters in a cotton-maize sequence. The authors tested annual tillage (ox-ploughing) and reduced tillage (ox-ploughing in the first year and hand-hoe scarifying in the second year) on eight fields with four for each type of tillage. The fields were further split into subplots that tested for any additional benefits from compost (mineral fertiliser was applied to all plots, compost consisting of crop residues and cow dung only to some). The authors discovered higher soil hydraulic conductivities in the Lixisol (saturated soil hydraulic conductivity of 18-275mm/h) than in the Luvisol (9-48 mm/h). The tillage frequency caused a statistically insignificant difference most likely due to the specific nature of the soil (prone to crust formation). The addition of compost, however, did improve soil hydraulic properties.

5.4.2 Asia

5.4.2.1 Prospecting cyanobacteria-fortified composts as plant growth promoting and biocontrol agents in cotton[1]

Key message: Cyanobacteria-fortified compost is an effective and environmentally-friendly fertiliser and biocontrol agent.

Location: Nagpur and Sirsa, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive			Positive*	Positive*	Positive
Quality	CRR	CRR					CRR

* Inferred positive impact on biodiversity based on assumed lower use of pesticide.

A controlled, randomised, replicated study looked at biocontrol and biofertilizer potential of cyanobacteria-based compost formulations in cotton. The study was conducted in two locations in India – Nagpur and Sirsa. In Nagpur, the bacteria were tested as a fertiliser. In Sirsa, the bacteria were introduced into a *Rhizoctonia*-infested (fungi) field. The study concluded that compost-based formulations with *Calothrix* sp. and *Anabaena* sp. performed well, fertilizing the soil about as good as, or better than, commercial fertiliser. The mixture increased available nitrogen in the soil by 20-50%. The biofilmed formulation (*Anabaena-T. viride*) also improved the fungi-infested fields at Sirsa, recording 11.1% lower plant mortality than commercial *Trichoderma* formulation.

5.4.2.2 Effect of organic amendments on Verticillium wilt on cotton[8]

Key message: Certain organic amendments (crab shell, soybean stalk, alfalfa) reduce the incidence of disease in cotton and support beneficial microbes in soil.

Location: Fengqiu Ecology Station, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive				Positive	Positive	
Quality	CRR				CRR	CRR	

A controlled, randomised, replicated experiment at Fengqiu Ecology Station, China evaluated the effects of organic materials on disease control in cotton, focusing on *Verticillium* wilt. The study also looked into the contribution of microorganisms in the rhizosphere (root zone) to disease control. The experiment was conducted in a laboratory setting as well as in the field. Seven organic amendments were tested: crab shell, soybean stalk, alfalfa, rice chaff, poultry manure, peanut cake and wheat straw. The amendments were also compared with an untreated control. The study showed that organic amendments could be used successfully for disease control. In the pot trial, crab shell performed best (80% protection for leaves, 72% for vascular tissues), followed by soybean stalk (65% and 60%) and alfalfa (63% and 56%). Poultry manure, peanut cake and wheat straw gave little protection. The field trial results mirrored the results from the pot experiment. The organic amendments also increased the populations of beneficial soil microbes.

5.4.2.3 Integrated use of farm manure and mineral fertilisers to maintain soil quality for better cotton[5]

Key message: Mineral fertiliser can be partially replaced by organic fertiliser without sacrificing cotton yields.

Location: Faisalabad, Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					No effect
Quality		CRR					CRR

A controlled, randomised, replicated study on sandy clay loam in Faisalabad, Pakistan examined the effects of farm manure and mineral fertiliser on yields and soil properties in a cotton field. The authors designed five treatments – farm manure at 20 Mg ha^{-1}, fermented farm manure at 20 Mg ha^{-1}, half the recommended dose of NPK mineral fertiliser combined with farm manure at 20 Mg ha^{-1}, half the recommended dose of NPK with fermented farm manure 20 Mg ha^{-1}, full recommended NPK treatment (170, 85 and 60 kg ha^{-1} – which they compared with a control. The study determined that combined ½ NPK with fermented farm manure produced similar results in terms of growth parameters and soil nutrient concentration as a full dose of mineral fertiliser by itself.

5.4.2.4 Yield and potassium use efficiency of cotton with wheat straw incorporation and potassium fertilisation on soils with various conditions in the wheat-cotton rotations system[2]

Key message: Wheat straw can replace synthetic fertiliser as a source of potassium.

Location: Dafeng and Nanjing, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					Increases
Quality	CRR	CRR					CRR

A controlled, randomised, replicated experiment on a sandy loam soil in Dafeng and a clay loam soil in Nanjing, China, explored the possibility of replacing a synthetic K fertiliser for another source of potassium – wheat straw – that is usually burned in China, rather than reused. The study consisted of five treatments: wheat straw at 4500 kg/ha, wheat straw at 9000 kg/ha, K fertiliser (K_2O) at 150 kg/ha and 300 kg/ha. The authors showed that soil available potassium concentration was the key factor influencing cotton lint yield and potassium use efficiency was higher for wheat straw than for K fertiliser (and higher for lower quantities of wheat straw or fertiliser). In conclusion, K fertiliser or wheat straw applied to soils with low available K concentration improved soil available K concentration, thus reducing soil K depletion.

5.4.3 Australia and Oceania

5.4.3.1 *Organic amendments influence nutrient availability and cotton productivity in irrigated Vertosols*[10]

Key message: Organic fertiliser does not affect soil structure, fertility, yields on a Vertosol.

Location: Narrabri, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	No effect	No effect					No effect
Quality	CRR	CRR					CRR

A controlled, randomised, replicated experiment on a Vertosol (cracking clay soil) in Narrabri, New South Wales, Australia examined the influence of organic fertiliser on soil health in a cotton field. Three treatments based on common local practice were tested: cattle manure (10 t/ha), composted cotton gin trash (7.5 t/ha), commercial vermicompost liquid (50 L/ha). The results were compared to a control plot that did not receive any organic fertiliser. All plots were also fertilized with a mineral fertiliser – urea (60 kg N/ha). The study did not find any significant differences in soil characteristics between treatments. Microbial biomass, respiration and nutrient uptake were not affected. The data on exchangeable K and Na concentrations did not display a clear pattern, but except for two occasions neither differed significantly. The phosphate-P concentration differed significantly only 12 months after first application (111% for cattle manure and 55% increase for cotton gin trash compared to the control). Also, vermicompost seemed to increase Zn, Fe, Cu and Mn concentrations. However, the authors warned that rapid mineralisation of soil organic matter could lead to a long-term decline in soil carbon stocks. Changes in the soil characteristics were only observed from one year to another regardless of treatment. Yield did not vary significantly, either. The study concluded that application of organic fertiliser at the rates used in the experiment did not have any major short-term effects on soil quality. The authors pointed out that the result was valid for alkaline, swelling soils typical for Australia's cotton growing regions. Most similar studies showing positive results of organic fertiliser application had been conducted on acidic, non-swelling soils.

5.4.4 Europe

5.4.4.1 *Cotton fertilisation with composts of (sugarbeet) vinasse and agricultural residues*[3]

Key message: Vinasse combined with organic waste increase cotton yields, do not affect quality.

Location: Sevilla, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							Positive
Quality							CRR

A controlled, randomised, replicated study in Sevilla, Spain tested mixtures of beet vinasse combined with different organic wastes. Beet vinasse is a biochemically desugarized remnant of sugarbeet rich in N, K and organic matter, but due to high salt content, low P content and high density it is not ideal as a standalone fertiliser. For that reason, it is mixed with other substances. The authors composted vinasse for seven months with ten different organic wastes: olive-pressed cake, olive-pressed cake and leonardite, cotton gin trash, cotton gin trash and leonardite, municipal solid waste, tobacco dust, composted olive-oil-mill effluents, olive-oil-mill sludge, grape marc, and rice husk. The results of this study were compared against a plot that received mineral fertiliser. A non-fertilized plot was used as a control. The authors did not observe any differences in quality between the treatments and control. All treatments produced higher yields than the control. Mineral fertiliser, rice husk, municipal solid waste and the non-fertilized plot all yielded less than the mean yield commonly obtained in the locality, whereas all the other treatments produced more than the mean.

5.4.4.2 Effects of a compost made from the solid by-product ("alperujo") of the two-phase centrifugation system for olive oil extraction and cotton gin waste on growth and nutrient content of ryegrass[9]

Key message: Cotton gin waste and alperujo mixture improves soil productivity, but works better in combination with mineral fertiliser.

Location: Murcia, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					No effect
Quality		C Rep					C Rep

A controlled, replicated laboratory experiment on calcareous clay loam tested three compost application rates (0, 40 and 80 t/ha) and two nitrogen fertilisation rates (0 kg N/ha and 60 kg N/ha) on ryegrass. The compost mixture consisted of cotton gin waste and 'alperujo' – a by-product of olive oil extraction. The mixture had basic pH, high C/N ratio, was rich in organic matter, and had high potassium and nitrogen content, albeit not bioavailable. It was also low in other nutrients compared to manure and other composts. The compost slightly stimulated plant growth and increased yields despite its poor quality; additional nitrogen fertilisation improved soil productivity considerably more. The authors recommended using compost in combination with mineral fertiliser to enhance soil productivity.

5.4.4.3 Oregano green manure for weed suppression in sustainable cotton and corn fields[4]

Key message: Oregano green manure inhibits pest growth, increases yields.

Location: Thessaloniki, Greece

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					Positive
Quality		CRR					CRR

A controlled, randomised, replicated two year experiment on calcareous loam in Thessaloniki, Greece studied the potential of oregano green manure as a green herbicide. The study was conducted with four treatments of different oregano biotypes and two controls, one of which had weed and the other was weed-free. The study revealed that oregano green manure could supplant synthetic herbicides, as the manure reduced the emergence of common purslane by 0-55%, of barnyard grass by 38-52%, and of bristly foxtail by 43-86%. At the same time, cotton lint yields in treatment plots exceeded those in the weedy control by 24-88%. However, they were significantly lower than those in the weed-free control.

5.5 Bibliography

[1]Prasanna, R., Babu, S., Bidyarani, N., Kumar, A., Triveni, S., Monga, D., . . . Saxena, A. K. (2015). Prospecting Cyanobacteria-Fortified Composts as Plant Growth Promoting and Biocontrol Agents in Cotton. *Experimental Agriculture, 51*(1), 42-65. doi: Doi 10.1017/S0014479714000143

[2]Sui, N., Zhou, Z. G., Yu, C. R., Liu, R. X., Yang, C. Q., Zhang, F., . . . Meng, Y. L. (2015). Yield and potassium use efficiency of cotton with wheat straw incorporation and potassium fertilisation on soils with various conditions in the wheat-cotton rotation system. *Field Crops Research, 172*, 132-144. doi: 10.1016/j.fcr.2014.11.011

[3]Madejon, E., Diaz, M. J., Lopez, R., Lozano, C., & Cabrera, F. (1996). Cotton fertilisation with composts of (sugarbeet) vinasse and agricultural residues. *Fertiliser Research, 43*(1-3), 179-182. doi: Doi 10.1007/Bf00747699

[4]Vasilakoglou, I., Dhima, K., Anastassopoulos, E., Lithourgidis, A., Gougoulias, N., & Chouliaras, N. (2011). Oregano green manure for weed suppression in sustainable cotton and corn fields. *Weed Biology and Management, 11*(1), 38-48. doi: DOI 10.1111/j.1445-6664.2011.00403.x

[5]Anwar-ul-Haq, M., Akhtar, J., Saqib, M., Hussain, A., & Hussain, T. (2014). Integrated Use of Farm Manure and Mineral Fertilisers to Maintain Soil Quality for Better Cotton (Gossypium Hirsutum L.) Production. *Pakistan Journal of Agricultural Sciences, 51*(2), 423-430.

[6]Ouattara, K., Ouattara, B., Nyberg, G., Sedogo, M. P., & Malmer, A. (2008). Effects of ploughing frequency and compost on soil aggregate stability in a cotton-maize (Gossypium hirsutum-Zea mays) rotation in Burkina Faso. *Soil Use and Management, 24*(1), 19-28. doi: DOI 10.1111/j.1475-2743.2007.00129.x

[7]Ouattara, K., Ouattara, B., Nyberg, G., Sedogo, M. P., & Malmer, A. (2007). Ploughing frequency and compost application effects on soil infiltrability in a cotton-maize (Gossypium hirsutum-Zea mays L.) rotation system on a Ferric Luvisol and a Ferric Lixisol in Burkina Faso. *Soil & Tillage Research, 95*(1-2), 288-297. doi: DOI 10.1016/j.still.2007.01.008

[8]Huang, J. L., Li, H. L., & Yuan, H. X. (2006). Effect of organic amendments on Verticillium wilt of cotton. *Crop Protection, 25*(11), 1167-1173. doi: DOI 10.1016/j.cropro.2006.02.014

[9]Alburquerque, J. A., Gonzalvez, J., Garcia, D., & Cegarra, J. (2007). Effects of a compost made from the solid by-product ("alperujo") of the two-phase centrifugation system for olive oil extraction and cotton gin waste on growth and nutrient content of ryegrass (Lolium perenne L.). *Bioresource Technology, 98*(4), 940-945. doi: DOI 10.1016/j.biortech.2006.04.014

[10]Ghosh, S., Hulugalle, N., Lockwood, P., King, K., Kristiansen, P., & Daniel, H. (2008). Organic amendments influence nutrient availability and cotton productivity in irrigated Vertosols. *Australian Journal of Agricultural Research, 59*(11), 1068-1074. doi: Doi 10.1071/Ar08141

6 Animal manure

6.1 Description

Animal manure, a traditional organic input, can be used as a fertiliser and is thought to provide benefits for long-term soil health (e.g. by adding organic matter content). While farmers often add manure to their fields as they perceive its long-term benefits, it is often argued that animal manure alone cannot provide all the nutrients for a number of reasons including the fact that slow release of nutrients from manure is not ideal considering cotton's needs.

6.2 Quick facts

Definition and purpose: Incorporating animal manure into cotton nutrient management plans as a means of fertilising crops using an organic waste product

Benefits: Improves soil health; and reduces reliance on synthetic fertiliser

6.3 Synthesis

Although there are only a few studies on the environmental effects of animal manure on cotton production, they all agree on animal manure's benefits to soil fertility. Some effects on biodiversity can be inferred from studies exploring the use of organic pesticides to treat cotton fields. Although studies are generally conclusive, one should note that manures themselves, the composition of manure mixtures generally, as well as experimental designs vary across locales and studies; for example, cattle manure can vary greatly in terms of quality and fertiliser value depending on where it comes from.

Animal manure is often unable to meet crop nutrient demand over large areas because of limited quantities available, low nutrient content and high labour demands with regards to processing and application. While there remain significant gaps in experimental design and information, supplementing animal manures with inorganic fertilisers should be considered[1]. A more recent study suggests that adding effective microorganisms to a mixture of inorganic and organic fertilisers would increase cotton crop yield and save mineral nitrogen fertilisation; however, this again needs further research[2].

6.3.1 Impact summary of the intervention

In total, 7 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
Limited evidence	Positive					Increases	Low	Is not affected

6.3.2 Soil

Three studies (two controlled, randomised and replicated, and one long-term) suggest that **mixing animal manure with regular fertiliser reduces the quantity of synthetic fertiliser needed**, while maintaining or improving yield levels[3-5].

Two studies (one controlled, randomised and replicated) indicate soils' **accelerated mineralisation of organic matter** after addition of animal manure[6,7].

Lastly, six studies (of which three were controlled, randomised, replicated, one was long-term and one randomised) agree on **improvements of soil fertility**[1,3-7]. One study concludes that animal manure has no effect[4], although it also notes that it was conducted on a particular type of Australian soil that differed from where most similar studies had been carried out.

6.3.3 Water

No effects on water have been identified.

6.3.4 Biodiversity

No effects on biodiversity have been identified.

6.4 Evidence review

6.4.1 Asia

6.4.1.1 Integrated use of farm manure and mineral fertilisers to maintain soil quality for better cotton[3]

Key message: Mineral fertiliser can be partially replaced by animal manure without sacrificing cotton yields.

Location: Faisalabad, Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					No effect
Quality		CRR					CRR

A controlled, randomised, replicated study on sandy clay loam in Faisalabad, Pakistan examined the effects of farm manure and mineral fertiliser on yields and soil properties in a cotton field. The authors designed five treatments – farm manure at 20 Mg ha^{-1}, fermented farm manure at 20 Mg ha^{-1}, half the recommended dose of NPK mineral fertiliser combined with farm manure at 20 Mg ha^{-1}, half the recommended dose of NPK with fermented farm manure 20 Mg ha^{-1}, full recommended NPK treatment (170, 85 and 60 kg ha^{-1}) – which they compared with a control. The study determined that combined ½ NPK with fermented farm manure produced similar results in terms of growth parameters and soil nutrient concentration as a full dose of mineral fertiliser by itself.

6.4.1.2 Trend and stability analysis to interpret results of long-term effects of application of fertilisers and manure to cotton grown on rainfed Vertisols[4]

Key message: Manure increases yields, improves soil structure. However, it performs best when combined with conventional fertiliser. Crop rotation increases yields, makes them more stable.

Location: Nagpur, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive						Positive
Quality	long-term (17 years)						long-term (17 years)

A long-term experiment on Vertisols in Nagpur, India running from 1985/86 until 2002/03 examined the influence of cropping systems (monocropping cotton and cotton in rotation with sorghum) and different fertilisers (manure and mineral) on yield outcomes under rainfed conditions. The study found that crop rotation as opposed to monocropping gave more stable and higher (1828 kg/ha versus 1384 kg/ha) yields. The authors also observed that manure and fertiliser applied together produced the highest mean yield response (1218 kg/ha). Lastly, soil available P and Zn were greater with manure added than without it.

5.5.1.1 Productivity and sustainability of cotton-wheat cropping system as influenced by prilled urea, farmyard manure and azotobacter[5]

Key message: Combination of mineral and organic fertiliser increases yields, maintains long-term soil fertility.

Location: New Delhi, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					Positive
Quality		CRR					CRR

A controlled, randomised, replicated experiment on sandy loam in New Delhi, India analysed the direct and residual effect of mineral, organic and *Azobacter*-combined sources of nitrogen on the performance of cotton-wheat rotation over two seasons. The experiment tested for eleven treatments combining various levels of the three aforementioned fertilisers. The results revealed that bolls per plant increased with increasing rates of nitrogen mineral fertiliser or mixtures of mineral fertiliser with organic fertiliser. In particular, 30 kg N/ha (mineral fertiliser) could be saved if farmyard manure were to be applied. Quality parameters of cotton were not significantly affected by either treatment. The study concluded that combined application of inorganic, organic and *Azobacter* sources of nitrogen increased cotton yield and maintained long-term soil fertility.

5.5.1.2 Effects of farmyard manure and fertilisers on yield, fibre quality and nutrient balance of rainfed cotton[7]

Key message: Manure contributes to positive nutrient balance, sustains soil fertility.

Location: Nagpur, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					Positive
Quality		CRR					CRR

A controlled, randomised, replicated study in Nagpur, India investigated the effects of farmyard manure, different mineral fertilisers, and their interactions on yield, fibre quality and nutrient balance. The authors applied 5 Mg/ha of manure or none on plots receiving different combinations of mineral fertiliser: PK, NK, NP and NPK. The mineral fertilisers used were 60 kg N/ha of urea (N), 13 kg P/ha of super phosphate (P) and 25kg K/ha of muriate of potash (K). The effects of manure and fertiliser were significant only in the first of the two years of the study, although control plots generally produced the lowest yield and the plots receiving manure yielded more than any other treatments. Of the mineral fertilisers, only N increased yields. The other minerals did not elicit a significant response. Likewise, interaction between mineral and organic fertiliser did not result in a significant effect. Fibre quality also remained unaffected by fertilisation, although per cent lint in the seed cotton was significantly greater in the manure treatments. Lastly, nutrient balance of the tree minerals (inputs of fertiliser and manure minus outputs represented by crop uptake) was positive for the plots that were treated with manure and negative in the other plots.

6.4.2 Australia and Oceania

6.4.2.1 Organic amendments influence nutrient availability and cotton productivity in irrigated Vertosols[8]

Key message: Organic fertiliser does not affect soil structure, fertility or yields on a Vertosol.

Location: Narrabri, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	No effect	No effect					No effect
Quality	CRR	CRR					CRR

A controlled, randomised, replicated experiment on a Vertosol (cracking clay soil) in Narrabri, New South Wales, Australia examined the influence of organic fertiliser on soil health in a cotton field. Three treatments based on common local practice were tested: cattle manure (10 t/ha), composted cotton gin trash (7.5 t/ha) and commercial vermicompost liquid (50 L/ha). The results were compared to a control plot that did not receive any organic fertiliser. All plots were also fertilized with a mineral fertiliser – urea (60 kg N/ha). The study did not find any significant differences in soil characteristics between treatments. Microbial biomass, respiration and nutrient uptake were not affected. The data on exchangeable K and Na concentrations did not display a clear pattern, but except for two occasions neither differed significantly. The phosphate-P concentration differed significantly only 12 months after first application (111% for cattle manure and 55% increase for cotton gin trash compared to the control). Also, vermicompost seemed to increase Zn, Fe, Cu and Mn concentrations. However, the authors warned that rapid mineralisation of soil organic matter could lead to a long-term decline in soil carbon stocks. Changes in the soil characteristics were only observed from one year to another regardless of treatment. Yield did not vary significantly, either. The study concluded that application of organic fertiliser at the rates used in the experiment did not have any major short-term effects on soil quality. The authors pointed out that the result was valid for alkaline, swelling soils typical for Australia’s cotton growing regions. Most similar studies showing positive results of organic fertiliser application had been conducted on acidic, non-swelling soils.

6.4.3 Europe

6.4.3.1 Chemical changes during vermicomposting of sheep manure mixed with cotton industrial wastes[6]

Key message: Vermicomposting reduces salinity, increases mineralization of organic matter.

Location: Barcelona, Spain

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					
Quality	-	-					

A study in Barcelona, Spain examined the variations in chemical composition of sheep manure alone and in combination with cotton gin waste during 12 weeks of vermicomposting. The authors also compared the results with treatments without earthworms. The presence of earthworms was associated with lower salinity. The increase in P, Na and K also indicated that vermicomposting accelerated mineralization of organic matter. The authors concluded that vermicomposting could be an alternative method for recovery of industrial wastes as well as a low-cost fertiliser.

6.4.4 North America

6.4.4.1 Long-term effects of poultry litter and conservation tillage on crop yields and soil phosphorus in cotton-cotton-corn rotation[9]

Key message: Poultry litter maintains soil fertility by maintaining soil pH and building up phosphorus in soil.

Location: Belle Mina, Alabama, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					Mixed
Quality		Ran					Ran

A long-term (5 years), randomised field experiment on a silt loam in Belle Mina, Alabama, USA assessed the benefits of poultry litter, conservation tillage and cover crop on cotton lint yields. Second, the status of phosphorus in soil after long-term application of poultry litter was evaluated. The study consisted of 11 treatments combining cover crops (or lack thereof), tillage systems and sources of nitrogen. Cotton was followed by rye or fallow, was conventionally tilled, mulch tilled or no-tilled, and the source of nitrogen was either none (unfertilized), ammonium nitrate or poultry litter. Ammonium was applied at 100 kg/ha of N, whereas poultry litter was applied at 100 kg/ha of N or 200 kg/ha of N. Different tillage systems produced similar yield at 100 kg/ha of N added by ammonium nitrate. Poultry litter at the same rate reduced yield by 12% in a conventionally tilled system and by 11% in a minimum tilled system. No-tilled plots with 200 kg/ha of N of poultry litter, however, gave similar yields as conventionally and mulched tilled plots with ammonium added at 100 kg/ha of N. In terms of soil health, long-term application of poultry manure at 100 kg/ha of N helped maintain original soil pH in conventional and mulched tillage systems, whereas soil pH decreased after ammonium application. In no-till plots, manure at 100 kg/ha was not enough to maintain pH, but 200 kg/ha did manage to maintain it. Finally, application of poultry litter generally resulted in build-up of phosphorus.

6.5 Bibliography

[1]Palm, C.A., Myers, R.J.K, Nandwa, S.M. (1997). Combined Use of Organic and Inorganic Nutrient Sources for Soil Fertility Maintenance and Replenishment. In American Society of Agronomy and Soil Science Society of America. (1997). *Replenishing Soil Fertility in Africa,* 193-213. SSSA Special Publicaiton no.51, Madison, WI, USA.

[2]Khaliq, A., Abbasi, M.K., Hussain, T. (2006). Effects of integrated use of organic and inorganic nutrient sources with effective miccroorganisms (EM) on seed cotton yield in Pakistan. *Bioresource Technology, 97(8),* 967-972. Doi: 10.1016/j.biortech.2005.05.002

[3]Anwar-ul-Haq, M., Akhtar, J., Saqib, M., Hussain, A., & Hussain, T. (2014). Integrated Use of Farm Manure and Mineral Fertilisers to Maintain Soil Quality for Better Cotton (Gossypium Hirsutum L.) Production. *Pakistan Journal of Agricultural Sciences, 51*(2), 423-430.

[4]Blaise, D., Ravindran, C. D., & Singh, J. V. (2006). Trend and stability analysis to interpret results of long-term effects of application of fertilisers and manure to cotton grown on rainfed vertisols. *Journal of Agronomy and Crop Science, 192*(5), 319-330. doi: DOI 10.1111/j.1439-037X.2006.00222.x

[5]Das, A., Prasad, M., Shivay, Y. S., & Subha, K. M. (2004). Productivity and sustainability of cotton (Gossypium hirsutum L.)-wheat (Triticum aestivum L.) cropping system as influenced by prilled urea, farmyard manure and Azotobacter. *Journal of Agronomy and Crop Science, 190*(5), 298-304. doi: DOI 10.1111/j.1439-037X.2004.00110.x

[6]Albanell, E., Plaixats, J., & Cabrero, T. (1988). Chemical-Changes during Vermicomposting (Eisenia-Fetida) of Sheep Manure Mixed with Cotton Industrial-Wastes. *Biology and Fertility of Soils, 6*(3), 266-269.

[7]Blaise, D., Singh, J. V., Bonde, A. N., Tekale, K. U., & Mayee, C. D. (2005). Effects of farmyard manure and fertilisers on yield, fibre quality and nutrient balance of rainfed cotton (Gossypium hirsutum). *Bioresource Technology, 96*(3), 345-349. doi: 10.1016/j.biortech.2004.03.008

[8]Ghosh, S., Hulugalle, N., Lockwood, P., King, K., Kristiansen, P., & Daniel, H. (2008). Organic amendments influence nutrient availability and cotton productivity in irrigated Vertosols. *Australian Journal of Agricultural Research, 59*(11), 1068-1074. doi: 10.1071/Ar08141

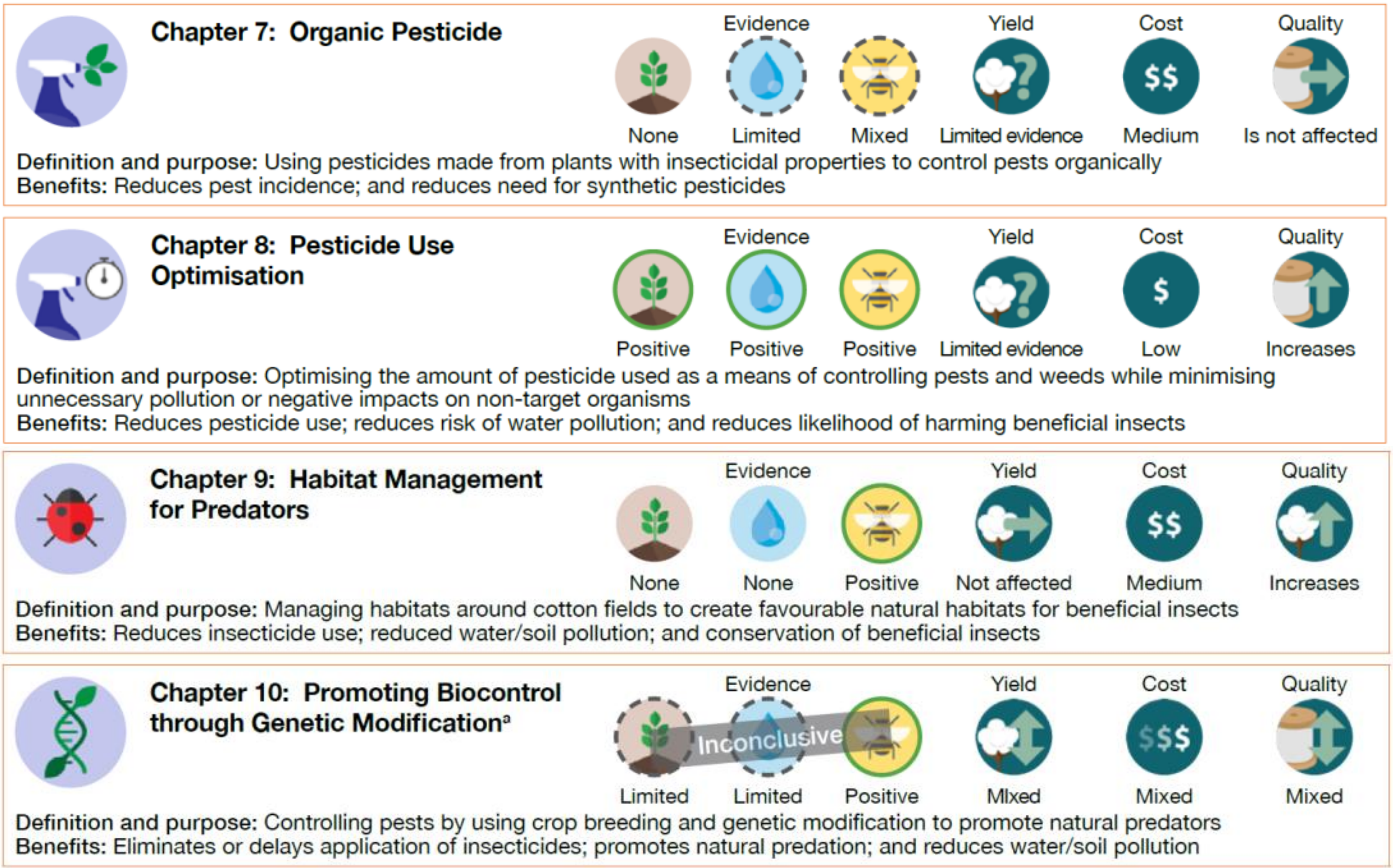
[9]Reddy, S. S., Nyakatawa, E. Z., Reddy, K. C., Raper, R. L., Reeves, D. W., & Lemunyon, J. L. (2009). Long-term effects of poultry litter and conservation tillage on crop yields and soil phosphorus in cotton-cotton-corn rotation. *Field Crops Research, 114*(2), 311-319. doi: 10.1016/j.fcr.2009.09.001

Pest management

Section Overview

Cotton production is threatened by a number of different pests. Production systems often rely on synthetic pesticides to control and manage pest populations; these inputs however can be costly and can cause significant damage to local water supplies, biodiversity and human health. To avoid overdependence on synthetic pesticides, a number of other practices are used, three of which were identified and researched using a number of terms (See Appendix 3.1: Primary Search and Appendix 3.2: Secondary Search). Reviewing 'Pest management ' interventions more generally yielded a number of studies on genetic modification and its impact on biocontrol services. The intervention 'Promoting Biocontrol using Genetic Modification' is therefore a compilation of the gm-focussed studies that were not captured by the other categories. This does not signify that there is a lack of studies or of evidence since the topic itself was not explicitly researched here.

Section Chapters



Organic pesticide

7.1 Description

Some naturally occurring substances (e.g. a compound extracted from neem tree) can be applied for pest control in lieu of synthetic pesticides. Organic pesticides like botanical sprays tend to be only selectively toxic, that is, they are usually not harmful to beneficial insects (although some are), other animals or humans. Owing to their lower toxicity and natural origin, it is generally assumed that they do not pollute soil and water.

7.2 Quick facts

Definition and purpose: Using pesticides made from plants with insecticidal properties to control pests organically

Benefits: Reduces pest incidence; and reduces need for synthetic pesticides

7.3 Synthesis

Studies highlight beneficial effects of organic pesticides on biodiversity, but the evidence is not clear-cut. Positive effects on water and biodiversity frequently have had to be assumed from studies whose primary research objective was a different aspect of organic pesticides. Contrary to expectations, no studies have been identified that would explain impacts of organic pesticides on water. Effects of any kind on soils have not been found, either.

7.3.1 Impact summary of the intervention

In total, 16 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
		Limited evidence		Mixed	Mixed	Limited evidence	Medium	Is not affected

7.3.2 Soil

No effects on soil have been identified.

7.3.3 Water

No effects on water have been identified.

7.3.4 Biodiversity

Interactions between different organic substances, other biological agents, such as natural predators, and cotton are complex. Effects of these interactions vary and are not yet fully understood. One (controlled, replicated) study claims that neem is selective and not harmful to natural predators[1], while two other studies (both randomised, one also controlled) maintain the opposite[2,3]. One study (controlled, randomised, replicated) concludes that some botanical substances produce a negative effect on plant-growth promoting bacteria, while others do not[4]. Therefore, the impacts of organic pesticides on biodiversity cannot be generalized.

Two studies (both controlled, randomised, replicated) show that botanical pesticides may only have short-term repellent effects or are not toxic to certain pests at all[5,6]. As two studies specifically recommend (both controlled and replicated, one also randomised), organic pesticides work best if **applied in combination with other measures**, for example, as part of Integrated Pest management strategies[4,7].

7.4 Evidence Review

7.4.1 Africa

7.4.1.1 Field evaluation of the efficacy of neem oil and Beauveria bassiana in cotton production[8]

Key message: Natural enemies are more abundant and yield is somewhat higher in fields treated with biopesticides. However, yield is even higher and production is more economically viable in fields utilizing synthetic pesticides.

Location: Kandi, N'Dali and Djidja districts, Benin

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	Negative
Quality					CRR	CRR	CRR

A controlled, randomised, replicated field experiment in Kandi, N'Dali and Djidja districts in Benin examined the differences in outcomes of four pest management strategies: a standard calendar-based application or synthetic pesticide, so-called LEC (Lutte Etagée Ciblée), in which farmers applied synthetic pesticides based on threshold levels of infestation, and two strategies based on organic pesticides (neem oil alone and neem oil combined with the entomopathogenic fungus *Beauveria bassiana*). The results were compared to a control that only received water. The study found that the plots that had received biopesticide produced 26-42% higher yields than the control and the conventional and LEC strategy produced 44-55% higher yields. The study recommended using LEC, as it scored best in terms of profitability as well as yield. The incidence of natural enemies, however, was highest in the control group and in the fields treated with organic pesticides.

7.4.1.2 Biological, cultural and selective methods for control of cotton pests in Egypt[9]

Key message: Strategies aiming to delay the first application of insecticide, which minimize its use, help preserve beneficial insects.

Location: Egypt

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					-	-	

A paper on pest control strategy in Egypt during the 1980s gave an overview of non-insecticidal practices such as paying children to collect the eggs of Egyptian cotton leaf worm. The authors concluded that practices delaying the use of synthetic insecticides helped preserve beneficial fauna.

7.4.2 Asia

7.4.2.1 Evaluation of botanical and synthetic insecticides for the management of cotton pest insects[10]

Key message: Synthetic insecticide is more toxic to pests than botanical insecticide and produces the highest yields, though botanical insecticide reduces pest populations significantly and still increases yields, as opposed to an untreated field.

Location: Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							Positive
Quality							CRR

A controlled, randomised, replicated experiment compared the performance of neem oil at 1, 1.5 and 2% concentrations, need seed water extract at 1, 2 and 3% concentrations, and a commercial synthetic insecticide (Polytrin-C). The study evaluated the efficiency of these insecticides on whiteflies, jassids, thrips, spotted bollworm, pink bollworm. Additionally, the study considered the impacts on yields. The synthetic pesticide generally achieved a reduction in pest populations between 75% and 90%. For example, Polytric-C reduced whitefly populations by 87.23%. The botanical sprays generally performed better at the highest concentrations and reduced the incidence of pest roughly by 25% to 60%. For example, whitefly populations were reduced by 57.46% (oil) and 48.29% (water extract). Lastly, the study revealed that neem oil at 1.5% and 2% and neem seed water extract at 3% increased yield of seed cotton. The treatments produced 676.2 kg/ha, 1095 kg/ha and 1010 kg/ha, respectively, compared to the untreated control that produced only 333.3 kg/ha. Lower concentrations of botanical insecticide yielded quantities statistically similar to the control. The plots treated with Polytrin-C produced 1600 kg/ha.

7.4.2.2 The joint action of destruxins and botanical insecticides (rotenone, azadirachtin and paeonolum) against the cotton aphid, Aphis gossypii Glover[7]

Key message: There are synergies between destruxins and botanical insecticides.

Location: China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Variable	Variable	
Quality					C Rep	C Rep	

A controlled, replicated experiment in China mixed destruxins and botanical insecticides to study their interactions and discover possible synergies. The insecticides consisted of 95% rotenone, 98% paeonolum and 34% azadirachtin powder. They were mixed with 34.2% destruxins powder at ratios from 10:0 to 0:10 (increments of 1). The study revealed additive effects in destruxins mixed with rotenone, azadirachtin and paeonolum for most ratios.

7.4.2.3 Effects of different neem preparations on comparison to synthetic insecticides on the whitefly parasitoid Encarsia sophia and the predator Chrysoperla carnea on cotton under laboratory conditions[1]

Key message: Neem-based insecticides are not toxic to beneficial predators.

Location: Punjab, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					C Rep	C Rep	

A controlled, replicated laboratory experiment in Punjab, India examined the effectiveness of a commercial neem-based insecticide and three synthetic insecticides (chlorpyriphos, endosulfan, triazophos) against immatures and adult emergence of natural predators of *Bemisia tabaci* (whitefly). Water was used as a control. The study evaluated toxicity upon contact and feeding toxicity of the insecticide NeemAzal T/S (1.0%) at 200mg/l, 400mg/l, and 800mg/l. The insecticide did not cause any effects on immatures of *Encarsia sophia* at lower concentrations (emergence 21 days after treatment of 88.2% and 84.4% for 200mg/l and 400mg/l, respectively), but it did cause a significant reduction (54.7% emergence compared to 89.6% in the control) at the highest concentration. The three synthetic insecticides all showed a significant reduction (emergence ranged from 13.23% for triazophos to 44.79% for chlorpyriphos). Similar effects were observed in *E. sophia* adults: synthetic insecticides nearly eradicated them (e.g. 97% mortality for triazophos), whereas neem extract caused a much smaller, albeit significant reduction (16-32% mortality, depending on concentration). Feeding toxicity of neem-based insecticide was dosage-dependent. In case of *Chrysoperla carnea*, the study examined the effects three neem-based insecticides, which did not induce any adverse effects on egg hatchability of the beneficial whitefly predator. The results were compared to a water control and a triazophos treatment. Triazophos, causing only 5.66% hatchability, proved extremely toxic. Higher concentrations of neem insecticide somewhat increased the mortality or first and second instar larvae, but the synthetic insecticide caused over 80% mortality for all three larvae stages. All three synthetic insecticides showed high contact as well as feeding toxicity. By contrast, organic insecticides were not toxic to beneficial predators.

7.4.2.4 Residual toxicity and biological effects of neem oil against cotton mealybug[11]

Key message: Neem oil is effective against cotton mealybug.

Location: Dera Ismail Khan, Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

A laboratory experiment investigated the effect of six concentrations of neem oil (5000, 10000, 15000, 20000, 25000, 30000 ppm) on residual toxicity and on growth regulating effects on cotton mealybug (*Phenacoccus solenopsis*). Distilled water was used as a control. Neem oil significantly affected the days to cocoon formation, pupal period and male adult longevity with 30000 ppm being the most effective concentration. The study also discovered that females laid significantly fewer eggs when treated (ranging from 229 eggs for 5000 ppm to 87.89 eggs for 30000 ppm), compared to control (325.8 eggs). 30000 ppm also eradicated 70% of cotton mealybug nymphs with lower concentrations having lesser effect. Only 5000 ppm did not produce significant nymph mortality. The study concluded that neem oil at higher concentrations (25000 and 30000) had significant adverse effects on cotton mealybug. The authors also discovered that neem oil could be stored up to three months under shade conditions and still preserve its effectiveness.

7.4.3 Australia and Oceania

7.4.3.1 Effects of neem-fed prey on the predacious insects Harmonia conformis and Mallada signatus[2]

Key message: Neem seed extract may adversely affect beneficial natural predators.

Location: Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Negative*	Negative*	
Quality					C Ran	C Ran	

* Though not directly toxic, the study showed negative effects of neem on certain predators.

A controlled, randomised experiment in Australia investigated the effects of indirect exposure of natural predators to neem seed extracts. *H. conformis* adults and *M. signatus* larvae (both predators) were fed *Helicoverpa armigera* larvae (prey) that had eaten neem oil solution. The experiment consisted of three treatments: 50 and 200 ppm azadirachtin (active substance from neem) and 50 ppm endosulfan (a synthetic pesticide). Distilled water was used as a control. The study concluded that neither pesticide caused direct mortality to the predators at the tested concentrations. However, both biopesticide treatments adversely affected pupal survival of *M. signatus*. The 50 ppm treatment killed some 50% of the individuals. The 200 ppm treatment killed all. The authors urged caution when applying neem-based pesticides due to their negative effects on natural predators.

7.4.4 North America

7.4.4.1 Management of Meloidogyne incognita on cotton by use of botanical aromatic-compounds[12]

Key message: Botanical substances reduce the incidence of pest, do not affect yield.

Location: Alabama, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive*		Positive*	Positive*	No effect
Quality			-		-	-	CRR

* Assumed, given that the study mentions negative effects of synthetic pesticides on groundwater quality and animal health.

A controlled, randomised, replicated experiment in Alabama, USA examined pesticidal properties of four botanical substances on a sandy loam soil infested with *Meloidogyne incognita*. Benzaldehyde, citral, furfural, menthol, and α-terpineol – all naturally occurring substances – were added to the soil at rates of 0.10, 0.25, and 0.50 millilitres per kilogram of soil. No compound in any rate reduced plant height. All rates of citral and menthol increased plant height. All compounds at all rates reduced the number of *Meloidogyne incognita*, but the rate of 0.25 ml/kg was as effective as the higher rate of 0.50 ml/kg in all cases. Thus, the study determined that effective rates were between 0.10 ml/kg and 0.25 ml/kg.

7.4.4.2 Effect of botanical aromatic compounds and seed-surface pH on growth and colonization of cotton plant growth-promoting rhizobacteria[4]

Key message: Some botanical substances (furfural) negatively affect plant-growth promoting bacteria, but others (citral, benzaldehyde) do not and can be used with bacteria as part of Integrated Pest management .

Location: Alabama, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Variable	Variable	
Quality					CRR	CRR	

A controlled, randomised, replicated experiment in Alabama, USA investigated the interaction between eleven strains of plant-growth promoting rhizobacteria and three botanical pesticides (furfural, citral, and benzaldehyde). The authors performed an in vitro test and a field experiment (both were controlled, randomised, replicated). Furfural and benzaldehyde adversely affected all bacterial strains in vitro, some of which were killed by the compounds. The strains tolerated citral, but their growth was still reduced. In the field, citral and benzaldehyde did not produce any effect on the beneficial bacteria, but furfural reduced the level of colonization across all strains. Citral and benzaldehyde affected only two strains (IMP 7 colonization was decreased by both, IMP 11 was increased by benzaldehyde and decreased by citral).

7.4.4.3 Inhibition of aflatoxin production in Aspergillus flavus infected cotton bolls after treatment with neem (Azadirachta indica) leaf extracts[13]

Key message: Neem inhibits contamination of cottonseed by aflatoxin from a parasitic fungus.

Location: USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

A controlled experiment in the USA studied insecticidal and fungicidal properties of neem. Neem extract was applied to two treatment groups: one received the extract 48 hours before infestation with *Aspergillus flavus* and the other received it at the same time as the infection. The authors measured fungal growth and aflatoxin production. The treatment 48 hours before inhibited over 98% of aflatoxin production, whereas only a 16% reduction was observed in the treatment with the simultaneous application. The authors also found that neem leaf extract did not kill the fungus.

7.4.4.4 *Deterrent effects of four neem-based formulations on gravid female boll weevil feeding and oviposition on cotton squares*[5]

Key message: Neem repels boll weevil for a short period of time, but is not toxic against it.

Location: Weslaco, Hidalgo County, Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

A controlled, randomised, replicated laboratory experiment in Weslaco, Hidalgo County, Texas, USA tested the reaction of gravid female boll weevils to three commercial neem-based insecticides (Agroneem, Neemix, Ecozin) and neem extracts of different concentrations (1,036µg, 16,506 µg, 471 µg and 223µg of azadirachtin per mL). The authors dipped 7mm diameter cotton square in a treatment or a control and released a weevil. They did not find any toxic effects of any formulation against the boll weevil adults. However, the study found that female boll weevils were positions on nontreated squares significantly more than on treated ones. The repellent effects, however, did not last beyond 3 hours in the case of Agroneem and Neemix. Ecozin and bitters repelled the boll weevil for up to and perhaps beyond 4.5 hours. The study inferred that since the content of azadirachtin (the supposed active substance in neem) in the bitters had been the lowest of all treatments, but the bitters repelled nonetheless, some other substance must have contributed to repellence. The authors also tried aging the treatments in sunlight for 24, 48 and 72 hours. Although some of the treatments exhibited increased reductions in feeding and oviposition punctures on the leaf squares, it was concluded that neem-based insecticides were too weak and, thus, not practical for commercial utilization against boll weevil.

7.4.4.5 *Tests of garlic oil for control of the silverleaf whitefly, Bemisia argentifolii Bellows and Perring in cotton*[6]

Key message: Garlic is not effective for control of whiteflies.

Location: Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					No effect	No effect	
Quality					CRR	CRR	

A controlled, randomised, replicated greenhouse experiment in Arizona, USA examined the potential of garlic products for control of whiteflies. The authors placed healthy, uninfested cotton plants treated with different garlic products into a greenhouse with infested plants. The treatments consisted of an extract from chopped garlic, garlic oil (different concentrations of garlic in soybean oil), and five commercially available garlic-based insecticides. The controls were differed based on the treatment, as the treatments were tested separately. The garlic extract significantly reduced the number of whitefly eggs, nymphs and resting adults. However, the authors admitted that the substance contained some soybean oil that could have contributed to whitefly control. Garlic oil showed little to no difference from soybean oil (control), giving little to no control of whiteflies. The commercial products were found somewhat effective, showing reductions in whiteflies in some weeks, but their performance did not exceed that of the control. Lastly, the study did not detect toxicity of garlic in regards to whiteflies, as no dead eggs or nymphs were found. Thus, garlic, compared to soybean oil, was deemed ineffective for whitefly control.

7.4.5 South America

7.4.5.1 Botanical insecticides applied on Aphis gossypii and its predator Cycloneda sanguinea on naturally colored cotton[3]

Key message: Botanical insecticides successfully kill pests, but they also affect their predators.

Location: Brazil

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Variable	Variable	
Quality					Ran	Ran	

A randomised laboratory experiment in Brazil examined the effect of botanical insecticides based on azadirachtin, aqueous extract, and castor oil on a common cotton pest (aphid) and its predator. Aphid mortality was 64-100% for azadirachtin, 12-92% for aqueous extract, and 8-68% for castor oil. The insecticides killed the larvae of the predator as well at even higher rates.

7.4.5.2 Effects of botanical insecticides on the instantaneous population growth rate of Aphis gossypii Glover (Hemiptera: Aphidae) in cotton[14]

Key message: Some botanical insecticides successfully kill pests.

Location: Brazil

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Variable	Variable	
Quality					RR	RR	

A randomised, replicated laboratory study in Brazil investigated the response of *Aphid gossypii* to botanical insecticides at different concentrations. The authors tested an insecticide containing essential oils of neem, karanja and castor beans, one with *Derris* sp., and three insecticides with *Azadirachta indica* (neem). The authors also tested essential oils of *Foeniculum vulgare*, *Cymbopogom winterianus*, *Chenopodium ambrosioides*, *Piper aduncum* – all at a range of concentrations. The first three insecticides nearly exterminated the pest, whereas the three essential oils had no effect and two insecticides with *A. indica* increased the pest populations.

7.4.5.3 Effect of neem extract on the cotton aphid[15]

Key message: Neem is effective against the cotton aphid.

Location: Sao Paulo, Brazil

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

A controlled, randomised, replicated laboratory experiment in Sao Paulo, Brazil tested the effectiveness of neem extract on cotton aphids. The authors prepared aqueous extract of neem in four concentrations: 23.8mg, 122mg, 410mg, and 1,441mg of neem seed powder per of 100mL of water. Distilled water was used as a control. With increasing concentration of neem, the number of cotton aphid molts decreased. On average, cotton aphids subjected to the highest concentration showed on average only 0.6 molts, those at 410mg showed 2.2 molts and those in the control group 3.5 molts. The authors also observed a change in nymph coloration from yellow to brownish black. Generally, the study concluded that with increasing concentration of neem extract, adverse effects on aphids such as mortality or reproductive difficulties also increased. For example, aphids exposed to the highest concentration showed 85.6% reduction in survival period and 100% mortality after the first instar, whereas mortality at the second highest concentration reached 60%.

7.4.5.4 Development of Clitoria Ternatea as a biopesticide for cotton pest management: assessment of product effect on Helicoverpa spp. and their natural enemies[16]

Key message: A biopesticide based on *Clitoria ternatea* is effective against the pest species *Helicoverpa*, does not harm beneficial insects.

Location: New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					CRR	CRR	

Five related laboratory and field experiments (all controlled, randomised, replicated) in New South Wales, Australia evaluated extracts from the plant *Clitoria ternatea* for insecticidal effects on *Helicoverpa* species (a common pest) as well as on its natural enemies. *C. ternatea* was identified as a plant that *Helicoverpa* tends to avoid, and so its extract sprayed on cotton could change the pest's behaviour, deter feeding or even kill it. The authors tested 10, 15, 20% extract by volume in water in the first two experiments. In the third experiment, they tested more commercially viable formulations, opting for a horticultural oil formulation containing *C. ternatea* for the fourth and fifth experiments. The controls were always, depending on the experiment, water, an untreated plot or conventional insecticide. The study concluded that an oil-based formulation with 1-2% (by volume) *C. ternatea* mixture successfully deterred *Helicoverpa* oviposition, larvae feeding, and exhibited direct mortality to larvae. The substance did not adversely affect beneficial insects.

7.5 Bibliography

[1]Aggarwal, N., & Brar, D. S. (2006). Effects of different neem preparations in comparison to synthetic insecticides on the whitefly parasitoid Encarsia sophia (Hymenoptera : Aphelinidae) and the predator Chrysoperla carnea (Neuroptera : Chrysopidae) on cotton under laboratory conditions. *Journal of Pest Science, 79*(4), 201-207. doi: 10.1007/s10340-006-0134-9

[2]Qi, B. Y., Gordon, G., & Gimme, W. (2001). Effects of neem-fed prey on the predacious insects Harmonia conformis (Boisduval) (Coleoptera : Coccinellidae) and Mallada signatus (Schneider) (Neuroptera : Chrysopidae). *Biological Control, 22*(2), 185-190. doi: 10.1006/bcon.2001.0965

[3]Breda, M. O., de Oliveira, J. V., Marques, E. J., Ferreira, R. G., & Santana, M. F. (2011). Botanical insecticides applied on Aphis gossypii and its predator Cycloneda sanguinea on naturally colored cotton. *Pesquisa Agropecuaria Brasileira, 46*(11), 1424-1431.

[4]Bauske, E. M., Backman, P. A., Harper, K. M., Brannen, P. M., RodriguezKabana, R., & Kloepper, J. W. (1997). Effect of botanical aromatic compounds and seed-surface pH on growth and colonization of cotton plant growth-promoting rhizobacteria. *Biocontrol Science and Technology, 7*(3), 415-421.

[5]Showler, A. T., Greenberg, S. M., & Arnason, J. T. (2004). Deterrent effects of four neem-based formulations on gravid female boll weevil (Coleoptera : curculionidae) feeding and oviposition on cotton squares. *Journal of Economic Entomology, 97*(2), 414-421. doi: 10.1603/0022-0493-97.2.414

[6]Flint, H. M., Parks, N. J., Holmes, J. E., Jones, J. A., & Higuera, C. M. (1995). Tests of Garlic Oil for Control of the Silverleaf Whitefly, Bemisla-Argentifolii Bellows and Perring (Homoptera, Aleyrodidae) in Cotton. *Southwestern Entomologist, 20*(2), 137-150.

[8]Togbe, C. E., Haagsma, R., Zannou, E., Gbehounou, G., Deguenon, J. M., Vodouhe, S., . . . van Huis, A. (2015). Field evaluation of the efficacy of neem oil (Azadirachta indica A. Juss) and Beauveria bassiana (Bals.) Vuill. in cotton production. *Journal of Applied Entomology, 139*(3), 217-228. doi: 10.1111/Jen.12174

[7]Yi, F., Zou, C. H., Hu, Q. B., & Hu, M. Y. (2012). The Joint Action of Destruxins and Botanical Insecticides (Rotenone, Azadirachtin and Paeonolum) Against the Cotton Aphid, Aphis gossypii Glover. *Molecules, 17*(6), 7533-7542. doi: 10.3390/molecules17067533

[9]Campion, D. G., & Hosny, M. M. (1987). Biological, Cultural and Selective Methods for Control of Cotton Pests in Egypt. Insect Science and Its Application, 8(4-6), 803-805.

[10]Mamoon-ur-Rashid, M., Khattak, M. K., & Abdullah, K. (2012). Evaluation of Botanical and Synthetic Insecticides for the Management of Cotton Pest Insects. *Pakistan Journal of Zoology, 44*(5), 1317-1324.

[11]Mamoon-ur-Rashid, M., Khattak, M. K., & Abdullah, K. (2012). Residual Toxicity and Biological Effects of Neem (Azadirachta indica) Oil Against Cotton Mealybug, Phenacoccus solenopsis Tinsley (Sternorrhyncha: Pseudococcidae). *Pakistan Journal of Zoology, 44*(3), 837-843.

[12]Bauske, E. M., Rodriguezkabana, R., Estaun, V., Kloepper, J. W., Robertson, D. G., Weaver, C. F., & King, P. S. (1994). Management of Meloidogyne-Incognita on Cotton by Use of Botanical Aromatic-Compounds. *Nematropica, 24*(2), 143-150.

[13]Zeringue, H. J., & Bhatnagar, D. (1990). Inhibition of Aflatoxin Production in Aspergillus-Flavus Infected Cotton Bolls after Treatment with Neem (Azadirachta-Indica) Leaf Extracts. *Journal of the American Oil Chemists Society, 67*(4), 215-216. doi: 10.1007/Bf02540646

[14]de Andrade, L. H., de Oliveira, J. V., Breda, M. O., Marques, E. J., & Lima, I. M. D. (2012). Effects of botanical insecticides on the instantaneous population growth rate of Aphis gossypii Glover (Hemiptera: Aphididae) in cotton. *Acta Scientiarum-Agronomy, 34*(2), 119-124. doi: 10.4025/actasciagron.v34i2.10863

[15]dos Santos, T. M., Costa, N. P., Torres, A. L., & Junior, A. L. B. (2004). Effect of neem extract on the cotton aphid. *Pesquisa Agropecuaria Brasileira, 39*(11), 1071-1076.

[16]Mensah, R., Leach, D., Young, A., Watts, N., & Glennie, P. (2015). Development of Clitoria ternatea as a biopesticide for cotton pest management: assessment of product effect on Helicoverpa spp. and their natural enemies. *Entomologia Experimentalis Et Applicata, 154*(2), 131-145. doi: 10.1111/eea.12263

8 Pesticide use optimisation

8.1 Description

Cotton's share (by value) of global pesticide consumption has declined substantially (although changes vary greatly from one country to the next[1]) from 11 per cent in 1988 to 6.8 per cent in 2008[2]. Optimising the use of synthetic pesticides has become a priority for many farmers as this can reduce costs while retaining high yields of good quality cotton.

8.2 Quick facts

Definition and purpose: Optimising the amount of pesticide used as a means of controlling pests and weeds while minimising unnecessary pollution or negative impacts on non-target organisms

Benefits: Reduces pesticide use; reduces risk of water pollution; and reduces likelihood of harming beneficial insects

8.3 Synthesis

Few studies actually review the effects of pesticide *optimisation* or *reduction* on soil, water and biodiversity. However, there is an abundance of materials that discuss harmful effects of pesticide use on the three aforementioned components of natural capital; such information can be used to draw conclusions on pesticide use optimisation or reduction. A large group of studies also focuses on the relation of genetically modified cotton to the environment, connecting the introduction of genetically-modified cotton to a large reduction in insecticide use (See Chapter 10 'Promoting biocontrol through genetic modification').

8.3.1 Impact summary of the intervention

In total, 15 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance	Limited evidence	Low	Increases
Positive		Positive		Positive	Positive			

8.3.2 Soil

Pesticides used in cotton can contaminate soil and may not decompose easily; their **residue can remain in soil for decades**[3-5]. Optimising use therefore alleviates this pressure.

Despite pesticides' perceived detrimental effects, one study (controlled and replicated) actually shows a positive, stimulating impact of glyphosate (active ingredient in the commonly used herbicide 'Roundup') on soil and soil microfauna if applied without any other pesticides (otherwise the opposite effect was observed)[6].

8.3.3 Water

Mechanisms, through which pesticides pollute water, are well established. For example, five studies (one of them a replicated experiment and one of them controlled, randomised and replicated) show how pesticides can run off the field[7,8] as often occurs with drainage water, or remain in the soil and percolate deeper and deeper while being firmly attached to small soil particles[3,4,9], thereby **polluting surface as well as ground water**. Legally mandated recirculation of farm water in many places prevents water from running off farm, thus mitigating this problem. As two experiments demonstrate, other precautionary measures, such as ponded wetlands[10] or a cover of old crop stubble or cotton gin trash[11] also have the potential to **reduce pesticide concentrations in farm water**.

8.3.4 Biodiversity

Two studies (one of which is controlled, replicated) suggest that **pests can be controlled naturally** by delaying spraying or avoiding it completely, thus letting natural processes work undisturbed and beneficial insects flourish[2,3].

Pesticides can affect biodiversity in two ways: Firstly, four studies (two replicated and controlled) expose that **pesticides harm beneficial insects** – often natural predators potentially able to control pests[12-15]. However, six studies (three of which were controlled, replicated and randomised, two of which were controlled and replicated) also add that **not all pesticides cause harm or harm equally**[16-21]. Secondly, two studies (a controlled, randomised and replicated experiment, and a field study) show that water pollution caused by misuse of pesticides **impairs fish populations**[7,8].

Three studies (of which one controlled and a review) show that **Integrated Pest management (IPM) positively stimulates biodiversity of beneficial insect populations**[22-24]. Although other studies might not explore IPM directly, their conclusions imply that pesticide use optimisation and reduction is an integral, and overall beneficial, component of IPM.

8.4 Evidence review

8.4.1 Africa

8.4.1.1 Assessment of the health status of wild fish inhabiting a cotton basin heavily impacted by pesticides in Benin (West Africa)[7]

Key message: Pesticides used in cotton production get washed off the field, pollute water, cause declines in fish health.

Location: northern Benin

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive			Positive	
Quality			-			-	

A study in in Benin examined fish samples (Guinean tilapia and Africa catfish) caught at different sites within the country's cotton producing region. Samples were obtained during both rainy and dry seasons from four locations. One of these was Pendjari River in Pendjari National Park, which lied outside the agricultural region and was used as a reference. The authors assessed the impact of pesticides by looking at biometric measurements, plasma sex steroid levels, and gonad and liver histology of the fish. The analyses indicated that all fish suffered from poorer health, compared to the reference site.

8.4.1.2 Pesticides used in cotton production affect reproductive development, endocrine regulation, liver status and offspring fitness in African catfish Clarias gariepinus (Burchell, 1822)[8]

Key message: Pesticides used in cotton production cause declines in fish health that manifest themselves even in the next generation.

Location: Benin

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive			Positive	
Quality			CRR			CRR	

A set of controlled, randomised, replicated experiments in Benin compared the effects of endosulfan and Tihan 175 O-TEQ on health of African catfish. The study examined sexual development, hepatic status, endocrine regulation, reproductive performances and larval fitness. Chronic exposures to the two compounds adversely affected fish health, decreasing fertilisation rate, hatching rate, ova and larval weight, and larval resistance to osmotic choc. Delayed hatching and other abnormalities persisted even into the next generation.

8.4.1.3 Effect of pesticidal application during the early and late cotton season on the abundance of certain predators associated with cotton plants[13]

Key message: Pesticide use negatively affects beneficial insects.

Location: Egypt

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					No effect	Positive	
Quality					-	-	

An experiment in Egypt surveyed the populations of six common predators (beneficial insects) over three seasons before and after application of several insecticides (kelthane-s, methomyl, D.C. 702, sumicidin, larvin and deenate). The study concluded that kelthane-s and methomyl reduced the predator populations by 10.6-17.9%. Also, D.C. 702, sumidicin, larvin and deesate drastically reduced the population of *Chrysoperla carnea*. However, since abundance of predators varied in different years, the effect often was not discernible due to low numbers of certain species. Lastly, populations of predators were lower in the second half of the growing season.

8.4.2 Asia

8.4.2.1 Integrated pest management (IPM) helps reduce pesticide load in cotton[22]

Key message: Integrated Pest management results in pesticide use reduction, thus contributing to conservation of beneficial insects.

Location: Punjab, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					C	C	

A controlled two-year study in Punjab, India explored the effects of adoption of integrated pest management (IPM) practices. Ten villages was selected, four of which adopted IPM, four followed conventional practices, and two villages without any supervision or guidance by the researchers served as controls. The study discovered that IPM reduced insecticidal applications 3-4 times compared to non-IPM villages. Only endosulfan was used significantly more by the IPM villages (1.07 and 0.85 applications compared to 0.49 and 0.32 in the first and second year, respectively). However, IPM villages used significantly less of all other insecticides. Also, they did not use any non-recommended insecticides, whereas non-IPM villages did. Overall, IPM strategies achieved a reduction in pest incidence (by 32-75%), a reduction in plant protection (17-34%) and total input costs (15-21%), and an increase in net profit (54-88%). Lastly, IPM conserved beneficial organisms (0.8-1.0 natural enemies per plant in IPM versus 0.4-0.7 in non-IPM). The farmers were still practicing IPM even five years after the study.

8.4.2.2 Persistence and behavior of pesticides in cotton production in Turkish soils[5]

Key message: Pesticides remain in soil for a long time, some degrade slower in soils with high organic matter content.

Location: Aydin, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive						
Quality	-						

An experiment in Aydin, Turkey examined the degradation of two pesticides – trufluralin and endosulfan – on five fields (four loam fields and one silty loam field). Trufluralin was applied just before sowing cotton and endosulfan was applied, once the seeds germinated and pests appeared. Soil samples indicated that as much as 70% of trifluralin eventually degraded. However, the degradation rate was lowest for soils with high organic matter content, in which sorption of the pesticide was tightest. Endosulfan degradation depended on soil type and specific isomer, with beta-endosulfan degrading fastest. 43% of beta-endosulfan had degraded, whereas only 20% of alpha-endosulfan and endosulfan sulphate had degraded by the time the experiment was over (after one year).

8.4.2.3 Influence of pesticides and application methods on pest and predatory arthropods associated with cotton[14]

Key message: The population of sucking pests does not differ significantly between genetically modified and non-GM cotton. Insecticides affect pests and beneficial insects; foliar application is more deadly to both.

Location: Aydin, Turkey

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					C Rep	C Rep	

A two-year controlled, replicated experiment in Sirsa, India compared the impact of several insecticides applied through different methods (foliar and stem application) on sucking pests and beneficial insects on genetically modified (*Bt*) cotton and non-*Bt* cotton. The insecticides applied were: imidacloprid 200SL, imidacloprid 70WG, clothianidin 50%, thiomethoxam 25, acetamiprid 20SP, spirotetramat 150OD, buprofezin 20%, fipornil 5% SC, and an untreated control. Foliar application proved to be more effective compared to stem application both at reducing pest as well as beneficial insect populations (e.g. imidacloprid killed 56% of beneficial ladybird beetles in foliar application and only 19% in stem application). Imidacloprid was the most toxic substance. As *Bt* cotton only prevents lepidopteran pests (caterpillars), the study confirmed that transgenic and non-transgenic cotton did not differ in their susceptibility to sucking pests. Similarly, no significant difference was found in the populations of beneficial insects.

8.4.2.4 Degradation and persistence of cotton pesticides in sandy loam soils from Punjab, Pakistan[4]

Key message: Cotton pesticides occur in drainage water, contaminate shallow groundwater, persist in soil.

Location: Lahore, Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive		Positive				
Quality	Rep		Rep				

A replicated experiment on sandy loam soil in Lahore, Pakistan looked at the effects of no-till and tillage systems on the leaching of several cotton pesticides (carbosulfan, lamba-cyhalothrin, endosulfan, and monocrotophos) to shallow groundwater. Cotton was grown in lysimeters (experimental tubes separated from the rest of the plot) as well as next to them to achieve field conditions. Cotton grown next to the lysimeters, however, was not subjected to any treatments and was not part of the experiment. Soil samples were also examined in the laboratory. The authors did not detect any carbosulfan, lamba-cyhalothrin or endosulfan in the drainage water in either tilling system. However, carbofuran (breakdown product of carbosulfan) and monocrotophos were found in quantities of over 0.1 µg/L, exceeding EU drinking water limits. Nitrate was found in excess of 10 mg/L and also above safe water drinking limits. Lastly, the study examined the distribution of pesticides within the soil after 139 days from sowing. Carbofuran and monocrotophos were found across the whole soil profile (0-150cm deep) and endosulfan and lambda-cyhalothrin were found in high concentrations in the top layer (0-10cm), demonstrating the persistence of pesticides in soil. The study revealed that cotton pesticides occurred in drainage water and persisted in soil. Pesticide and nitrate concentrations were slightly higher, but not significantly, in no-tillage treatments than in tillage treatments.

8.4.2.5 Influence of pesticide applications on pest and predatory arthropods associated with transgenic Bt cotton and nontransgenic cotton plants[25]

Key message: Pesticide reduces certain beneficial insect populations, while it has no effect on others. *Bt* cotton does not reduce pesticide use.

Location: Fugou County, Henan Province, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Variable	
Quality						RR	

A three-year randomised, replicated field experiment on a silty loam in Fugou County, Henan Province, China examined the effects of pesticides on common pests (aphids and acarid mites) and beneficial insects (ladybeetles and spiders) in *Bt* cotton and non-transgenic cotton. The experiment consisted of four treatments: non-transgenic cotton with and without pesticide applications and *Bt* cotton with and without pesticide applications. Insecticides were applied based on thresholds. Pesticides did not affect ladybeetle populations significantly in any year in any cotton variety. As to no pesticide treatments, ladybeetle populations were significantly greater on non-transgenic cotton than on *Bt* cotton in one year. By contrast, in two out of three years spiders marked a severe decrease in numbers after pesticide applications regardless of the cotton variety. In plots not treated with pesticide, spiders fared better in *Bt* plots where their numbers were greater compared to non-transgenic plots in two out of three years. As non-transgenic cotton had received eight pesticide applications and *Bt* plots had required nine pesticide applications (to control other pests that became more abundant), the study concluded that *Bt* did not reduce pesticide use. Regarding predators, *Bt* cotton did not affect them and pesticide effects varied.

8.4.2.6 The evolution of cotton pest management practices in China[26]

Key message: Owing to lower insecticide use following the adoption of *Bt* cotton, the number of natural enemies increased and successfully reduced pest populations.

Location: China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A review discussed the history of cotton pest management in China. The review discussed three regions. While crop in the Northwestern Region (mostly Xinjiang) is grown by large establishments similar to those in the U.S. and Australia, the two other large Chinese cotton growing regions (Changjiang River Region and Yellow River Region) are mostly based on small-holder agriculture that the review focused on. As Chinese farmers started relying on insecticides, cotton pest developed resistance, which required stronger and more frequent insecticide applications. Since the 1980s, the frequency of cotton aphid infestations increased because insecticides killed most natural enemies. Eventually, it was not uncommon for a field in the early 1990s to undergo as many as 30 insecticide applications in one season. Though the adoption of *Bt* cotton drastically reduced the number of insecticide applications, the risk of developing pest resistance became a concern. Whereas large farms would normally set aside a part of their land for non-Bt crop as a 'refuge' for non-resistant pests, small-holders with fields of less than one hectare could not adopt such a strategy. However, the study found that given that the farmers grew other crops (corn, soybean and peanut), resistance would not develop because these crops would act as a refuge for non-resistant pests.

8.4.3 Australia and Oceania

8.4.3.1 Integrated pest management in cotton: exploiting behaviour-modifying (semiochemical) compounds for managing cotton pest[23]

Key message: Compounds that modify pest behaviour (semiochemicals) can be utilized in pest management; they have limited effects on beneficial insects.

Location: Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					No effect	No effect	
Quality					Review	Review	

As the *Bt* toxin in cotton did not affect sucking pests, a review from Australia mapped research on semiochemicals (natural compounds that attract or repel pests, or otherwise stimulate their behaviour) that could help control these pests. The study concluded that the evidence on semiochemicals proved the usefulness of these substances. They could be used alone or in combinations with other pesticides in various strategies (e.g. attract-and-kill) to control pests with limited adverse effects on beneficial insects.

8.4.3.2 Organochlorine pesticides in soil under irrigated cotton farming systems in Vertisols of the Namoi Valley, north-western New South Wales, Australia[3]

Key message: Harmful pesticides contaminate soil, remain there over 20 years. They have been detected up to 1.2m deep, could eventually contaminate groundwater.

Location: near Narrabri, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive		Positive				
Quality							

A study in near Narrabri, New South Wales, Australia aimed to find out if organochlorine pesticides (such as DDT and its breakdown product DDE) were present in the soil up to a depth of 1.2m. 99% of the 211 soil samples contained detectable organochlorine pesticides. DDE was the most common with the highest concentrations at all depths analysed (although DDT had been banned in Australia since 1982), followed by endosulfan sulphate. The authors also detected Difocol and Dieldrin, which had gone undetected in previous studies. The authors hypothesized that the compounds were being transported to lower layers of soil by rain and irrigation, and could potentially contaminate groundwater.

8.4.3.3 Pesticide removal from cotton farm tailwater by a pilot-scale ponded wetland[10]

Key message: Ponded wetlands can remove pesticides from cotton farm tailwater.

Location: New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive				
Quality							

A two-year field trial examined if ponded wetland could filter out pollutants (pesticides used in cotton fields) from irrigation tailwater. The water would first flow to the open pond and then to the vegetated one. Residues were reduced by 22-53% in the first season and by 32-90% in the second season. Half-lives of common pesticides were reduced in the open pond. Further reductions occurred after algal bloom in this pond. The vegetated pond reduced half-lives further. The study concluded that macrophytes and algae could help clean farm runoff.

8.4.3.4 Management practices for control of runoff losses from cotton furrows under storm rainfall. II. Transport of pesticides in runoff[11]

Key message: Cover helps reduce concentrations of pesticide in runoff.

Location: near Emerald, Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive				
Quality							

A field experiment on a Vertosol near Emerald, Queensland, Australia simulated rainfall (65mm storm three weeks after planting) to determine how two management options (retention of on-ground cover and controlling wheel traffic) affect pesticide transport pesticide concentrations in runoff. The rainfall event was tested on a range of on-ground covers (from 0%, or no cover, to 60% surface coverage). The covers used were cotton trash (1-2%, 6-10%, and 47-56% cover) and wheat stubble (15-25% cover and 30-35% cover). The study found that concentrations of all pesticides (except prometryn) decreased. 45-60% cover reduced concentrations of endosulfan fivefold, whereas reductions in concentrations of other pesticides were somewhat lower. Also, avoiding wheel traffic resulted in 20-30% lower concentrations.

8.4.4 North America

8.4.4.1 Conservation of natural enemies in cotton: role of insect growth regulators in management of Bemisia tabaci[24]

Key message: Selective insect-growth regulators (buprofezin and proxyfen) can be used as part of integrated pest management, because they are relatively benign to natural predators compared to conventional insecticides.

Location: Maricopa, Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					CRR	CRR	

A three-year controlled, randomised, replicated field experiment in Maricopa, Arizona, USA compared a conventional insecticide and two selective insect-growth regulators (buprofezin and pyriproxyfen) on whiteflies – a common pest species. An untreated plot was used as a control. Additionally, each plot was split in two (treated and untreated with insecticide) for control of *Lygus hesperus*. The study found that the insect-growth regulators reduced 8 out of 20 taxa of beneficial organisms, including very common ones, in at least one year. However, data suggested that other factors aside from toxicity (e.g. reduction in prey availability) contributed to these reductions. The treatment with conventional insecticides reduced nearly all taxa, causing more serious and quicker reductions than the insect-growth regulators. Compared with the control as well as the conventional treatment, predator:prey ratios were significantly higher with the insect-growth regulators. The study also testified that the conventional insecticide applied to control the populations of *Lygus hesperus* diminished the selective nature of the insect-growth regulators. The authors recommended using buprofezin and pyriproxyfen to control whiteflies, citing their selectivity and the potential to use them in integrated pest management strategies.

8.4.4.2 Conservation of natural enemies in cotton: comparative selectivity of acetamiprid in the management of Bemisia tabaci[18]

Key message: Acetamiprid is less selective to natural predators than buprofezin or pyriproxyfen, can be used in later stages of crop growth when selectivity is less important.

Location: Maricopa, Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Variable	Variable	
Quality					CRR	CRR	

A two-year controlled, randomised, replicated field study in Maricopa, Arizona, USA examined the effects of acetamiprid and two selective insect-growth regulators (buprofezin, pyriproxyfen) on whiteflies (pest) and their natural predators. An untreated plot was used as a control. Acetamiprid produced lower pest densities than the insect-growth regulators and severely negatively affected 9 out of 17 taxa of beneficial arthropods. For 8 taxa, its effects roughly equalled those of a regular broad-spectrum insecticide. The insect-growth regulators, however, significantly reduced only 4 taxa and 3 of those were omnivores primarily considered plant pests, rather than beneficial organisms. Predator:prey ratios increased with the use of all three substances, but the ratios were higher with the two insect-growth regulators. The authors recommended using acetamiprid for whiteflies in later stages when selectivity matters less.

8.4.4.3 Plant compensation, natural biological control, and herbivory by Aphis gossypii on pre-reproductive cotton: the anatomy of a non-pest[19]

Key message: Cotton aphid does not cause damage that would justify the use of chemical pesticides, it can be controlled naturally.

Location: Central Valley, California, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive*	Positive*	
Quality					Assumed	Assumed	

* The study mentions that foregoing pesticide treatments will benefit natural enemies.

A controlled, replicated study in the Central Valley, California, USA explored the ability of cotton to compensate for pest damage incurred early in the season. The study established four treatments with different densities of cotton aphids: control with as few aphids as possible, two medium levels, and high level with as many aphids as possible. Aphicide (pirimicarb) was used to suppress aphids in the control. All predators were manually removed from the high density plants and controlled by a low rate of carbaryl. The study reported that cotton leaf area had been reduced by up to 58% and total above-ground plant biomass had been reduced by 45%. However, by harvest time the plants had recovered in terms of the timing of crop maturation and the yield and quality of cotton fibre. Even the more serious outbreaks during one of the two years of the study were suppressed by natural enemies prior to the initiation of flower bud production. The authors recommended not controlling aphid populations through pesticide applications during early-season, because the damage aphids caused did not cause economic losses.

8.4.4.4 Disruptive sublethal effects of insecticides on biological control: altered foraging ability and lifespan of a parasitoid after feeding on extrafloral nectar of cotton treated with systemic insecticides[15]

Key message: Selective insecticides can still affect natural enemies.

Location: USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Negative	Negative	
Quality							

A study in the USA tested the impact of three systemic insecticides (acephate, imidacloprid, aldicarb) on the parasitoid *Microplitis croceipes* – wasp. The results were compared against a control of plants sprayed with water. The authors discovered that after feeding on nectar contaminated with systemic insecticides, *M. croceipes*' longevity and its host foraging ability decreased.

8.4.4.5 The contribution of conservation biological control to integrated control of *Bemisia tabaci* in cotton[20]

Key message: Natural predators can be conserved by the use of selective insecticides; together they will successfully suppress pests.

Location: Maricopa, Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					CRR	CRR	

A controlled, randomised, replicated experiment in Maricopa, Arizona, USA attempted to quantify the contribution of conserved natural enemies towards pest suppression. The experiment tested four plots – one treated with conventional broad-spectrum pesticide, two treated with different types of selective insect growth regulators, and an untreated control. Each plot was split in two – treated and untreated with *Lygus hesperus*. Based on the causes of mortality of whiteflies (*Bemisia tabaci*), the study revealed that conserved natural enemies reached levels similar to the control in plots treated with insect growth regulators and were the main cause of mortality of whiteflies there.

8.4.4.6 Soil microbial activity is affected by Roundup WeatherMax and pesticides applied to cotton[6]

Key message: Glyphosate-based herbicides (such as Roundup) benefit soils and soil microfauna.

Location: Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Variable					Variable	
Quality	C Rep					C Rep	

A laboratory, controlled, replicated experiment on a clay loam soil in Texas, USA examined how combinations of pesticides affected soil microbial activity. The study evaluated carbon and nitrogen mineralization as a proxy for microbial activity. The pesticides tested were: fluometuron, trifluralin, aldicarb, and mefenoxam + pentachloronitrobenzene (PCNB). The treatments comprised each individual pesticide alone, each pesticide mixed with glyphosate, glyphosate by itself, and an untreated soil was used as a control. All treatments were applied to a soil that had been previously sown with cotton. Soils treated with glyphosate unaccompanied by any pesticides exhibited greater carbon mineralization after 30 days, compared to all other treatments, which resembled the values of the control. However, soil microbial activity was reduced under glyphosate applications combined with fluometuron, aldicarb, and mefenoxam + PCNB, compared to when these substances were applied without glyphosate. The authors concluded that glyphosate altered the soil microbial response to other pesticides.

8.4.4.7 Coccinellids in cotton: population response to pesticide application and feeding response to cotton aphids[17]

Key message: Some, but not all, pesticides negatively affect common beneficial insects; numbers of beneficial insects follow pest populations.

Location: Georgia, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Variable	
Quality						C Rep	

A two-year controlled, replicated experiment in Georgia, USA examined the effects of an insecticide (imidacloprid) and a fungicide (chlorothalonil) on populations of a beneficial insect species (coccinellids) predating on the cotton aphid. The study also followed the development of the cotton aphid population. The experiment comprised four treatments: chlorothalonil applied in weekly intervals, imidacloprid applied in weekly intervals, imidacloprid applied when aphid populations exceeded a threshold of 30 aphids per leaf or were present on 50% of the plants, and an untreated control. Greatest cotton aphid populations and coccinellid densities were observed in the fungicide treatment during both years of the study. The authors attributed non-random prey search behaviour of the coccinellids (that searched for places with highest aphid densities) as the reason for their high concentrations in the fungicide treatment, speculating that their numbers would drop in the long-term due to constant fungicide use. In both years, coccinellid populations closely tracked those of the aphid. The lowest coccinellid populations were observed in the weekly imidacloprid treatment.

8.4.4.8 Lethal and sublethal effects of insecticides on two parasitoids attacking Bemisia argentifolii[16]

Key message: Insecticides adversely affects beneficial insects, but the toxicity varies. Certain beneficial organisms can be integrated with the use of certain insecticides.

Location: Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					C Rep	C Rep	

A controlled, replicated laboratory experiment in Texas, USA tested the toxicity of six insecticides (buprofezin, azinphos-methyl, endosulfan, thiodicarb, methyl-parathion, bifenthrin, and water as a control) on the early and late pre-emergence stages of two parasitoids (desirable beneficial organisms) *Eretmocerus tejanus* and *Eretmorecus mundus*. The study found that all insecticides had adverse effects on the two organisms, but their toxicity varied. Thiodicarb proved to be the least toxic to early larvae; 65.9% of *E. tejanus* larvae (water 86.2%) and 35.8% *E. mundus* larvae (water 81.1%) emerged as adults. By contrast, bifenthrin was the most toxic, recording an emergence rate of 3.8% and 0, respectively. The emergence rate for the remaining insecticides oscillated between 5% and 36%. In the late pre-emergence stage (after parasitization as parasitoid pupae), thiocarb, buprofezin and endosulfan did not differ significantly from the water control in the case of *E. tejanus.* The emergence rates ranged between 78.1% and 89.5%, compared to water at 97.7%. The other insecticides proved toxic. In the case of *E. mundus*, only buprofezin marked a 92.2% emergence rate (compared to 94.5% for water), whereas the rate was 0 to 56.3% for all other insecticides. Longevity was also adversely affected by insecticides, except for buprofezin and azinphos-methyl in the case of *E. tejanus*, as these two substances did not reduce its longevity significantly.

8.4.4.9 Effect of selective insecticides on the natural enemies Coleomegilla maculata and Hippodamia convergens, Geocoris punctipes, and Bracon mellitor, Cardiochiles nigriceps, and Cotesia marginiventris in cotton[21]

Key message: Selective insecticides are not toxic to certain natural enemy species, but they will always negatively affect several.

Location: Georgia, Mississippi, USA

	Soil		Water		Biodiversity		Yield
	Structure	**Fertility**	**Quality**	**Quantity**	**Diversity**	**Abundance**	
Impacts					Negative	Negative	
Quality					CRR	CRR	

A laboratory experiment (controlled, replicated) and a field experiment (controlled, randomised, replicated) in the USA tested the toxicity of three insecticides on natural enemies. The three insecticides were lambda cyhalothrin, spinosad, and S-1812. Three methods were selected to examine these substances: topical application in a laboratory to check for direct toxicity, a residual toxicity study in the field to observe the effect of insecticide residues on leaves, and a field study comparing the natural enemy populations before and after insecticide application. In all trials, water was used as a control. The study found that lambda cyhalothrin exhibited the greatest toxicity in topical tests, adversely affecting each natural enemy species. However, its residues were not toxic to two species, one of which was the predator *H. convergens*. The number of cotton aphids (pest species), though increasing in all treatments, was significantly higher in lambda cyhalothrin than in all other treatments. As the numbers of aphids increased, so did the population of the predator *H. convergens*, since this species was susceptible to lambda cyhalothrin residues (as shown by the laboratory test). The authors assessed the other two insecticides as having good to excellent selectivity. However, each significantly adversely affected several natural enemy species.

8.4.5 South America

8.4.5.1 Determination of pesticides multiresidues in shallow groundwater in a cotton-growing region of Mato Grosso, Brazil[9]

Key message: Cotton pesticides pollute shallow groundwater, exceed safe levels.

Location: Mato Grosso, Brazil

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts			Positive				
Quality			-				

A study in Mato Grosso, Brazil aimed to develop a method to test groundwater for the presence of common cotton pesticides. The presence of the following twelve pesticides was analysed in shallow groundwater samples collected at two cotton farms: lufenuron, azoxystrobin, thiamethoxan, teflubenzuron, carbofuran (a breakdown product of carbosulfan), diafenthurion, thiacloprid, imidacloprid, aldicarb, carbendazin, diuron, acetamiprid, methomyl, and triflumuron. Of these, eight were detected (acetamiprid, aldicarb, cabendazin, diuron, imidacloprid, methomyl, teflubenzuron). Acetamiprid and carbofuran were detected most frequently with detection rates of 4% and 9%, respectively. Carbofuran was also the pesticide most frequently detected in high concentrations. 18% of the water samples contained at least one pesticide; the pesticide concentration would sometimes exceed European Union limits for safe drinking water.

8.4.5.2 Selectivity of pesticides used on cotton to Trichogramma pretiosum reared on two laboratory-reared hosts[12]

Key message: Synthetic pesticides harm beneficial insects.

Location: Mato Grosso, Brazil

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Negative	
Quality						C Rep	

A controlled, replicated laboratory experiment in Mato Grosso, Brazil examined the side-effects of 21 different pesticides (insecticides, fungicides, herbicides and plant growth regulators) on the *Trichogramma* wasp – a beneficial insect – in its pupal and adult stages. The wasp is a highly effective and easily breedable parasitoid of many cotton pests, especially the cotton leafworm. The pupae received direct sprays, while the adults were exposed to the treatments through parasitism on sprayed eggs. Reactions to different pesticides varied greatly depending the host that the wasps had been reared on or the developmental stage of the wasp. Though sometimes pesticides did not seem to affect certain populations in certain cases (e.g. insect growth regulator lufenuron and organophosphate insecticide monocrotophos had no effect on the pupae developing in the host *Ephestia kuehniella*), negative effects were observed for most pesticides.

8.5 Bibliography

[1]Brookes, G., & Barfoot, P. (2013). Key environmental impacts of global genetically modified (GM) crop use 1996–2011. *GM crops & food, 4*(2), 109-119.

[2]Anstey, C. (2011). The Better Cotton Fast Track Program: Accelerating the cultivation of cotton that's better for the people who produce it and for the environment where it's grown: Better Cotton Initiative.

[3]Weaver, T. B., Ghadiri, H., Hulugalle, N. R., & Harden, S. (2012). Organochlorine pesticides in soil under irrigated cotton farming systems in Vertisols of the Namoi Valley, north-western New South Wales, Australia. *Chemosphere, 88*(3), 336-343. doi: 10.1016/j.chemosphere.2012.03.008

[4]Tariq, M. Y., Afzal, S., & Hussain, I. (2006). Degradation and persistence of cotton pesticides in sandy loam soils from Punjab, Pakistan. *Environmental Research, 100*(2), 184-196. doi: 10.1016/j.envres.2005.05.002

[5]Turgut, C., Erdogan, O., Ates, D., Gokbulut, C., & Cutright, T. J. (2010). Persistence and behavior of pesticides in cotton production in Turkish soils. *Environmental Monitoring and Assessment, 162*(1-4), 201-208. doi: 10.1007/s10661-009-0788-x

[6]Lancaster, S. H., Haney, R. L., Senseman, S. A., Hons, F. M., & Chandler, J. M. (2006). Soil microbial activity is affected by Roundup WeatherMax and pesticides applied to cotton (Gossypium hirsutum). *Journal of Agricultural and Food Chemistry, 54*(19), 7221-7226. doi: 10.1021/Jf061673p

[7]Agbohessi, P. T., Toko, I. I., Ouedraogo, A., Jauniaux, T., Mandiki, S. N. M., & Kestemont, P. (2015). Assessment of the health status of wild fish inhabiting a cotton basin heavily impacted by pesticides in Benin (West Africa). *Science of the Total Environment, 506*, 567-584. doi: 10.1016/j.scitotenv.2014.11.047

[8]Agbohessi, P. T., Toko, I. I., Atchou, V., Tonato, R., Mandiki, S. N. M., & Kestemont, P. (2015). Pesticides used in cotton production affect reproductive development, endocrine regulation, liver status and offspring fitness in African catfish Clarias gariepinus (Burchell, 1822). *Comparative Biochemistry and Physiology C-Toxicology & Pharmacology, 167*, 157-172. doi: 10.1016/j.cbpc.2014.10.002

[9]Carbo, L., Souza, V., Dores, E. E. G. C., & Ribeiro, M. L. (2008). Determination of pesticides multiresidues in shallow groundwater in a cotton-growing region of Mato Grosso, Brazil. *Journal of the Brazilian Chemical Society, 19*(6), 1111-1117.

[10]Rose, M. T., Sanchez-Bayo, F., Crossan, A. N., & Kennedy, I. R. (2006). Pesticide removal from cotton farm tailwater by a pilot-scale ponded wetland. *Chemosphere, 63*(11), 1849-1858. doi: DOI 10.1016/j.chemosphere.2005.10.24

[11]Silburn, D. M., Simpson, B. W., & Hargreaves, P. A. (2002). Management practices for control of runoff losses from cotton furrows under storm rainfall. II. Transport of pesticides in runoff. *Australian Journal of Soil Research, 40*(1), 21-44. doi: 10.1071/Sr00083

[12]Bastos, C. S., de Almeida, R. P., & Suinaga, F. A. (2006). Selectivity of pesticides used on cotton (Gossypium hirsutum) to Trichogramma pretiosum reared on two laboratory-reared hosts. *Pest management Science, 62*(1), 91-98. doi: 10.1002/Ps.1140

[13]Elmaghraby, M. M. A., Eltantawy, M. A., Gomaa, E. A. A., & Nada, M. (1994). Effect of Pesticidal Application during the Early and Late Cotton Season on the Abundance of Certain Predators Associated with Cotton Plants. *Anzeiger Fur Schadlingskunde Pflanzenschutz Umweltschutz, 67*(3), 60-62. doi: 10.1007/Bf01906429

[14]Kumar, R., Kranthi, S., Nitharwal, M., Jat, S. L., & Monga, D. (2012). Influence of pesticides and application methods on pest and predatory arthropods associated with cotton. *Phytoparasitica, 40*(5), 417-424. doi: 10.1007/s12600-012-0241-5

[15]Stapel, J. O., Cortesero, A. M., & Lewis, W. J. (2000). Disruptive sublethal effects of insecticides on biological control: Altered foraging ability and life span of a parasitoid after feeding on extrafloral nectar of cotton treated with systemic insecticides. Biological Control, 17(3), 243-249. doi: 10.1006/bcon.1999.0795

[16]Jones, W. A., Ciomperlik, M. A., & Wolfenbarger, D. A. (1998). Lethal and Sublethal Effects of Insecticides on Two Parasitoids AttackingBemisia argentifolii(Homoptera: Aleyrodidae). *Biological Control, 11*(1), 70-76. doi: 10.1006/bcon.1997.0581

[17]Wells, M. L., McPherson, R. M., Ruberson, J. R., & Herzog, G. A. (2001). Coccinellids in cotton: Population

response to pesticide application and feeding response to cotton aphids (Homoptera : Aphididae). *Environmental Entomology, 30*(4), 785-793.

[18]Naranjo, S. E., & Akey, D. H. (2005). Conservation of natural enemies in cotton: comparative selectivity of acetamiprid in the management of Bemisia tabaci. Pest management Science, 61(6), 555-566. doi: 10.1002/ps.1030

[19]Rosenheim, J. A., Wilhoit, L. R., Goodell, P. B., GraftonCardwell, E. E., & Leigh, T. F. (1997). Plant compensation, natural biological control, and herbivory by Aphis gossypii on pre-reproductive cotton: the anatomy of a non-pest. Entomologia Experimentalis Et Applicata, 85(1), 45-63. doi: 10.1046/j.1570-7458.1997.00233.x

[20]Naranjo, S. E., & Ellsworth, P. C. (2009). The contribution of conservation biological control to integrated control of Bemisia tabaci in cotton. Biological Control, 51(3), 458-470. doi: 10.1016/j.biocontrol.2009.08.006

[21]Tillman, P. G., & Mulrooney, J. E. (2000). Effect of selected insecticides on the natural enemies Coleomegilla maculata and Hippodamia convergens (Coleoptera : Coccinellidae), Geocoris punctipes (Hemiptera : Lygaeidae), and Bracon mellitor, Cardiochiles nigriceps, and Cotesia marginiventris (Hymenoptera : Braconidae) in cotton. Journal of Economic Entomology, 93(6), 1638-1643.22. Dhawan, A. K., Singh, S., & Kumar, S. (2009). Integrated Pest management (IPM) Helps Reduce Pesticide Load in Cotton. *Journal of Agricultural Science and Technology, 11*(5), 599-611.

[23]Mensah, R. K., Gregg, P. C., Del Socorro, A. P., Moore, C. J., Hawes, A. J., & Watts, N. (2013). Integrated pest management in cotton: exploiting behaviour-modifying (semiochemical) compounds for managing cotton pests. *Crop & Pasture Science, 64*(8), 763-773. doi: 10.1071/CP13060

[24]Naranjo, S. E., Ellsworth, P. C., & Hagler, J. R. (2004). Conservation of natural enemies in cotton: role of insect growth regulators in management of Bemisia tabaci. Biological Control, 30(1), 52-72. doi: 10.1016/j.biocontrol.2003.09.010

[25]Men, X. Y., Ge, F., Edwards, C. A., & Yardim, E. N. (2004). Influence of pesticide applications on pest and predatory arthropods associated with transgenic Bt cotton and nontransgenic cotton plants. *Phytoparasitica, 32*(3), 246-254. doi: 10.1007/Bf02979819

[26]Wu, K., & Guo, Y. (2005). The evolution of cotton pest management practices in China. *Annu. Rev. Entomol., 50*, 31-52.

9 Habitat management for predators

9.1 Description

Rather than using pesticides, it is possible to control pests by managing farm or landscape level habitats that support beneficial insects, bacteria or fungi. The alternative – pest control by broad-spectrum synthetic insecticide – reduces biodiversity by killing beneficial insects and potentially leads to pest resurgence in a field with no natural enemies. Beneficial insects can be nurtured through various means: this chapter (Habitat management for predators) investigates managing habitat around cotton fields to control pests, Chapter 12 (Habitat diversity) discusses how managing habitat diversity within cotton fields, through intercropping for example, can harbour beneficial insects. Managing habitats for pest control is a form of biological control; Chapter 10 (Promoting biocontrol through genetic modification) presents genetic modification as a means of controlling pest populations as this was unearthed in a number of other intervention reviews.

9.2 Quick facts

Definition and purpose: Managing habitats around cotton fields to create favourable natural habitats for beneficial insects

Benefits: Reduces insecticide use; reduces water/soil pollution and promotes conservation of beneficial insects

9.3 Synthesis

An overwhelming majority of studies on managing habitats for predators investigates the direct effects of the intervention on pest populations. Very few cotton-related studies discuss the impact of this intervention on natural capital, i.e. soil, water or biodiversity.

9.3.1 Impact summary of the intervention

In total, nine studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
				Positive	Positive		Medium	Increases

9.3.2 Soil

No effects on soil have been identified.

9.3.3 Water

No direct effects on water have been identified.

9.3.4 Biodiversity

Studies generally highlighted **the functions of landscape, vegetation and crops other than cotton in promoting beneficial insect populations**[1].

Six studies (two of which were randomised and replicated and three of which were reviews) concluded on positive impacts of habitat management on biological diversity and abundance by luring pests away from cotton production to adjacent Bt-fields[2,3], to maize fields[4,5] and to wheat fields[6]. Nevertheless, as one study points out, adjacent fields may also harbour cotton pests[7].

9.4 Evidence Review

9.4.1 Asia

9.4.1.1 Maize benefits the predatory beetle, Propylea japonica (Thunberg), to provide potential to enhance biological control for aphids in cotton[5]

Key message: Placing maize fields next to cotton fields will benefit natural predator populations, thus enhancing biological pest control in cotton.

Location: China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Ran	Ran	

A three-year randomised field study in China analysed the behaviour of cotton aphids and their predators – *Propylea japonica*. The experiment looked into the oviposition preference, preferred crop patches to inhabit and feeding behaviour of *P. japonica*, comparing crop and maize fields with different area ratios (100/0, 75/25, 50/50, 25/75 and 0/100) and different spatial arrangements. The study found that predators preferred maize to cotton, but they actively searched for aphids, and thus would venture into cotton fields, where aphids were more abundant. In conclusion, maize could serve as a habitat for predators that could enhance biological control in cotton.

9.4.1.2 Evaluation of winter wheat as a potential relay crop for enhancing biological control of cotton aphids in seedling cotton[6]

Key message: Wheat next to cotton conserves natural predators, helps suppress pest in cotton.

Location: Roayang County, Hebei Province, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					RR	RR	

A randomised, replicated experiment in Roayang County, Hebei Province, China over two seasons explored the effects of wheat planted adjacent to *Bt* cotton on insect populations (both pests and beneficial), determined their spatial distribution, and investigated the time of migration of natural enemies from wheat to cotton. The treatments were wheat plots and cotton plots with a 0.3m strip of bare soil between them. The authors found a linear relationship between pest abundance and the distance from field edge. Other insects were also affected by the spatial arrangement of the experiment. The predators could keep the pest populations at the edges of cotton fields under the threshold level of 100 aphids per m^2. The wheat fields proved successful in conserving the predator populations.

9.4.1.3 The evolution of cotton pest management practices in China[3]

Key message: Owing to lower insecticide use following the adoption of *Bt* cotton, the number of natural enemies increased and successfully reduced pest populations.

Location: China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A review discussed the history of cotton pest management in China. The review discussed three regions. While crop in the Northwestern Region (mostly Xinjiang) is grown by large establishments similar to those in the U.S. and Australia, the two other large Chinese cotton growing regions (Changjiang River Region and Yellow River Region) are mostly based on small-holder agriculture that the review focused on. As Chinese farmers started relying on insecticides, cotton pest developed resistance, which required stronger and more frequent insecticide applications. Since the 1980s, the frequency of cotton aphid infestations increased because insecticides killed most natural enemies. Eventually, it was not uncommon for a field in the early 1990s to undergo as many as 30 insecticide applications in one season. Though the adoption of *Bt* cotton drastically reduced the number of insecticide applications, the risk of developing pest resistance became a concern. Whereas large farms would normally set aside a part of their land for non-Bt crop as a ‘refuge’ for non-resistant pests, small-holders with fields of less than one hectare could not adopt such a strategy. However, the study found that given that the farmers grew other crops (corn, soybean and peanut), resistance would not develop because these crops would act as a refuge for non-resistant pests.

9.4.1.4 Effects of land use and insecticides on natural enemies of aphids in cotton: First evidence from smallholder agriculture in the North China Plain[4]

Key message: Landscapes with a higher proportion of maize and grassland exhibit higher ladybeetle populations in cotton fields.

Location: North China Plain, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A study based on household datasets and cotton field surveys in North China Plain, China found that there was a positive association between the average population of ladybeetles (natural predator) and the proportion of maize area. Secondly, the presence of maize area in the landscape increased the number of ladybeetles in cotton. Third, the study identified a negative association between the density of ladybeetles and the area proportion of cotton. These relationships were statistically significant. Lastly, ladybeetle densities increased with increasing time period from the last insecticide application and the volume of insecticide used had a significant negative impact on ladybeetle densities.

9.4.2 Australia and Oceania

9.4.2.1 Lure-and-kill as reduced-risk strategy for managing Helicoverpa spp. on conventional cotton crops within transgenic cotton fields[2]

Key message: Luring pests from a conventional field to an adjacent *Bt*-field with an attractant that kills them reduces insecticide use, thus conserving beneficial insects.

Location: Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					-	-	

A controlled experiment in Queensland, Australia tested a commercial attractant containing, among other things, a feeding stimulant (20% sucrose) and a toxic compound (0.5% thiodicarb). The goal was to lure pests (cotton bollworm) from a conventional cotton field a to a genetically modified cotton field where they would be killed after ingesting the toxic attractant. The treatments included fields positioned at different distances from a field with transgenic cotton treated with the attractant. A control field of transgenic cotton untreated with the attractant was used for comparison. The study showed that the method reduced the cotton bollworm population in the conventional cotton plot by 91.5%, as compared to 40% in conventional cotton next to the untreated control field. The results led the authors to conclude that this lure-and-kill strategy could help conserve beneficial insects in conventional cotton and lower costs of pest control thanks to reduced use of pesticide.

9.4.2.2 An Australian approach to IPM in cotton: integrating new technologies to minimise insecticide dependence[8]

Key message: *Bt* cotton integrated with a comprehensive, mutually reinforcing set of measures (breeding, selective pesticides, natural predators, intercropping,...) can reduce reliance on chemical insecticides, protect soil, water, biodiversity.

Location: Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A study reviewed pest management approaches designed to reduce environmental damage in the Australian cotton industry. The author pointed out the environmental and economic costs of reliance on chemical pesticides and then outlined a mix of measures that would reduce the use of these substances. He proposed using selective chemicals (labelled as more expensive than broad-spectrum ones), nurture host plant resistance (e.g. through conventional breeding of resistance traits inherent to cotton), protect beneficial insects, increase habitat diversity (e.g. through intercropping and using food sprays) and plant *Bt* cotton. The author also highlighted a number of outstanding issues, for example, the relatively higher costs of new chemicals, the complexity and economic costs of maintaining habitat diversity or the risk of pest resistance to *Bt* cotton (as well as strategies to manage this risk).

9.4.2.3 Evidence of a latitudinal gradient in spider diversity in Australian cotton[9]

Key message: Biodiversity increases from high to low latitudes.

Location: Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Variable	Variable	
Quality					-	-	

A study at seven locations across Australia aimed to find out if latitudinal gradient (that is, biodiversity increases the close one gets to the equator) applied to species in a monoculture. Spiders were sampled in seven locations (1-3 fields in each location were sampled 3-5 times) in different latitudes and different climatic conditions. Although some theories had speculated that biodiversity increased due of increasing diversity of habitats the closer one were to the tropics, the authors showed that spider diversity increased even within a single habitat.

9.4.3 North America

9.4.3.1 Effects of adjacent habitat on populations of stink bugs in cotton as part of a variable agricultural landscape in South Carolina[7]

Key message: Adjacent fields may harbour cotton pests and some crops, such as peanut, attract them more than others.

Location: South Carolina, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Variable		
Quality					-		

A two-year study in North Carolina, USA investigated if there was a difference in stink bug (a pest species) numbers depending on which type of vegetation had been planted next to cotton. The authors looked at peanut, corn, soybean, cotton, and woodlands. Pest density was greatest in cotton adjacent to peanut and boll injury was significantly greater in cotton adjacent to peanut and soybean, compared to all other habitats.

9.4.4 Worldwide

9.4.4.1 Habitat management to conserve natural enemies of arthropod pests in agriculture[1]

Key message: Habitat management enhances biological control, benefits biodiversity.

Location: Worldwide (review)

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

The authors reviewed available Evidence on habitat management – a process aiming to create an environment favouring beneficial insects in crops. The review distinguished three levels, on which habitat management could take place: within-crop, within-farm and at the landscape level. The authors mentioned several constituent factors essential to the process, namely availability of food (nectar, pollen, honeydew), shelter, microclimate allowing beneficial insects to overwinter or seek refuge (e.g. from environmental extremes and pesticides), and habitat for alternative hosts or prey. The authors also mentioned the necessity to pay close attention to temporal availability of the aforementioned resources (for example, to encourage early season activity) as well as to spatial arrangements. Negative aspects and risks were also discussed: some land could be put out of production, farmers would have little control over the community in the habitat once it is created, and there may be a risk of establishing plants that could potentially turn into invasive weeds. When referring directly to cotton, the study commended cotton-wheat relay intercropping in China that had helped reduce cotton aphid damage, as natural enemies could feed on prey in wheat and then disperse to emerging cotton.

9.5 Bibliography

[1]Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology, 45*(1), 175-201.

[2]Robert, K. M., & Macpherson, I. (2010). Lure-and-kill as Reduced-risk Strategy for Managing Helicoverpa spp. on Conventional Cotton Crops within Transgenic Cotton Fields. *Journal of Biological Control, 24*(2), 91-103.

[3]Wu, K., & Guo, Y. (2005). The evolution of cotton pest management practices in China. Annu. Rev. Entomol., 50, 31-52.

[4]Zhou, K., Huang, J. K., Deng, X. Z., van der Werf, W., Zhang, W., Lu, Y. H., . . . Wu, F. (2014). Effects of land use and insecticides on natural enemies of aphids in cotton: First evidence from smallholder agriculture in the North China Plain. Agriculture Ecosystems & Environment, 183, 176-184. doi: 10.1016/j.agee.2013.11.008

[5]Ouyang, F., Men, X. Y., Yang, B., Su, J. W., Zhang, Y. S., Zhao, Z. H., & Ge, F. (2012). Maize Benefits the Predatory Beetle, Propylea japonica (Thunberg), to Provide Potential to Enhance Biological Control for Aphids in Cotton. *Plos One, 7*(9). doi: 10.1371/journal.pone.0044379

[6]Men, X. Y., Ge, F., Yardim, E. N., & Parajulee, M. N. (2004). Evaluation of winter wheat as a potential relay crop for enhancing biological control of cotton aphids in seedling cotton. *Biocontrol, 49*(6), 701-714. doi: DOI 10.1007/s10526-004-5278-z

[7]Reeves, R. B., Greene, J. K., Reay-Jones, F. P. F., Toews, M. D., & Gerard, P. D. (2010). Effects of Adjacent Habitat on Populations of Stink Bugs (Heteroptera: Pentatomidae) in Cotton as Part of a Variable Agricultural Landscape in South Carolina. Environmental Entomology, 39(5), 1420-1427. doi: 10.1603/EN09194

[8]Fitt, G. P. (2000). An Australian approach to IPM in cotton: integrating new technologies to minimise insecticide dependence. Crop Protection, 19(8), 793-800.

[9]Whitehouse, M. E. A., Hardwick, S., Scholz, B. C. G., Annells, A. J., Ward, A., Grundy, P. R., & Harden, S. (2009). Evidence of a latitudinal gradient in spider diversity in Australian cotton. *Austral Ecology, 34*(1), 10-23. doi: 10.1111/j.1442-9993.2008.01874.x

10 Promoting biocontrol through genetic modification

10.1 Description

Pest management can be carried out through different mechanisms including pesticide use (Chapters 7 and 8), on farm conservation and promotion of natural predators (Chapter 9), maintenance of on field habitat diversity (Chapter 12), disruption of pest life cycles and reproduction and the use of pest resistant strains of crops. The searches on pest management interventions (Chapters 7-9) brought up a number of studies on the use of genetic modification to promote biocontrol services; these were clustered to constitute a separate intervention that specifically explores how genetic modification as a pest management tool impacts on water, soil and biodiversity.

10.2 Quick facts

Definition and purpose: Controlling pests by using crop breeding and genetic modification to promote natural predators

Benefits: Eliminates or delays application of insecticides; promotes natural predation; and reduces water/soil pollution

10.3 Synthesis

An overwhelming majority of studies on biocontrol of cotton investigates the effects of various biological agents on pests rather than on natural capital. The searches on pest management interventions did not identify any studies that have experimented with the release of natural predators on cotton pests but a number did point to how the use of genetically modified cotton species impact pest populations by enhancing biocontrol; some impacts on natural capital were also highlighted. While the synthesis highlights primarily positive impacts of this intervention on soil, water and biodiversity they should not overshadow any impacts on human health, labour and/or wellbeing; considering local contexts and expert advice is crucial for appropriate decision making. Due to the nature of the search criteria that was used to draw evidence on promoting biocontrol through genetic modification, the results are inconclusive; a number of other searches and studies would have to be included in the review to yield any sort of categorical claims.

10.3.1 Impact summary of the intervention

In total, 11 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
Limited evidence		Limited evidence		Positive	Positive	Mixed	Mixed	Mixed

Inconclusive

10.3.2 Soil

Very few studies explored impacts on soil structure and/or fertility. One study (controlled and replicated) highlighted that glyphosate-based herbicides can benefit soils and soil microfauna[1].

10.3.3 Water

No direct effects on water have been identified.

10.3.4 Biodiversity

A number of studies, including those whose primary objective is not research into *Bt* cotton as well as three reviews and a survey represented in this Evidence review, agree that ***Bt* cotton reduces insecticide use and enhances the populations of beneficial insects**[2-5]. An economic analysis from Pakistan also confirms that *Bt* cotton farmers use pesticides less extensively and generally opt for those of lower toxicity, compared to non-*Bt* farmers[6]. Only one experiment (randomised, replicated) when *Bt* cotton was first used in China claims that *Bt* cotton does not reduce pesticide use[7].

Lastly, five studies (one randomised and replicated, one long-term data analysis and two reviews from Australia and China) conclude that **genetically modified (*Bt*) cotton enhances biocontrol**, as it is generally associated with lower pesticide use and higher incidence of beneficial insects[4,5,8,9].

10.4 Evidence Review

10.4.1 Asia

10.4.1.1 Influence of pesticide applications on pest and predatory arthropods associated with transgenic Bt cotton and nontransgenic cotton plants[7]

Key message: Pesticide reduces certain beneficial insect populations, while it has no effect on others. *Bt* cotton does not reduce pesticide use.

Location: Fugou County, Henan Province, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Variable	
Quality						RR	

A three-year randomised, replicated field experiment on a silty loam in Fugou County, Henan Province, China examined the effects of pesticides on common pests (aphids and acarid mites) and beneficial insects (ladybeetles and spiders) in *Bt* cotton and non-transgenic cotton. The experiment consisted of four treatments: non-transgenic cotton with and without pesticide applications and *Bt* cotton with and without pesticide applications. Insecticides were applied based on thresholds. Pesticides did not affect ladybeetle populations significantly in any year in any cotton variety. As to no pesticide treatments, ladybeetle populations were significantly greater on non-transgenic cotton than on *Bt* cotton in one year. By contrast, in two out of three years spiders marked a severe decrease in numbers after pesticide applications regardless of the cotton variety. In plots not treated with pesticide, spiders fared better in *Bt* plots where their numbers were greater compared to non-transgenic plots in two out of three years. As non-transgenic cotton had received eight pesticide applications and *Bt* plots had required nine pesticide applications (to control other pests that became more abundant), the study concluded that *Bt* did not reduce pesticide use. Regarding predators, *Bt* cotton did not affect them and pesticide effects varied.

10.4.1.2 Bt cotton, pesticide use and environmental efficiency in Pakistan[6]

Key message: *Bt* cotton farmers in Pakistan are more environmentally efficient than non-*Bt* farmers.

Location: Punjab, Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

An economic analysis based on surveys conducted in Punjab, Pakistan showed that adoption of *Bt* cotton increased yields and reduced pesticide applications. When they did resort to pesticide, the adopters of *Bt* technology used pesticides with lower toxicity. The authors quantified the environmental benefit of *Bt* cotton, claiming that *Bt* farmers produced cotton with 37% higher environmental efficiency.

10.4.1.3 Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services[10]

Key message: *Bt* cotton supports natural predators, thus enhancing biocontrol services.

Location: China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Long-term data analysis (20 years)	Long-term data analysis (20 years)	

A study examining data gathered between 1990 and 2010 from 36 sites in China examined the relationship between genetically modified pest resistant cotton (Bt cotton), insecticide use, abundance of natural predators and biocontrol services. The authors observed that insecticide use declined sharply after the introduction of Bt cotton. The abundance of cotton pest was highest and the abundance of predators lowest in plots treated with insecticides, while the insecticide-free plots showed the exact opposite trend. Three neighbouring crops (maize, peanut and soybean) also benefited from reduced pesticide sprays. The study concluded that Bt cotton enhanced biocontrol services, since it increased abundance of natural predators.

10.4.1.4 Evaluation of winter wheat as a potential relay crop for enhancing biological control of cotton aphids in seedling cotton[9]

Key message: Wheat next to Bt cotton conserves natural predators, helps suppress pest in cotton.

Location: Roayang County, Hebei Province, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					RR	RR	

A randomised, replicated experiment in Roayang County, Hebei Province, China over two seasons explored the effects of wheat planted adjacent to *Bt* cotton on insect populations (both pests and beneficial), determined their spatial distribution, and investigated the time of migration of natural enemies from wheat to cotton. The treatments were wheat plots and cotton plots with a 0.3m strip of bare soil between them. The authors found a linear relationship between pest abundance and the distance from field edge. Other insects were also affected by the spatial arrangement of the experiment. The predators could keep the pest populations at the edges of cotton fields under the threshold level of 100 aphids per m^2. The wheat fields proved successful in conserving the predator populations.

10.4.1.5 The evolution of cotton pest management practices in China[5]

Key message: Owing to lower insecticide use following the adoption of *Bt* cotton, the number of natural enemies increased and successfully reduced pest populations.

Location: China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A review discussed the history of cotton pest management in China. The review discussed three regions. While crop in the Northwestern Region (mostly Xinjiang) is grown by large establishments similar to those in the U.S. and Australia, the two other large Chinese cotton growing regions (Changjiang River Region and Yellow River Region) are mostly based on small-holder agriculture that the review focused on. As Chinese farmers started relying on insecticides, cotton pests developed resistance, which required stronger and more frequent insecticide applications. Since the 1980s, the frequency of cotton aphid infestations increased because insecticides killed most natural enemies. Eventually, it was not uncommon for a field in the early 1990s to undergo as many as 30 insecticide applications in one season. Though the adoption of *Bt* cotton drastically reduced the number of insecticide applications, the risk of developing pest resistance became a concern. Whereas large farms would normally set aside a part of their land for non-Bt crop as a 'refuge' for non-resistant pests, small-holders with fields of less than one hectare could not adopt such a strategy. However, the study found that given that the farmers grew other crops (corn, soybean and peanut), resistance would not develop because these crops would act as a refuge for non-resistant pests.

10.1.1.1 Performance of Bt cotton (MECH-162) under Integrated Pest management in farmers' participatory field trial in Nanded district, Central India[8]

Key message: Integrated Pest management with Bt cotton is associated with thriving populations of beneficial insects.

Location: Nanded district, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	Positive
Quality					-	-	-

An experiment in India compared non-genetically modified MECH-162 cotton cultivar, and *Bt* MECH-

162, and conventional cotton in an integrated pest management (IPM) regime, and non-genetically modified conventional cotton grown in a non-IPM regime. The *Bt* plot exhibited the lowest incidence of pest and crop damage. The same plot also produced the highest seed cotton yield. The study also showed that the natural enemy population was highest in the IPM plot growing conventional cotton, followed by the *Bt* IPM plot. The non-IPM conventional plot, which received the most insecticide applications, had lowest natural enemy populations. The authors hypothesized that the lower number of natural enemies on *Bt* cotton was caused by lack of prey, rather than by the effects of the *Bt* toxin.

10.4.2 Australia and Oceania

10.4.2.1 An Australian approach to IPM in cotton: integrating new technologies to minimise insecticide dependence[4]

Key message: *Bt* cotton integrated with a comprehensive, mutually reinforcing set of measures (breeding, selective pesticides, natural predators, intercropping,...) can reduce reliance on chemical insecticides, protect soil, water, biodiversity.

Location: Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A study reviewed pest management approaches designed to reduce environmental damage in the Australian cotton industry. The author pointed out the environmental and economic costs of reliance on chemical pesticides and then outlined a mix of measures that would reduce the use of these substances. He proposed using selective chemicals (labelled as more expensive than broad-spectrum ones), nurture host plant resistance (e.g. through conventional breeding of resistance traits inherent to cotton), protect beneficial insects, increase habitat diversity (e.g. through intercropping and using food sprays) and plant *Bt* cotton. The author also highlighted a number of outstanding issues, for example, the relatively higher costs of new chemicals, the complexity and economic costs of maintaining habitat diversity or the risk of pest resistance to *Bt* cotton (as well as strategies to manage this risk).

10.4.3 North America

10.4.3.1 Soil microbial activity is affected by Roundup WeatherMax and pesticides applied to cotton[1]

Key message: Glyphosate-based herbicides (such as Roundup) alters soil microbial response to other pesticides.

Location: Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Variable					Variable	
Quality	C Rep					C Rep	

A laboratory, controlled, replicated experiment on a clay loam soil in Texas, USA examined how combinations of pesticides affected soil microbial activity. The study evaluated carbon and nitrogen mineralization as a proxy for microbial activity. The pesticides tested were: fluometuron, trifluralin, aldicarb, and mefenoxam + pentachloronitrobenzene (PCNB). The treatments comprised each individual pesticide alone, each pesticide mixed with glyphosate, glyphosate by itself, and an untreated soil was used as a control. All treatments were applied to a soil that had been previously sown with cotton. Soils treated with glyphosate unaccompanied by any pesticides exhibited greater carbon mineralization after 30 days, compared to all other treatments, which resembled the values of the control. However, soil microbial activity was reduced under glyphosate applications combined with fluometuron, aldicarb, and mefenoxam + PCNB, compared to when these substances were applied without glyphosate. The authors concluded that glyphosate altered the soil microbial response to other pesticides.

10.4.3.2 Farm-scale evaluation of the impacts of transgenic cotton on biodiversity, pesticide use, and yield[2]

Key message: *Bt* cotton reduces insecticide use, enhances biodiversity.

Location: Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	Positive
Quality					Survey	Survey	Survey

A two-year survey of 81 commercial farms in Arizona examined the differences between two types of transgenic cotton (pest resistant *Bt* and pest resistant with herbicide resistance) and conventional cotton in terms of yields, pesticide use and impacts on biodiversity. The study found that *Bt* cotton reduced insecticide use. *Bt* cotton with herbicide resistance did not affect herbicide use. Regardless of the number of insecticide applications, *Bt* cotton produced higher yield. Nevertheless, the three types of cotton had quite similar yields, which the authors attributed to higher use of insecticide with conventional cotton to control key pests. Lastly, regarding non-target species, insecticides reduced the diversity of non-target insects.

10.1.1.2 Impacts of Bt transgenic cotton on integrated pest management[3]

Key message: *Bt* cotton reduces the need to use insecticide, thus enhancing the abundance and diversity of beneficial insects.

Location: USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A review from the U.S. discussed the impacts of *Bt* cotton on targeted pests (lepidopteran insects – caterpillars) as well as on other pests and beneficial insects. Between 1996 and 2008, over 140 million kilograms of insecticide active ingredient was saved. Thus, the study showed that *Bt* cotton was responsible for a major worldwide reduction in insecticide use in cotton. Although several pest species became more abundant, they could be easily managed through integrated pest management. Also, the reduction in insecticide use enhanced biocontrol due to more abundant natural enemies of other pests. Lastly, the study reported that experiments on *Bt* cotton unequivocally demonstrated that *Bt* protein had no effects on natural enemies.

10.1.1.3 Arthropod abundance and diversity in Bt and non-Bt cotton fields[11]

Key message: Genetically modified cotton does not harm biodiversity.

Location: Arizona, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					No effect	No effect	
Quality					-	-	

A two-year study in Arizona, USA surveyed arthropods (beneficial insects) in plots with genetically modified (*Bt*) cotton, non-*Bt* cotton, and a mixture (75% genetically modified, 25% non-*Bt*), aiming to determine any differences in abundance and diversity of the insect population. More arthropods were collected from the mixed plots than *Bt* plots. Still, abundance did not differ significantly between *Bt* and non-*Bt*. Regarding diversity, 57 families was found in mixed plots, 55 in non-*Bt* plots, and 47 in *Bt* plots. Again, however, the differences in diversity were attributed to differences in abundance, rather than differences between cultivars. Within row mixture plots, abundance and diversity did not differ significantly.

Note: Genetically modified cotton was not the main search topic for this section; rather, it was a consolidation of studies found through several other intervention searches. This section is only framed in the context of genetically modified cotton for pest management.

10.5 Bibliography

[1]Lancaster, S. H., Haney, R. L., Senseman, S. A., Hons, F. M., & Chandler, J. M. (2006). Soil microbial activity is affected by Roundup WeatherMax and pesticides applied to cotton (Gossypium hirsutum). *Journal of Agricultural and Food Chemistry, 54*(19), 7221-7226. doi: 10.1021/Jf061673p

[2]Cattaneo, M. G., Yafuso, C., Schmidt, C., Huang, C. Y., Rahman, M., Olson, C., . . . Carriere, Y. (2006). Farm-scale evaluation of the impacts of transgenic cotton on biodiversity, pesticide use, and yield. *Proceedings of the National Academy of Sciences of the United States of America, 103*(20), 7571-7576. doi: 10.1073/pnas.0508312103

[3]Naranjo, S. E. (2011). Impacts of Bt Transgenic Cotton on Integrated Pest management . *Journal of Agricultural and Food Chemistry, 59*(11), 5842-5851. doi: 10.1021/jf102939c

[4]Fitt, G. P. (2000). An Australian approach to IPM in cotton: integrating new technologies to minimise insecticide dependence. *Crop Protection, 19*(8), 793-800.6. Men, X. Y., Ge, F., Edwards, C. A., & Yardim, E. N. (2004). Influence of pesticide applications on pest and predatory arthropods associated with transgenic Bt cotton and nontransgenic cotton plants. *Phytoparasitica, 32*(3), 246-254. doi: 10.1007/Bf02979819

[5]Wu, K., & Guo, Y. (2005). The evolution of cotton pest management practices in China. *Annual Review of Entomoogy, 50*, 31-52. 5.

[6]Abedullah, Kouser, S., & Qaim, M. (2015). Bt Cotton, Pesticide Use and Environmental Efficiency in Pakistan. *Journal of Agricultural Economics, 66*(1), 66-86. doi: 10.1111/1477-9552.12072

[7]Men, X. Y., Ge, F., Edwards, C. A., & Yardim, E. N. (2004). Influence of pesticide applications on pest and predatory arthropods associated with transgenic Bt cotton and nontransgenic cotton plants. *Phytoparasitica, 32*(3), 246-254. doi: 10.1007/Bf02979819

[8]Bambawale, O. M., Singh, A., Sharma, O. P., Bhosle, B. B., Lavekar, R. C., Dhandapani, A., . . . Pawar, V. M. (2004). Performance of Bt cotton (MECH-162) under Integrated Pest management in farmers' participatory field trial in Nanded district, Central India. *Current Science, 86*(12), 1628-1633.

[9]Men, X. Y., Ge, F., Yardim, E. N., & Parajulee, M. N. (2004). Evaluation of winter wheat as a potential relay crop for enhancing biological control of cotton aphids in seedling cotton. *Biocontrol, 49*(6), 701-714. doi: DOI 10.1007/s10526-004-5278-z

[10]Lu, Y. H., Wu, K. M., Jiang, Y. Y., Guo, Y. Y., & Desneux, N. (2012). Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services. *Nature, 487*(7407), 362-365. doi: 10.1038/nature11153

[11]Sisterson, M. S., Biggs, R. W., Olson, C., Carriere, Y., Dennehy, T. J., & Tabashnik, B. E. (2004). Arthropod abundance and diversity in Bt and non-Bt cotton fields. *Environmental Entomology, 33*(4), 921-929.

Land and diversity management

Section Overview

Cotton production requires suitable and available land within appropriate landscapes. Careful land management is crucial for resilient production systems. There are a number of interventions that address land and diversity management, five of which were identified and researched using a number of terms (See Appendix 4.1: Primary Search and Appendix 4.2: Secondary Search).

Section Chapters

Chapter 11: Crop Rotation

Evidence			Yield	Cost	Quality
Positive	Limited	Positive	Increases	Medium	Increases

Definition and purpose: Growing a rotation of different crops in different years and during different seasons to improve long-term soil fertility and nutrition with time as well as to enhance biological control
Benefits: Eliminates or delays application of insecticides; promotes natural predation; and reduces water/soil pollution

Chapter 12: Habitat Diversity

Evidence			Yield	Cost	Quality
None	None	Positive	Increases	Medium	Increases

Definition and purpose: Safeguarding habitat diversity on farmed lands and managing different types of vegetation within-crop and within-field to protect insects, including the beneficial insects that predate upon cotton pests and maintain soil fertility and structure
Benefits: Reduces incidence of pests; reduces insecticide use; protects other species; and maintains ecological productivity

Chapter 13: Keeping a Tidy Farm

Evidence			Yield	Cost	Quality
Limited	None	None	Increases	Low	Increases

Definition and purpose: Removing weeds and spontaneously appearing crops from cotton fields to reduce competition for nutrients and remove potential harbours of pests
Benefits: Increases crop yields; and reduces pest populations

Chapter 14: Removing Volunteer Cotton

Evidence			Yield	Cost	Quality
None	None	None	Limited Evidence	Medium	Increases

Definition and purpose: Removing volunteer (spontaneously appearing) cotton from cotton fields to remove harbours for cotton pests, prevent wasting fertiliser and moisture on unwanted crops and avoid unfavourable gene flows
Benefits: Maintains yields and quality

Chapter 15: Limiting Cotton Expansion

Evidence			Yield	Cost	Quality
None	None	Positive	Limited Evidence	Low	Is not affected

Definition and purpose: Limiting cotton expansion to previously farmed land to avoid clearing new areas of natural habitat for cotton production
Benefits: Reduces controversies over land rights; prevents clearing; and decreases loss of native biodiversity

11 Crop rotation

11.1 Description

Crop rotation is the practice of growing different crops in sequence (whereas in a continuous system the same one crop is grown all the time). Rotating crops is used to maintain soil fertility, increase yields as well as to facilitate pest management. Crop rotation is a form of on field habitat diversity management that occurs across temporal scales. It allows soils to be replenished and a better exchange of nutrients whilst preventing some pests from establishing themselves.

11.2 Quick facts

Definition and purpose: Growing a rotation of different crops in different years and during different seasons to improve long-term soil fertility and nutrition with time as well as to enhance biological control

Benefits: Increases yields; improves soil health; mitigates losses of soil organic carbon resulting from cultivation; and stimulates beneficial insects and soil microbes

11.3 Synthesis

As crop rotation has been relatively thoroughly researched, plentiful evidence exists regarding its impacts on soil (although research is heavily skewed towards Australia and the U.S.). However, studies regarding the impacts on water and biodiversity are sparse, even though rotations clearly influence both. This lack of evidence for these two natural capital variables is acknowledged even in the few studies that investigate them.

Crop rotation is now a widely adopted recommended practice. Most studies (eleven, including five of which were randomised and replicated) across several regions report that **yields increase in crop rotations** compared to cotton planted continuously[1-11]. Only one study (controlled, replicated and long-term) reports negligible effects of crop rotations on yields[12].

11.3.1 Impact summary of the intervention

In total, 18 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
Positive	**Positive**		**Limited evidence**	**Positive**	**Positive**	**Increases**	**Medium**	**Increases**

11.3.2 Soil

Crop rotation undoubtedly benefits soil, but the actual mechanisms are only partially clear. For example, many studies report on soil organic carbon, but they fail to agree on precise benefits. Two studies (one controlled, replicated and long-term, and a review) claim that crop rotations **do not return enough carbon to the soil**, albeit they may **slow down the depletion** caused by cultivation[3,12]. One study (randomised, replicated) finds **no change in soil organic carbon**[8]. Three independently conducted studies all from the same controlled, long-term experiment (Alabama's 'Old Rotation' lasting over 100 years) report that **soil organic matter increases** over time[1,2,7].

Three studies (two randomised, replicated) show that crop rotation allows **better access of air to**

soil, as rotating crops tends to reduce compaction[8,11,13].

Three studies (one randomised, replicated, and a review) highly **recommend rotating wheat** with cotton, asserting its superiority over other crops[3,8,14]. One study recommends both legumes and cereals[13].

Although crop rotation seems to provide tremendous benefits, several studies agree that **tillage systems have a greater effect** on the crop[4,6].

Lastly, two studies (both randomised and replicated) suggest that **exchangeable cations in soil decrease** with crop rotation[4,11], while one study shows exchangeable cations remain unaffected[13].

11.3.3 Water

Two studies (both randomised, one of which is also replicated) show that crop rotation results in **minor benefits in water use efficiency**. One of these studies (long-term, randomised) highlights that crop rotation improves water-use efficiency especially under water stress[9]. The second study (randomised, replicated) shows that total amount of water used does not differ significantly between rotations and tillage systems, but improvements in water use efficiency result from higher yield in rotations, rather than less water used[5].

11.3.4 Biodiversity

Three studies (one controlled, randomised, replicated, one controlled long-term and one review) suggest that **crop rotation has positive effects on micro- and macrofauna in soil**[1,3,15].

One study (randomised, replicated) suggests that some crop rotations help **control weeds**[16].

11.4 Evidence Review

11.4.1 Africa

11.4.1.1 Maîtrise des mauvaises herbes de la culture cotonnière par des rotations culturales en Côte d'Ivoire[16]

Key message: Some rotations, notably corn-cotton-rice and rice-cotton corn, reduce weeds.

Location: Bouaké, Côte d'Ivoire

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					
Quality		RR					

A randomised, replicated three year experiment in Bouaké, Côte d'Ivoire compared seven crop rotations (corn-cotton-rice, cotton-rice-peanuts, rice-peanuts-corn, peanuts-corn-cotton, rice-cotton-corn, cotton-corn-peanuts, and cotton-cotton-cotton. The study found that corn-cotton-rice and rice-cotton corn reduced weed incidence the most, as the population densities of weeds decreased by 83%.

11.4.1.2 Carbon losses and primary productivity decline in savannah soils under cotton-cereal rotations in semiarid Togo[12]

Key message: Cereal-cotton crop rotation does not add enough carbon to the soil to maintain long-term soil fertility.

Location: Dalanda and Elavagnon, Togo

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		No effect					No change
Quality		C Rep long-term					C Rep long-term

A meta-analysis of data from thirty years of controlled, replicated field experiments in Dalanda and Elavagnon, Togo investigated the impacts of rotations and fertiliser over a period of thirty years. In the first ten years, the experiments differed to some degree. In the subsequent twenty, the experiment continued as cereal-cotton rotation and continuous cotton. Aside from various rotations, the treatments in Dalanda also included different rates of fertiliser (no fertiliser, recommended rate and 1.5 times recommended rate). However, yields of all crops declined over the 30 years, irrespective of crop rotation, fertiliser use or crop residue management. The authors concluded that rotations did not add enough carbon to offset carbon depletion and decomposition that was high in continuously cultivated tropical, sandy soils such as those found in Togo.

11.4.2 Asia

11.4.2.1 Trend and stability analysis to interpret results of long-term effects of application of fertilisers and manure to cotton grown on rainfed Vertisols[10]

Key message: Manure increases yields, improves soil structure. However, it performs best when combined with conventional fertiliser. Crop rotation increases yields, makes them more stable.

Location: Nagpur, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive						Positive
Quality	long-term (17 years)						long-term (17 years)

A long-term experiment on Vertisols in Nagpur, India running from 1985/86 until 2002/03 examined the influence of cropping systems (monocropping cotton and cotton in rotation with sorghum) and different fertilisers (manure and mineral) on yield outcomes under rainfed conditions. The study found that crop rotation as opposed to monocropping gave more stable and higher (1828 kg/ha versus 1384 kg/ha) yields. The authors also observed that manure and fertiliser applied together produced the highest mean yield response (1218 kg/ha). Lastly, soil available P and Zn were greater with manure added than without it.

11.4.2.2 Biodiversity of foliage arthropods in the mixed crop zone and cotton-wheat zone in Punjab Province, Pakistan[18]

Key message: Mixed cropping system with smaller plots and a greater variety of crops is better for biodiversity than mono-cropping.

Location: Punjab, Pakistan

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive		
Quality					-		

A study in Punjab, Pakistan surveyed two major crop zones to determine differences in biodiversity. One was a mixed zone dominated by smallholder agriculture and a great diversity of crops, and the other a cash crop zone characterized by cotton-wheat rotation, extensive mono-cropping and more widespread use of pesticides. Three orders out of five detected were found in significantly greater diversity in the mixed zone and one (Araneae – spiders) was more diverse in the cotton-wheat zone, leading the authors to conclude that the mixed system with fewer applications of synthetic chemicals was better suited for biodiversity conservation.

11.4.3 Australia and Oceania

11.4.3.1 A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006[3]

Key message: Crop rotation, especially cotton-wheat, improves soil health by adding soil organic content and improving nitrogen fixation, exhibits positive effects on biodiversity.

Location: Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive				Positive	Increases
Quality	Review	Review				Review	Review

A study from Australia reviewed crop rotation experiments in Australia between 1970 and 2006. Most experiments assessed 1:1 cotton rotations, whereas there research into complex (three or more crops) or more unconventional rotations was lacking. While crop rotations generally improved soils, overall depletion of soil organic carbon continued in Australia even after introduction of crop rotation at a rate of roughly 0.22 to 0.35 kg/m^2. An estimated amount of 2-3 kg/m^2 of organic matters needs to be returned to soil every year, yet rotations were adding back only 0.8-1.2 kg/m^2. The review, therefore, endorsed especially rotations returning above 2 kg/m^2 of residues per growing cycle to soil. Management practices, for example intensive tillage, crop stubble burning, and excessive water and N application rates were also weakening the positive effects of crop rotation. Nevertheless, yields were overall better in rotation than in monoculture. Physical and chemical properties were also improving. Leguminous cover crops improved nitrogen fixation.

Though few studies on biodiversity were in existence, the authors found generally positive effects of crop rotation on soil macro- and microfauna. Likewise, better biodiversity provided benefits for soil. For example, more abundant ants increased soil organic matter, nitrates and phosphates.

While some studies reported better results with different rotation crops (e.g. safflower), they proved to be inconvenient for farmers for various reasons (for example, safflower is thorny). The authors recommended adopting cotton-wheat rotation as a long-term solution for Australian farmers.

11.4.3.2 Soil properties and crop yields in a dryland Vertisol sown with cotton-based crop rotations[11]

Key message: Crop rotation increases yields, loosens compacted soil.

Location: Warra, Queensland, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	No effect					Increases
Quality	RR	RR					RR

A randomised, replicated, twelve-year experiment on a Vertisol in Warra, Queensland, Australia aimed to investigate impacts of different cereal and leguminous crops sown in rotation with cotton under a dryland system on yields, physical and chemical properties of soil. The five treatments tested were continuous cotton, cotton-sorghum, cotton-wheat double cropped, cotton-chickpea double cropped followed by wheat, and cotton-wheat. The study found that air-filled porosity of the soil under continuous cotton exhibited the lowest values (i.e. was the most compacted), with sorghum-cotton also having low values, whereas cotton-wheat double cropped had the highest. Soil organic carbon concentrations were not affected by crop rotation, were already low and decreased with depth. Exchangeable cations were not affected by rotation, either. Yields were similar among all treatments, except cotton-sorghum, which produced the lowest yields. Average cotton lint yields were 0.66 t/ha for continuous cotton, 0.54 t/ha for cotton-sorghum, 0.71 t/ha for cotton-wheat double cropped, 0.76 t/ha for cotton-chickpea double cropped followed by wheat, and 0.67 t/ha for cotton-wheat. The authors recommended including wheat in a rotation, as it would likely result in better soil structure and higher cotton-lint yield than either rotation with legumes or sorghum.

11.4.3.3 Impact of crop rotation and minimum tillage on water use efficiency of irrigated cotton in a Vertisol[5]

Key message: Crop rotation increases yield and crop water use efficiency, although the total amount of water required does not change.

Location: Narrabri, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				Positive			Increases
Quality				RR			RR

A six-year randomised, replicated experiment on a Vertisol near Narrabri, New South Wales, Australia aimed to quantify the impact of two tillage systems and wheat in rotation with cotton on crop water use efficiency. The treatments were continuous cotton monoculture under conventional tillage, continuous cotton under minimum tillage, and cotton-wheat rotation under minimum tillage. In terms of yield, cotton-wheat rotation proved most productive with 1,624 kg/ha of lint, followed by minimum tilled continuous cotton with 1,447 kg/ha and conventional continuous cotton with

1,373 kg/ha. Overall, wheat rotated with cotton improved water-use efficiency in some years and application efficiency in all years. However, the total amount of irrigation water used did not differ significantly between treatments. Rather, the improvement in crop water use efficiency of the cotton-wheat rotation (some 12% compared to conventionally tilled continuous cotton) happened as a result of higher yield.

11.4.3.4 Effect of crop rotation and residue management on properties of cracking clay soils under irrigated cotton-based farming systems of New South Wales[13]

Key message: Rotating cotton with cereal or leguminous crops improves soil physical and chemical properties; retaining stubble in the field is superior to burning it.

Location: Macquarie and Namoi Valleys in New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					
Quality	-	-					

A study sampled data from five commercial farms with Vertisol soils in the Macquarie and Namoi Valleys in New South Wales, Australia and evaluated for a number of soil quality criteria: the particle size distribution, the dispersion index, the plastic limit, the percentage of coarse and fine particulate soil organic matter, soil respiration rate, soil reactivity, soil aggregate density, pH, nitrate-N, and exchangeable Ca, Mg, K and Na. The effects of rotations differed between variables and the two locations. Nevertheless, based on the results the authors recommended rotating cotton with cereal or leguminous crops, as they improved soil physical and chemical properties, as compared to continuous cotton. Also, retaining crop residue, rather than burning it, was seen as improving soil properties.

11.4.3.5 Residual effects of cotton-based crop rotations on soil properties of irrigated Vertosols in central-western and north-western New South Wales[14]

Key message: Crop rotation improves soil health, especially cotton-wheat rotation.

Location: Warren and Merah North, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					
Quality	-	-					

A study examining samples of a Vertisol at two locations in New South Wales, Australia assessed the effects of crop rotation history. At Warren, the rotations were continuous cotton, long-fallow cotton, cotton and high input wheat, cotton and low input wheat, cotton and green manured field pea. At Merrah North, the rotations were continuous cotton, long-fallow cotton, cotton and green manured faba bean (then replaced by sorghum), cotton and dolichos, and cotton and fertilized dolichos. Best soil structure occurred where cotton-wheat rotations had been sown, especially those with high input (fertilized) wheat. At Merrah North, the values at the long fallow field were similar to cotton-wheat rotation.

11.4.3.6 Rotation crops for irrigated cotton in a medium-fine, self-mulching, grey Vertosol[8]

Key message: Wheat rotation performs better than legume rotation, all rotations improve soil.

Location: Wee Waa, New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	No effect					Increases
Quality	RR	RR					RR

A randomised, replicated experiment on a Vertosol in Wee Waa, New South Wales, Australia aimed to evaluate the changes in soil organic carbon, nitrate-N, soil structure, cotton growth and yield. The paper also looked at economic issues. The treatments were cotton followed by nitrogen fertilized wheat (140 kg/ha of N in the first year and 120 kg/ha in thereafter), cotton followed by unfertilized wheat, cotton followed by unfertilized legumes harvested, and cotton followed by unfertilized legumes incorporated into the field. The study found that soil organic carbon was unaffected by the rotation, as there was no net loss or gain. However, soil compaction was lower with all rotation crops. Sharp increases in soil nitrate were observed in the leguminous rotations. Lint yield and fibre quality were higher in the wheat rotations.

11.4.4 North America

11.4.4.1 Influence of management practices on soil organic matter, microbial biomass and cotton yield in Alabama's "Old Rotation"[1]

Key message: Winter legume and crop rotation increase soil microbial activity, organic matter content, yields.

Location: Auburn, Alabama, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive			Positive	Positive	Increases
Quality	C, long-term (99 years)	C, long-term (99 years)			C, long-term (99 years)	C, long-term (99 years)	C, long-term (99 years)

A 99 years long controlled experiment on a sandy loam soil evaluated the effect of winter legumes in different cotton rotations on soil organic matter content, soil microbial biomass and yield. The experiment consisted of six treatments: cotton only (planted every year, no rotation) without a winter legume cover crop or fertilisation, cotton only with winter legume and without fertilisation, cotton only without winter legume and fertilized with 134kg of N per hectare per year, cotton rotated with corn with a winter legume and without fertilisation, cotton rotated with corn with a winter legume and with the aforementioned fertilisation, and cotton rotated with corn and soybean/rye (three year rotation) with legume and without fertilisation (controls are treatments without legumes). Only some of the treatments were replicated and if they were, it was only twice, so this experiment is, for all intents and purposes, considered not replicated. The cotton in rotation with a winter legume had a higher seed cotton yield than cotton planted without rotation. Winter legume yield did not differ among treatments that had it. The three year rotation exhibited higher organic matter and carbon in the top 10cm than all other four rotations. Cotton without rotation (that is, also without winter legume) had lower organic carbon content than all other treatments. Lastly, the cotton-corn rotations and the three year rotation had higher microbial biomass than the three other rotations and soil microbial biomass was lower in most months in cotton only treatments without winter legume.

11.4.4.2 Use of winter legumes as banker plants for beneficial insect species in a sorghum and cotton rotation system[15]

Key message: Legumes (vetch and faba, in particular) provide refuge for beneficial insects.

Location: Tifton, Georgia, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					CRR	CRR	

A three-year controlled, randomised, replicated experiment in Tifton, Georgia, USA aimed to assess the potential of different winter cover crops to harbour beneficial insects and pests and to relay them into the cotton and sorghum crops planted later. Nine treatments, including three controls, were tested: Austrian winter pea, faba bean, blue lupin, white vetch, winter rye. The controls were: fallow with standard fertiliser, fallow with natural fertiliser, fallow without fertilisation. Over the three years of the study, beneficial insects were most abundant in the faba, vetch and lupin crops. Relay was observed, as all insects tended to appear in the sorghum and cotton crops. Faba stands were poor, according to the study, so the authors did not recommend using it as a cover crop. Vetch and lupin, therefore, emerged as ideal cover crops because they consistently sustained pea aphids (not a pest of sorghum or cotton) and coccinellids (beneficial insects).

11.4.4.3 Improved growth and nutrient status of an oat cover crop in sod-based versus conventional peanut-cotton rotations[17]

Key message: Crop rotation improves soil, sod-based one more so than conventional peanut rotation.

Location: Quincy, Florida, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					
Quality		-					

An experiment on a sandy loam soil in Quincy, Florida, USA compared the performance of a conventional rotation (peanut-cotton-cotton) and sod-based rotation (Bahiagrass-Bahiagrass-Peanut-Cotton). In both rotations, oat was used as the winter cover crop. The goal of the study was to determine the plant growth and shoot biomass production of oat. Another goal was to investigate the influence of the summer crop (peanut, cotton or bahiagrass) on oat shoot N, P, and K concentrations and total uptake. Oat grown in the sod-based rotation had greater biomass, leaf chlorophyll and leaf sap NO_3-N concentrations, compared to oat in the conventional rotation. Increased oat growth and N in the sod-based rotation indicated greater soil quality.

11.4.4.4 A historical summary of Alabama's Old Rotation (circa 1896): The world's oldest, continuous cotton experiment[2]

Key message: Crop rotation and winter legume cover crops increase soil organic matter, preserving soil fertility.

Location: Auburn, Alabama, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					Increases
Quality	C long-term	C long-term					C long-term

A meta-analysis of data from a long-term (over 100 years) experiment in Auburn, Alabama, USA document the effect of winter legumes, corn and soybean on yields and soil health. The treatments consisted of 1) continuous cotton without winter legumes, 2) continuous cotton with legumes, 3) continuous cotton with N fertiliser, 4) two year cotton-corn rotation with winter legumes, 5) two year cotton-corn rotation with winter legumes and N fertiliser, and 5) three year cotton-winter legumes-corn rotation followed by grain-soybean. Fertiliser was added at 134 kg/ha per year. Crimson clover had been used as the only kind of winter legume since 1990. The results showed that yield of cotton increased over time, as fertiliser rates kept increasing, and it also increased with addition of winter legumes. Yield declined gradually when no legumes or N fertiliser were used, before eventually stabilizing at about half the beginning yield. The results also indicated that winter legumes increased yield as much as or higher than N fertiliser. Long-term planting of winter legumes also increased soil organic carbon, thus improving soil structure and fertility. The two year rotation with winter legumes and N and all the three year rotations had higher soil organic carbon than the other rotations. Cotton only with winter legumes exhibited lower soil organic carbon than all other rotations. Overall, the authors showed that winter legume cover crops built soil organic carbon, supplied additional nitrogen, and reduced erosion during the winter.

11.4.4.5 Stratification of nutrients in soil for different tillage regimes and cotton rotations[4]

Key message: Crop rotation increases yields, but tillage system displays a greater effect.

Location: Burleson County, Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Mixed					Increases
Quality		RR					RR

A four-year randomised, replicated experiment on a silty clay loam soil in Burleson County, Texas, USA aimed to determine the distribution of macro- and micronutrients in soil between 0cm and 90cm depth, comparing different tillage regimes, crop rotations and nitrogen fertilisation rates. The treatments were continuous cotton monoculture under reduced tillage, continuous cotton monoculture under conventional tillage, and cotton-corn rotation under conventional tillage. Additionally, each of these underwent three different nitrogen application rates for cotton (0, 80 and 160 kg/ha). There was only one nitrogen rate for corn (90 kg/ha). Soil pH was significantly higher for unfertilized continuous cotton under conventional tillage, compared to the other two systems.

Also, reduced tillage had 14% and 19% higher plant-available phosphorus in soil than continuous cotton and the rotation, respectively. However, compared to the rotation treatments, cotton lint yields were significantly lower for 0 kg/ha (and 160kg/ha of nitrogen of both continuous cotton. On average, reduced tillage continuous cotton had 55% higher yields than conventional continuous cotton and cotton-corn rotation had 66% higher yields than conventional continuous cotton. Therefore, rotation significantly increased yield. However, the authors also concluded that inclusion of corn decreased plant-available micronutrient concentrations below 0-15cm relative to the continuous cotton at the 160 kg/ha nitrogen fertilisation rate. Yet, crop rotation did increase micronutrient concentrations relative to monoculture on plots without fertiliser. The rotation also had significantly lower K, Ca, Mg, Na and SO_2 concentrations than conventional continuous cotton.

11.4.4.6 Cotton and corn rotation under reduced tillage management: impacts on soil properties, weed control, yield, and net return[6]

Key message: Crop rotation increases yields, helps maintain soil health, but effects of tillage on soil were of greater consequence.

Location: Stoneville, Mississippi, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					Increases
Quality		RR					RR

A six-year randomised, replicated experiment on a silty loam soil in Stoneville, Mississippi, USA compared soil properties, weed control, yields, and net return in continuous cotton and corn-cotton rotation. The treatments consisted of continuous cotton, continuous corn, cotton-corn rotation, and corn-cotton rotation. Additionally, each of these was tested for glyphosate-resistant genetically modified cotton and conventional cotton cultivar. The authors showed that soil organic carbon in the top 5cm of the soil increased progressively regardless of rotation. The improvements were attributed to tillage practices. However, in the second half of the study some differences in soil organic carbon were observed. Lowest values were measured in continuous cotton, since corn left behind greater amount of residues after harvest than cotton. Cotton yield was found to increase in rotation by 10-32% for the conventional seed and by 14-19% for the genetically modified cultivar, compared to continuous cotton.

11.4.4.7 Cotton-grain sorghum rotation under extreme deficit irrigation conditions[9]

Key message: Crop rotation increases yields under water-stressed conditions, likely has no effect on water-use efficiency, but makes water management more flexible.

Location: Halfway, Texas, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts				No effect			Increases
Quality				Ran			Ran

An eight-year long randomised experiment on clay loam in Halfway, Texas, USA compared cotton in different rotations with sorghum to continuous cotton under deficit irrigation conditions. The study found that in years of below average rain cotton following sorghum would yield 18% to 44% more lint than continuous cotton. In years of average rain, cotton in rotation gave higher yields (21%), but this increase had partially been caused by increased irrigation. The authors noticed little difference in yields in years of above average rain. In regards to water-use efficiency, the data did not display a clear pattern.

In adverse weather, sorghum residue provided protection to cotton plants from blowing sand, thus reducing the number of field operations necessary to prevent blowing sand. The rotation also likely reduced the number of disease outbreaks in cotton.

11.4.4.8 Soil C, N and crop yields in Alabama's long-term 'Old Rotation' cotton experiment[7]

Key message: Crop rotation and winter legume cover crops increase soil organic matter, preserving soil fertility.

Location: Auburn, Alabama, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	Positive	Positive					Increases
Quality	C long-term	C long-term					C long-term

A study drawing on data from a long-term (Alabama's Old Rotation - over 100 years) cotton experiment in Auburn, Alabama, USA analysed the trend in soil organic carbon and nitrogen cycling in soil. The treatments were 1) continuous cotton without winter legumes, 2) continuous cotton with legumes, 3) continuous cotton with N fertiliser, 4) two year cotton-corn rotation with winter legumes, 5) two year cotton-corn rotation with winter legumes and N fertiliser, and 5) three year cotton-winter legumes-corn rotation followed by grain-soybean. Additionally, the treatments were fertilized at different rates, creating additional treatments. The authors showed that long-term use of winter legumes resulted in higher soil organic carbon values compared to continuous cotton (9.5 g/kg of carbon to 4.2 g/kg). A significant quadratic cotton yield response was observed to increasing soil organic carbon. Winter legume cover crops were estimated to supply between 100 kg/ha to 190 kg/ha of nitrogen to soil. Where no nitrogen had been applied, either by fertiliser or from a legume, cotton crop removed around 13 kg/ha of nitrogen annually.

11.5 Bibliography

[1]Entry, J. A., Mitchell, C. C., & Backman, C. B. (1996). Influence of management practices on soil organic matter, microbial biomass and cotton yield in Alabama's "Old Rotation". *Biology and Fertility of Soils, 23*(4), 353-358. doi: 10.1007/s003740050182

[2]Mitchell, C. C., Delaney, D. P., & Balkcom, K. S. (2008). A historical summary of Alabama's Old Rotation (circa 1896): The world's oldest, continuous cotton experiment. *Agronomy Journal, 100*(5), 1493-1498. doi: 10.2134/agronj2007.0395

[3]Hulugalle, N. R., & Scott, F. (2008). A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006. *Australian Journal of Soil Research, 46*(2), 173-190. doi: 10.1071/SR07077

[4]Wright, A. L., Hons, F. M., Lemon, R. G., McFarland, M. L., & Nichols, R. L. (2007). Stratification of nutrients in soil for different tillage regimes and cotton rotations. *Soil & Tillage Research, 96*(1-2), 19-27. doi: 10.1016/j.still.2007.02.005

[5]Tennakoon, S. B., & Hulugalle, N. R. (2006). Impact of crop rotation and minimum tillage on water use efficiency of irrigated cotton in a Vertisol. *Irrigation Science, 25*(1), 45-52. doi: 10.1007/s00271-006-0033-0

[6]Reddy, K. N., Locke, M. A., Koger, C. H., Zablotowicz, R. M., & Krutz, L. J. (2006). Cotton and corn rotation under reduced tillage management: impacts on soil properties, weed control, yield, and net return. *Weed Science, 54*(4), 768-774. doi: 10.1614/Ws-06-031r.1

[7]Mitchell, C. C., & Entry, J. A. (1998). Soil C, N and crop yields in Alabama's long-term 'Old rotation' cotton experiment. *Soil & Tillage Research, 47*(3-4), 331-338. doi: 10.1016/S0167-1987(98)00121-4

[8]Hulugalle, N. R., Entwistle, P. C., Scott, F., & Kahl, J. (2001). Rotation crops for irrigated cotton in a medium-fine, self-mulching, grey Vertosol. *Australian Journal of Soil Research, 39*(2), 317-328. doi: 10.1071/Sr00035

[9]Bordovsky, J. P., Mustian, J. T., Cranmer, A. M., & Emerson, C. L. (2011). Cotton-Grain Sorghum Rotation under Extreme Deficit irrigation Conditions. *Applied Engineering in Agriculture, 27*(3), 359-371.

[10]Blaise, D., Ravindran, C. D., & Singh, J. V. (2006). Trend and stability analysis to interpret results of long-term effects of application of fertilisers and manure to cotton grown on rainfed vertisols. *Journal of Agronomy and Crop Science, 192*(5), 319-330. doi: 10.1111/j.1439-037X.2006.00222.x

[11]Hulugalle, N. R., Weaver, T. B., Finlay, L. A., Hare, J., & Entwistle, P. C. (2007). Soil properties and crop yields in a dryland Vertisol sown with cotton-based crop rotations. *Soil & Tillage Research, 93*(2), 356-369. doi: 10.1016/j.still.2006.05.008

[12]Kintche, K., Guibert, H., Sogbedji, J. M., Leveque, J., & Tittonell, P. (2010). Carbon losses and primary productivity decline in savannah soils under cotton-cereal rotations in semiarid Togo. *Plant and Soil, 336*(1-2), 469-484. doi: 10.1007/s11104-010-0500-5

[13]Hulugalle, N. R., & Cooper, J. (1994). Effect of Crop-Rotation and Residue Management on Properties of Cracking Clay Soils under Irrigated Cotton-Based Farming Systems of New-South-Wales. *Land Degradation and Rehabilitation, 5*(1), 1-11. doi: 10.1002/ldr.3400050102

[14]Hulugalle, N. R., Weaver, T. B., & Finlay, L. A. (2006). Residual effects of cotton-based crop rotations on soil properties of irrigated Vertosols in central-western and north-western New South Wales. *Australian Journal of Soil Research, 44*(5), 467-477. doi: 10.1071/SR05141

[15]Olson, D. M., Webster, T. M., Scully, B. T., Strickland, T. C., Davis, R. F., Knoll, J. E., & Anderson, W. F. (2012). Use of Winter Legumes as Banker Plants for Beneficial Insect Species in a Sorghum and Cotton Rotation System. *Journal of Entomological Science, 47*(4), 350-359.

[16]Kouakou, E. T., & Traore, D. (2010). Mastery of weeds in cotton cultivation by crop rotations in Cote d'Ivoire. *Cahiers Agricultures, 19*(3), 200-204. doi: 10.1684/agr.2010.0397

[17]Zhao, D., Wright, D. L., Marois, J. J., Mackowiak, C. L., & Brennan, M. (2010). Improved growth and nutrient status of an oat cover crop in sod-based versus conventional peanut-cotton rotations. *Agronomy for Sustainable Development, 30*(2), 497-504. doi: 10.1051/agro/2009045

[18]Ruby, T., Rana, S.A., Afzal, M. & Hameed, M. (2010). Biodiversity of Foliage Arthropods in the Mixed Crop Zone and Cotton-Wheat Zone in Punjab Province, Pakistan. *International Journal of Agriculture & Biology* 12: 861-866.

12 Habitat diversity

12.1 Description

Habitat diversity within this chapter refers to diversity of vegetation within crop and within field as a means of improving soil quality and controlling pests. It compares to Chapter 9 on 'Habitat management for predators' but focusses primarily on intercropping for enhancing soil quality rather than for controlling pests.

12.2 Quick facts

Definition and purpose: Safeguarding habitat diversity on farmed lands and managing different types of vegetation within-crop and within-field to protect insects, including the beneficial insects that predate upon cotton pests and to maintain soil fertility and structure

Benefits: Reduces incidence of pests; reduces insecticide use; protects other species; and maintains ecological productivity

12.3 Synthesis

The search mostly yielded studies focusing on genetic diversity of cotton itself and these results have been incorporated into Chapter 10. Studies pertaining to habitat diversity – an all-encompassing term – look, for the most part, into biodiversity effects. Soil and water are not discussed.

12.3.1 Impact summary of the intervention

In total, seven studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
Limited evidence				Positive	Positive	Increases	Medium	Increases

12.3.2 Soil

Studies on habitat diversity in cotton generally remain silent on soils. One experiment shows that lucerne (alfalfa), though perhaps providing minor benefits, does not influence overall soil quality[1].

12.3.3 Water

No effects on water have been identified.

12.3.4 Biodiversity

Overall, six studies (two of which were randomised, replicated and controlled, two controlled and one review) suggest that **habitat management enhances biocontrol and conserves biodiversity**[2-7].

In particular, five studies (four controlled studies, two of which are also randomised and replicated) highlight that **intercropping helps control pests**[3-6,8].

12.4 Evidence Review

12.4.1 Asia

12.4.1.1 Impact of habitat manipulation on insect pests and their natural enemies in hybrid cotton[7]

Key message: Intercropping helps control pests, increases yield.

Location: Anand, Gujarat state, India

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	Positive
Quality					C	C	C

A controlled three-year field experiment in Anand, Gujarat state, India aimed to determine the effects of intercropping on cotton pests and beneficial insects. The study's treatments were: cotton intercropped with *Cassia occidentalis* at a ratio of 6 to 1 with maize or zinnia planted at 10% of the cotton plants, the same treatment except with the release of two beneficial insects (*Trichogramma chilonis* and *Chrysoperla carnea*), cotton sprayed with need based insecticide treatments, and an untreated control. The study concluded that pest populations were reduced significantly in intercropped plots, compared to the control. Reductions of different pests ranged between 68% and 85%. As a result, the intercropped plots also produced higher yield.

12.4.1.2 Assessment of cotton aphids, Aphis gossypii, and their natural enemies on aphid-resistant and aphid-susceptible wheat varieties in a wheat-cotton relay intercropping system[5]

Key message: Intercropping favours beneficial insects, thus contributing to pest control.

Location: Hebei province, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Positive	
Quality						CRR	

A two-year controlled, randomised, replicated study in Hebei province, China examined four wheat varieties intercropped with cotton and how they affected pests (cotton aphid) and predator populations. The study consisted of five treatments: four wheat varieties with different levels of resistance (from susceptible to resistant) to wheat aphids and one treatment of genetically modified (*Bt*) cotton monoculture. The authors concluded that intercropped fields preserved and increased the populations of beneficial insects. Also, the beneficial insect populations differed significantly between individual wheat varieties; they were most abundant in wheat susceptible to wheat aphid and least abundant in a resistant variety.

12.4.1.3 Impact of alfalfa/cotton intercropping and management on some aphid predators in China[6]

Key message: Intercropping favours beneficial insects, thus contributing to pest control.

Location: Xinjiang, China

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Positive	
Quality						C	

A controlled study in Xinjiang, China observed a cotton field intercropped with alfalfa, investigating whether cutting alfalfa would lead to migration of beneficial insects from alfalfa strips to cotton. The alfalfa belt in the field had been divided into six blocks, three of which were to be cut and three were designated as controls and did not receive any treatment. Cotton aphid populations grew significantly slower in cotton near cut alfalfa when compared with aphids near uncut alfalfa. At the same time, beneficial insect populations grew significantly faster in cotton next to cut alfalfa, compared to cotton next to uncut treatments.

12.4.2 Australia and Oceania

12.4.2.1 Can lucerne strips improve soil quality in irrigated cotton fields?[1]

Key message: Lucerne (alfalfa) strips may have some beneficial effects on soil, but do not improve soil quality overall.

Location: New South Wales, Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts	No effect						
Quality	-						

A two-year experiment on a Vertisol and an Alfisol in New South Wales, Australia evaluated the use of lucerne strips for improving soil quality. Compared to cotton, lucerne strips exhibited higher air-filled porosity and higher organic carbon in the sub-soil at two of the tree farms where research had been conducted (one farm only displayed higher organic carbon content at the soil surface). Lucerne also seemed to increase soil strength and reduce soil salinity. Also, earthworm activity was higher at two out of three farms. Nevertheless, the authors concluded that lucerne strips did not affect soil quality, as only one farm (that at the research centre) marked an overall improvement.

12.4.3 North America

12.4.3.1 Interplanting alfalfa as a source of Metaseiulus occidentalis for managing spider mites in cotton[3]

Key message: Lucerne (alfalfa) provides habitat for beneficial insects.

Location: San Joaquin Valley, California, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Positive	Positive
Quality						-	-

A two-year experiment in San Joaquin Valley, California, USA investigated whether alfalfa (lucerne) provided habitat for the western predatory mite (beneficial predator) that would predate upon, and thus control, spider mites (pest species). In the first year, three four metre wide strips of alfalfa were planted, one of which was in the middle and the other two on the edges, in a single cotton field. The second year the design was changed to eight smaller plots and narrower bands of alfalfa. Western predatory mite successfully established itself in alfalfa during both years. Its density was higher near alfalfa (and density of spider mites was lower there as well), leading the authors to infer that alfalfa was the source. However, spider mites were effectively controlled and cotton yield was higher near alfalfa only in the second year of the study. Nevertheless, the authors concluded that alfalfa had potential to serve as a habitat for western predatory mites.

12.4.4 South America

12.4.4.1 Assessment of fennel aphids and their predators in fennel intercropped with cotton with colored fibers[4]

Key message: Intercropping helps control pests.

Location: Montandas, Paraiba, Brazil

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Positive	Positive
Quality						CRR	CRR

A two-year controlled, randomised, replicated study in Montandas, Paraiba, Brazil evaluated if intercropping fennel and cotton would more effectively control fennel aphids. The study tested the following treatments: two rows of fennel and one row of cotton, three rows of fennel and one row of cotton, one row of fennel and two rows of cotton, two rows of fennel and three rows of cotton and sole fennel. Additionally, each of these five treatments was either treated or untreated with insecticides, giving a total of ten treatments. The fennel aphid populations were significantly larger in sole fennel plots and the predator populations were significantly larger in intercropped plots. Overall, fennel aphids reduced fennel yield by 80% in the sole plots, compared to 30% in the intercropped plots. Thus, the results confirmed the hypothesis that intercropping fennel and cotton could reduce the fennel aphid populations.

12.4.5 Worldwide

12.4.5.1 Habitat management to conserve natural enemies of arthropod pests in agriculture[2]

Key message: Habitat management enhances biological control, benefits biodiversity.

Location: Worldwide (review)

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

The authors reviewed available Evidence on habitat management – a process aiming to create an environment favouring beneficial insects in crops. The review distinguished three levels, on which habitat management could take place: within-crop, within-farm and at the landscape level. The authors mentioned several constituent factors essential to the process, namely availability of food (nectar, pollen, honeydew), shelter, microclimate allowing beneficial insects to overwinter or seek refuge (e.g. from environmental extremes and pesticides), and habitat for alternative hosts or prey. The authors also mentioned the necessity to pay close attention to temporal availability of the aforementioned resources (for example, to encourage early season activity) as well as to spatial arrangements. Negative aspects and risks were also discussed: some land could be put out of production, farmers would have little control over the community in the habitat once it is created, and there may be a risk of establishing plants that could potentially turn into invasive weeds. The study commended cotton-wheat relay intercropping in China that had helped reduce cotton aphid damage, as natural enemies could feed on prey in wheat and then disperse to emerging cotton.

12.5 Bibliography

[1]Hulugalle, N. R., Entwistle, P. C., & Mensah, R. K. (1999). Can lucerne (Medicago sativa L.) strips improve soil quality in irrigated cotton (Gossypium hirsutum L.) fields? *Applied Soil Ecology, 12*(1), 81-92. doi: 10.1016/S0929-1393(98)00154-1

[2]Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology, 45*(1), 175-201.

[3]Corbett, A., Leigh, T. F., & Wilson, L. T. (1991). Interplanting Alfalfa as a Source of Metaseiulus occidentalis (Acari: Phytoseiidae) for Managing Spider Mites in Cotton. *Biological Control, 1*(3), 188-196. doi: 10.1016/1049-9644(91)90066-9

[4]Ramalho, F. S., Fernandes, F. S., Nascimento, A. R. B., Nascimento, J. L., Malaquias, J. B., & Silva, C. A. D. (2012). Assessment of Fennel Aphids (Hemiptera: Aphididae) and Their Predators in Fennel Intercropped With Cotton With Colored Fibers. *Journal of Economic Entomology, 105*(1), 113-119. doi: 10.1603/EC11219

[5]Ma, X. M., Liu, X. X., Zhang, Q. W., Zhao, J. Z., Cai, Q. N., Ma, Y. A., & Chen, D. M. (2006). Assessment of cotton aphids, Aphis gossypii, and their natural enemies on aphid-resistant and aphid-susceptible wheat varieties in a wheat-cotton relay intercropping system. *Entomologia Experimentalis Et Applicata, 121*(3), 235-241. doi: 10.1111/j.1570-8703.2006.00484.x

[6]Lin, R., Liang, H., Zhang, R., Tian, C., & Ma, Y. (2003). Impact of alfalfa/cotton intercropping and management on some aphid predators in China. *Journal of Applied Entomology-Zeitschrift Fur Angewandte Entomologie, 127*(1), 33-36. doi: DOI 10.1046/j.1439-0418.2003.00672.x

[7]Godhani, Pl.H., Patel, R.M., Jani, J.J., Yadav, D.N., Korat, D.M. & Paterl. B.H. (2009) Impact of habitat manipulation on insectpests and their natural enemies in hiypride cotton. *Karnataka Journal of Agricultural Sciences(22),* 1.

[8]Godhani, P. H., Jani, J. J., Patel, R. M., & Yadav, D. N. (2010). Impact of intercropping on natural enemies of insect-pests in cotton. *Research on Crops, 11*(2), 511-515.

13 Keeping a tidy farm

13.1 Description

In order to support plant growth, weeds competing for nutrients need to be removed. While this is normally achieved through the use of synthetic herbicides before sowing and after crop emergence, there are also ‘cultural’, or non-chemical, methods that suppress weeds, such as hoeing and the use of cover crops. A related problem is that of ‘volunteer crops’ – crops from the previous season that emerge spontaneously in or near the field (Chapter 14 ‘Removing volunteer cotton’).

13.2 Quick facts

Definition and purpose: Removing weeds and spontaneously appearing crops from cotton fields to reduce competition for nutrients and remove potential harbours of pests

Benefits: Increases crop yields; and reduces pest populations

13.3 Synthesis

Nearly all published studies on weed or unwanted substance control for cotton production focus on measuring the efficacy of individual substances against weeds. Studies that discuss ‘cultural’, or non-chemical, methods of controlling weeds still focus on efficacy, rather than on their contribution to the environment. There are no studies that would explore the impacts of weed control within cotton fields on soil, water or biodiversity.

13.3.1 Impact summary of the intervention

In total, two studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
	Limited evidence					**Increases**	**Low**	**Increases**

13.3.2 Soil

No effects on soil have been identified.

13.3.3 Water

No effects on water have been identified.

13.3.4 Biodiversity

No effects on biodiversity have been identified.

13.4 Evidence Review

13.4.1 Europe

13.4.1.1 Oregano green manure for weed suppression in sustainable cotton and corn fields[1]

Key message: Oregano green manure inhibits pest growth, increases yields.

Location: Thessaloniki, Greece

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts		Positive					Positive
Quality		CRR					CRR

A controlled, randomised, replicated two year experiment on calcareous loam studied the potential of oregano green manure as herbicide. The study was conducted with four treatments of different oregano biotypes and two controls, one of which had weed and the other was weed-free. The study revealed that oregano green manure could supplant synthetic herbicides, as the manure reduced the emergence of common purslane by 0-55%, of barnyard grass by 38-52%, and of bristly foxtail by 43-86%. At the same time, cotton lint yields in treatment plots exceeded those in the weedy control by 24-88%. However, they were significantly lower than those in the weed-free control.

13.4.2 North America

13.4.2.1 Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton[2]

Key message: Cover crops help control weeds, reduce the number of herbicide applications, increase yields.

Location: near Headland, Alabama, USA

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							Positive
Quality							CRR

A three-year replicated experiment on a fine sandy loam examined the effects of three cover crops (black oat, rye, wheat) on weed control in a conservation tillage system. The results were compared to a fallow. Additionally, applying herbicide pre-emergence, pre- and post-emergence, and not at all was tested. The study found that no cover crop could adequately control weeds without a herbicide. However, black oat and rye used with pre-emergence herbicide only achieved similar results as the pre- and post-emergence system. Also, systems with a cover crop tended to produce higher yields.

13.5 Bibliography

[1]Vasilakoglou, I., Dhima, K., Anastassopoulos, E., Lithourgidis, A., Gougoulias, N., & Chouliaras, N. (2011). Oregano green manure for weed suppression in sustainable cotton and corn fields. *Weed Biology and Management, 11*(1), 38-48. doi: 10.1111/j.1445-6664.2011.00403.x

[2]Reeves, D. W., Price, A. J., & Patterson, M. G. (2005). Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton. *Weed Technology, 19*(3), 731-736. doi: 10.1614/Wt-04-245r1.1

14 Removing volunteer cotton

14.1 Description

Volunteer cotton grows on its own, rather than being sown. For example, cotton could germinate from seeds from previous harvests and act as a weed in subsequent harvests. In other cases, cotton plants grow voluntarily on field margins, such volunteer cotton can shelter pests or carry infections that can be transmitted to the planted crop through irrigation water or wind-driven rains. These volunteer cotton crops compete for nutrients with current crops,upset harvest purity and potentially harbour pests. Volunteer crops usually need to be weeded manually or mechanically, but chemical control or keeping a field fallow are two other methods that are often adopted, although they are sometimes not efficient. Removing volunteer cotton constitutes an important part of 'Keeping a tidy farm' (Chapter 13).

14.2 Quick facts

Definition and purpose: Removing volunteer (spontaneously appearing) cotton from cotton fields to remove harbours for cotton pests, prevent wasting fertiliser and moisture on unwanted crops and avoid unfavourable gene flows

Benefits: Maintains yields and quality

14.3 Synthesis

There are no studies that explore impacts of volunteer cotton weed control in cotton production systems on soil, water or biodiversity. Similarly, the sparse body of evidence on volunteer cotton in other crop fields examines cotton's response to herbicides as a weed, rather than the environmental effects of its removal.

14.3.1 Impact summary of the intervention

In total, 2 studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
							Medium	**Increases**

14.3.2 Soil

No effects on soil have been identified.

14.3.3 Water

No effects on water have been identified.

14.3.4 Biodiversity

No effects on biodiversity have been identified.

14.4 Evidence Review

14.4.1 Australia and Oceania

14.4.1.1 *Adaptive management of pest resistance by* Helicoverpa *species (*Nocuidae*) in Australia to the Cry2Ab Bt toxins in Bollard II cotton*[1]

Key message: Second generation Bt cotton is showing increasing resistance to Cry2Ab toxin.

Location: Australia

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

Increasing resistance to Cry2Ab toxin, with increasing frequency of Cry2Ab resistance alleles, in second generation Bt cotton – warning of potential failures of the technology. Mitigation strategies were discussed including mandating larger structured refuges, applying insecticide to crops late in the season, and restricting the area of Bollgard II cotton.

14.4.1.2 *The winter carry-over of angular leaf spot infection in Arizona Cotton fields*[2]

Key message: Angular leaf spot of cotton (*Phytomonas malvacearum*) is capable of surviving the winder on seed left unpicked in the field Second generation.

Location: Arizona

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts							
Quality							

Presents evidence that the causal organism of angular leaf spot of cotton (*Phytomonas malvacearum*) is capable of surviving the winder on seed left unpicked in the field. Infections from volunteer seedlings can be transmitted to the planted crop through irrigation water or wind-driven rains. Some suggested methods: turning cattle on the fields after the harvesting of the crop, raking and burning the plant debris, and early cultivation to destroy the volunteer seedlings before irrigation.

14.5 Bibliography

[1]Downes, S., Mahon, R.J., Rossiter, L., Kauter, G., Leven, T., Fitt, G. & Baker, G. (2010). Adaptive management of pest resistance by *Helicoverpa* species (Nocuidae) in Australia to the Cry2Ab Bt toxin in Bollgard II cotton. *Evolutionary Applications, 3(5-6),* 574-584. Doi: 10.111/j.1752-4571.2010.00146.x

[2]Hare, J.F. & King, C., J. (1940). The winter carry-over of angular leaf spot infection in Arizona Cotton fields. *Phytopathology, 30(8)*, 679-684.

15 Limiting cotton expansion

15.1 Description

Clearing land and converting it to fields for productive purposes, including cash crop farming is a common practice. This raises a number of issues around governance, land management and conservation. To increase cotton supply while avoiding expansion into new lands, cotton expansion can be limited to previously farmed land.

15.2 Quick facts

Definition and purpose: Limiting cotton expansion to previously farmed land to avoid clearing new areas of natural habitat for cotton production

Benefits: Reduces controversies over land rights; prevents clearing; and decreases loss of native biodiversity

15.3 Synthesis

Although a sizeable body of research on land issues exists, very few studies discuss environmental effects of opening new land for cotton production. Only studies from Africa have been found during the review process. No studies that would link cotton production to clearing of the Amazon (or any other parts of the world, for that matter) have been discovered. General assumptions can be made regarding the natural capital impacts of limiting cotton expansion.

15.3.1 Impact summary of the intervention

In total, three studies were relevant, accessible and reviewed.

Soil		Water		Biodiversity		Yield	Costs	Quality
Structure	Fertility	Quality	Quantity	Diversity	Abundance			
				Limited evidence	**Positive**		**Low**	**Is not affected**

15.3.2 Soil

No effects on soil have been identified.

15.3.3 Water

No effects on water have been identified.

15.3.4 Biodiversity

Expansion of cotton production to new land often drives habitat destruction. Three studies (one review) link the expansion of cotton production in Africa to **loss of African elephant habitat**[1,2] and general biodiversity loss[3].

15.4 Evidence Review

15.4.1 Africa

15.4.1.1 *Cotton fields drive elephant habitat fragmentation in the Mid Zambezi Valley, Zimbabwe*[2]

Key message: Cotton fields drive elephant habitat fragmentation in Zimbabwe.

Location: Mid Zambezi Valley, Zimbabwe

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Positive	
Quality						-	

A study in Mid Zambezi Valley, Zimbabwe used remote sensing (MODIS, or Moderate Resolution Imaging Spectroradiometer – a satellite imagery system) and regression analyses to determine whether cereal fields or cotton fields drove woodland fragmentation (which, in turn, drives elephant habitat loss) along the Zambezi River. The analysis showed that cotton fields had contributed more to habitat fragmentation than cereal fields, especially at the wildlife frontier with newly opened up agricultural areas. Also, elephant frequency increased where cotton fields were abundant and small compared to the cereal fields. Lastly, increased distances between patches of woodland repelled elephants from the Mid Zambezi Valley.

15.4.1.2 *Delineating the drivers of waning wildlife habitat: the predominance of cotton farming on the fringe of protected areas in the Mid-Zambezi Valley, Zimbabwe*[1]

Key message: Cotton fields reduce wildlife habitat in Zimbabwe.

Location: Mid Zambezi Valley, Zimbabwe

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts						Positive	
Quality						-	

A study in Mid Zambezi Valley, Zimbabwe aimed to determine land use changes since 1980 until 2011 and review their potential drivers (population growth, increase in cattle population linked to plough-based agriculture, and expansion of cotton farming). The area dedicated to farming increased exponentially within the study area, reaching 47% from 5-15% in one of the districts. The population in the study area also almost doubled between 1992 and 2002. 64% of the farm sampled were 'immigrant households', that is, people who migrated to the area after 1980. Immigrant farmers tended to cultivate larger areas (including larger areas of cotton, in particular). The authors determined, however, that farmland increased faster than human population. Despite increases in these variables, crop damage caused by wildlife decreased, suggesting decreasing wildlife densities. The study concluded that cotton farming was the most important driver of wildlife habitat reduction, arguing that without a cash crop like cotton land use changed would not have been as extensive or rapid.

15.4.1.3 Cotton expansion and biodiversity loss in African savannahs, opportunities and challenges for conservation agriculture: a review paper based on two case studies[3]

Key message: Cotton drives biodiversity loss in Africa; conservation agriculture could help.

Location: Africa

	Soil		Water		Biodiversity		Yield
	Structure	Fertility	Quality	Quantity	Diversity	Abundance	
Impacts					Positive	Positive	
Quality					Review	Review	

A review of two similar farming areas in Africa – one in West Africa and another one in Mid Zambezi Valley – looked at the role of cotton production in land use change and biodiversity loss. The authors also explored the possibilities that could alleviate these environmental pressures. The study suggested that conservation agriculture would increase nutrient uptake efficiency, conserve water resources, and be a good fit for both environments overall. However, the farmers faced a number of constraints that would have to be dealt with first. For example, due to their risk-averse nature, they would avoid changes and investments whose benefits would arrive only in several years.

15.5 Bibliography

[1]Baudron, F., Corbeels, M., Andersson, J. A., Sibanda, M., & Giller, K. E. (2011). Delineating the drivers of waning wildlife habitat: The predominance of cotton farming on the fringe of protected areas in the Mid-Zambezi Valley, Zimbabwe. *Biological Conservation, 144*(5), 1481-1493. doi: 10.1016/j.biocon.2011.01.017

[2]Sibanda, M., & Murwira, A. (2012). Cotton fields drive elephant habitat fragmentation in the Mid Zambezi Valley, Zimbabwe. *International Journal of Applied Earth Observation and Geoinformation, 19*, 286-297. doi: 10.1016/j.jag.2012.05.014

[3]Baudron, F., Corbeels, M., Monicat, F., & Giller, K. E. (2009). Cotton expansion and biodiversity loss in African savannahs, opportunities and challenges for conservation agriculture: a review paper based on two case studies. *Biodiversity and Conservation, 18*(10), 2625-2644. doi: 10.1007/s10531-009-9663-x

Appendices

Appendix 1: Water consumption Search Criteria

A total of 57 studies was relevant, accessible and reviewed.

Appendix 1.1: Primary Search

Source	Search terms	Number of potentially relevant studies found	Date of search
Web of Science	drip / trickle / micro irrigation cotton (field TITLE: drip OR trickle OR micro AND irrigat* AND cotton)	108	29 June, 2015
Web of Science	deficit / incomplete / supplemental / regulated irrigation cotton (field TITLE: deficit OR incomplete OR supplemental OR regulat* AND irrigat* AND cotton)	22	6 July, 2015
Web of Science	brackish saline cotton (field TITLE: brack* OR saline AND cotton)	20	16 July, 2015

Appendix 1.2: Secondary Search

Source	Search terms	Number of additional studies found	Date of search
Google Scholar	drip furrow cotton	2	2 July, 2015
‘Deficit irrigation’		1	6 July, 2015
‘Drip irrigation’ sources	drip/trickle/micro irrigation cotton (field TITLE: drip OR trickle OR micro AND irrigat* AND cotton)	11	29 June, 2015
‘Drip irrigation’		7	29 June, 2015
Web of Science	grey water cotton (field TITLE: grey AND cotton)	0	22 July, 2015
Google Scholar	grey water cotton	0	22 July, 2015

Keywords: deficit irrigation, soil salinity, saline water irrigation, furrow versus drip irrigation, vertisol, plastic mulch, arid regions; drip irrigation, arid region, plant water stress, canopy temperature, water-use efficiency; salinity, exchangeable sodium percentage, brackish water

Appendix 2: Soil fertilisation Search Criteria

A total of 32 studies was relevant, accessible and reviewed.

Appendix 2.1: Primary search

Source	Search terms	Number of potentially relevant studies found	Date of search
Web of Science	compost cotton (field TITLE: *compost* AND cotton)	34	9 July, 2015
Web of Science	cotton manure (field TITLE: cotton AND manure)	7	13 July, 2015

Appendix 2.2: Secondary search

Source	Search terms	Number of *additional* studies found	Date of search
Google	Cotton Gin Trash Composting Studies	1	10 July, 2015
Web of Science	compost cotton soil health (field ABSTRACT/KEYWORDS: *compost* AND cotton AND soil AND health)	4	10 July, 2015
Web of Science	cotton organic amendments (field TITLE: cotton AND organic AND amendment*)	2	13 July, 2015
Web of Science	cotton vermi* (field TITLE: cotton AND vermi*)	0	13 July, 2015
Web of Science	cotton vermicast (field ABSTRACT/KEYWORDS: cotton AND vermicast)	1	13 July, 2015
Web of Science	cotton manure (field TITLE: cotton AND manure)	7	13 July, 2015
Web of Science	cotton animal (field TITLE: cotton AND animal)	0	13 July, 2015
Web of Science	cotton organic matter (field TITLE: cotton AND organic AND matter)	5	13 July, 2015
Web of Science	cotton humus (field TITLE: cotton AND humus)	0	13 July, 2015
Web of Science	gin trash (field TITLE: gin AND trash)	14	13 July, 2015

Web of Science	cotton alperujo (field TITLE: cotton AND alperujo)	0	15 July, 2015
Web of Science	rotation cotton (field TITLE: rotat* AND cotton)	132	26 August, 2015
Web of Science	compost cotton (field TITLE: *compost* AND cotton)	34	9 July, 2015

Keywords: cotton gin trash, cotton gin waste, compost, organic amendment, vermicompost, manure, organic matter, water pollution; cotton gin trash, cotton gin waste, compost, organic amendment, organic matter, water pollution;, organic matter, water pollution

Appendix 3: Pest management Search Criteria

A total of 64 studies was relevant, accessible and reviewed.

Appendix 3.1: Primary Search

Source	Search terms	Number of potentially relevant studies found	Date of search
Web of Science	biological cotton (field TITLE: biological AND cotton)	11	27 July, 2015
'Biological Control'	-		29 September, 2015
'Habitat diversity'	-		29 September, 2015
Web of Science	garlic cotton (field TITLE: garlic AND cotton)	1	28 July, 2015
Web of Science	pesticide cotton (field TITLE: pesticid* AND cotton)	134	10 July, 2015

Appendix 3.2: Secondary Search

Source	Search terms	Number of *additional* relevant studies found	Date of search
Web of Science	biocontrol cotton (field TITLE: biocontrol AND cotton)	2	28 July, 2015
Google scholar	biocontrol insecticide cotton	3	30 July, 2015
Google scholar	cotton biological control versus insecticide	2	30 July, 2015
Web of Science	natural enemy cotton (field TITLE: natural AND enem* AND cotton)	7	30 July, 2015
Dr Robert Mensah, Australian Cotton Research Institute	-	1	4 August, 2015
'Botanical Spray'	-	3	21 August, 2015
Web of Science	natural cotton (field TITLE: natural AND cotton)	292 (too many, results not filtered)	29 September, 2015
Web of Science	natural pest cotton (field TITLE: natural AND pest AND cotton)	8 (0)	29 September, 2015
Web of Science	neem cotton (field TITLE: neem AND cotton)	15	23 July, 2015
Web of Science	pyrethrum cotton (field TITLE: pyrethrum AND cotton)	0	23 July, 2015
Web of Science	pyrethrum cotton (field ABSTRACT/KEYWORDS: pyrethrum AND cotton)	0	23 July, 2015
Web of Science	natural pesticide cotton (field ABSTRACT/KEYWORDS: natural AND pesticide AND cotton)	1	23 July, 2015
Web of Science	custard apple cotton (field TITLE: custard AND cotton);	0	28 July, 2015

	(field TITLE: apple AND cotton)		
Web of Science	botanical spray cotton (field TITLE: botanical OR spray AND cotton)	10	21 July, 2015
Web of Science	sweet flag cotton (field TITLE: sweet AND cotton); (field TITLE: flag AND cotton)	0	28 July, 2015
Web of Science	turmeric cotton (field TITLE: turmeric AND cotton)	0	28 July, 2015
Web of Science	chili cotton (field TITLE: chili AND cotton)	0	28 July, 2015
Web of Science	basil cotton (field TITLE: basil AND cotton)	0	28 July, 2015
Dr Robert Mensah, Australian Cotton Research Institute	-	1	4 August, 2015
Web of Science	integrated pest management cotton (field TITLE: integrated pest management AND cotton)	15	27 July, 2015
'Biological control'	-	3	21 July, 2015

Keywords: biocontrol, natural enemy, predator, parasitoid, beneficial insects, Bt cotton; biocontrol, natural enemy, predator, parasitoid, beneficial insects, habitat management; garlic cotton, neem cotton, pyrethrum, natural pesticide cotton, custard apple cotton, botanical spray, sweet flag cotton, turmeric cotton, chili cotton, basil cotton; beneficial insects, natural enemy, natural predator, Bt cotton, insecticide, fungicide, herbicide, glyphosate, Integrated Pest management , IPM, farm runoff, tail water, drainage water, groundwater

Appendix 4: Land and diversity management Search Criteria

A total of 32 studies was relevant, accessible and reviewed.

Appendix 4.1: Primary Search

Source	Search terms	Number of potentially relevant studies found	Date of search
Web of Science	rotation cotton (field TITLE: rotat* AND cotton)	132	26 August, 2015
Web of Science	habitat animal biodiversity cotton (field TITLE: habitat* OR animal* OR *diversity AND cotton)	184	28 July, 2015
Web of Science	cotton weed (field TITLE: cotton AND weed)	213 (2)	28 July, 2015
Web of Science	volunteer cotton (field TITLE: volunteer AND cotton)	1	28 July, 2015
Web of Science	land cotton (field TITLE: land AND cotton)	65 (0)	29 September, 2015

Appendix 4.2: Secondary Search

Source	Search terms	Number of *additional* studies found	Date of search
Web of Science	cotton organic matter (field TITLE: cotton AND organic AND matter)	1	13 July, 2015
Google Scholar	habitat diversity cotton	4	31 July, 2015
Web of Science	intercropping multiple cropping cotton (field TITLE: intercrop* OR multiple crop* AND cotton)	83	31 July, 2015
Web of Science	interplanting cotton (field TITLE: interplant* AND cotton)	15	6 August, 2015
Dr Robert Mensah	Australian Cotton Research Institute	1	4 August, 2015
'Biological control'	-	4	4 August, 2015
Web of Science	volunteer cotton (field TITLE: volunteer AND cotton)	1	28 July, 2015
'Habitat diversity'	-	3	26 July, 2015

Keywords: tomato, wheat, corn, legumes, sorghum, Old Rotation, soil organic carbon, organic matter; intercropping, interplanting, habitat management, landscape, fragmentation; volunteer, herbicide, weed; herbicide, weed; habitat diversity, land use, habitat fragmentation, cash crop

UNIVERSITY OF CAMBRIDGE
INSTITUTE FOR SUSTAINABILITY LEADERSHIP

Cambridge insight, policy influence, business impact

The University of Cambridge Institute for Sustainability Leadership (CISL) brings together business, government and academia to find solutions to critical sustainability challenges.

Capitalising on the world-class, multidisciplinary strengths of the University of Cambridge, CISL deepens leaders' insight and understanding through its executive programmes; builds deep, strategic engagement with leadership companies; and creates opportunities for collaborative enquiry and action through its business platforms.

Over 25 years, we have developed a leadership network with more than 7,000 alumni from leading global organisations and an expert team of Fellows, Senior Associates and staff.

HRH The Prince of Wales is the patron of CISL and has inspired and supported many of our initiatives.

Head Office
1 Trumpington Street
Cambridge, CB2 1QA
United Kingdom
t: +44 (0)1223 768850
e: info@cisl.cam.ac.uk

EU Office
The Periclès Building
Rue de la Science 23
B-1040 Brussels, Belgium
t: +32 (0)2 894 93 20
e: info.eu@cisl.cam.ac.uk

South Africa
PO Box 313
Cape Town 8000
South Africa
t: +27 (0)21 469 4765
e: info.sa@cisl.cam.ac.uk