INTERNATIONAL COTTON ADVISORY COMMITTEE

REGENERATIVE AGRICULTURE PRACTICES

2024

REGENERATIVE AGRICULTURE PRACTICES

Report prepared by
Dr. Kater Hake, former SEEP member,
with the ICAC Expert Panel on Social, Environmental
and Economic Performance of Cotton Production

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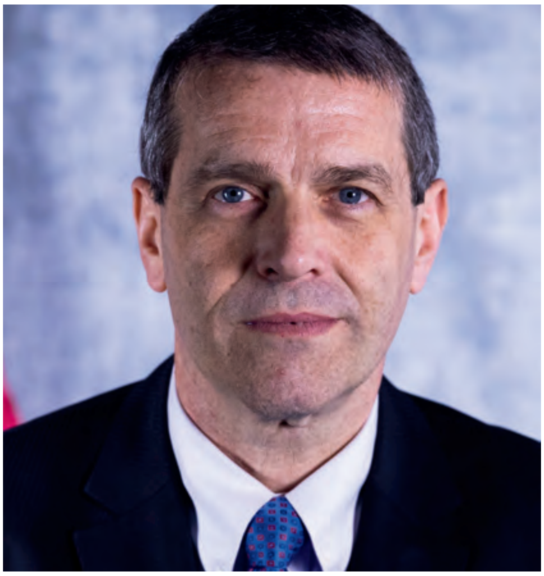
FOREWORD BY ICAC

The Expert Panel on the Social, Environmental, and Economic Performance of Cotton Production (SEEP) was established in 2006 to provide objective, science-based information on the negative and positive social, environmental, and economic aspects of global cotton production and to make recommendations to improve the social, environmental, and economic performance of the cotton industry. In the past, SEEP has focused on many issues of great importance, including how to measure sustainability, soil health, pesticide and energy use, and labor costs. As climate change accelerates and pest and other pressures rise, it has become increasingly important to promote farming systems focused on enhancing soil health. Good soil management can mitigate the impacts of climate change through practices that rebuild soils and create a base for higher levels of sustainable future production.

To support long-term production sustainability, this report focuses on Regenerative Agriculture. It addresses the feasibility and challenges of diverse regenerative agriculture practices that are aligned with different philosophies and standards.

The aim is to help readers understand the implications of these standards for farming systems of varying sizes and levels, outlining the necessary changes for farmers while addressing the associated risks of different approaches.

This report is designed to support the global cotton sector as it looks to engage in constructive regulatory dialogues, deepen collaboration with environmental civil society groups, advance work in agricultural development, communicate the truth about cotton and encourage its use.



Eric Trachtenberg
Executive Director, ICAC

FOREWORD BY SEEP CHAIR

There is an increased interest by the cotton supply chain in procuring cotton grown in accordance with the principles of regenerative agriculture, and there is also an increasing number of definitions of, and standards for, regenerative agriculture. And while perhaps not as diverse as the conditions under which cotton is grown, there is nevertheless a wide range of perspectives as to what constitutes 'regenerative agriculture' and therefore the types of farming practices that would be considered acceptable by the proponent of the definition. The genesis of this report was to provide an overview of the implications of adopting the range of commonly – agreed regenerative farming practices from a farmer's perspective. Ultimately it is practices that need to be implemented by the farmer, and the adoption of new farming practices can bring risks as well as rewards.

These risks will vary depending on the circumstances of the farming system; for example, is it irrigated or rain-fed? how reliable is the access to water? what is the size of the farm and the availability of mechanization?

SEEP believes that developing a better understanding of the level of risk associated with a practice can do things:

- Help guide the research needed to mitigate that risk and, therefore, increase the feasibility of adopting the practice and
- Inform readers about the appropriateness and feasibility of implementing a particular regenerative farming practice in a diverse range of contexts (farming systems).

On behalf of SEEP, I would like to thank and congratulate Dr Hake for his work in synthesising and distilling the extensive research literature. The report provides an excellent primer that concisely explains each practice, the science behind the practice and - importantly the benefits, risks and research needs to facilitate adoption.

Allan Williams
Executive Director, CRDC


CO2
NEUTRAL

PREFACE

Regenerative agriculture is becoming a cornerstone in the evolution of the expectations of the textile and apparel industry, signaling a significant shift in their approach to sustainability and ecological responsibility. Regenerative agriculture focuses on revitalizing the soil, increasing its organic matter, and promoting biodiversity. For cotton producers, the transition to regenerative practices offers a dual benefit: it plays a critical role in combating climate change by sequestering carbon in the soil and ensures the sustainability of their farms for generations to come. This movement towards regenerative agriculture represents a commitment to preserving the earth's natural resources while maintaining the economic viability of cotton farming.

The significance of adopting regenerative agriculture practices for cotton farmers is multifaceted. It leads to better water efficiency, decreases the dependence on synthetic fertilizers and pesticides, and increases the resilience of cotton crops to extreme weather and diseases. These improvements not only contribute to the reduction of the environmental impact associated with cotton farming but also position farmers to benefit from higher quality yields and potentially greater financial returns.

ACRONYMS AND ABBREVIATIONS

GMOs	Genetically Modified Organisms
PGRs	Plant Growth Regulators
RA	Regenerative Agriculture
SEEP	Social, Environmental, and Economic Performance
ICAC	International Cotton Advisory Committee
IPM	Integrated Pest Managment

ABOUT SEEP

The Expert Panel on the Social Environmental and Economic Performance of Cotton Production (SEEP) is an advisory body of the International Cotton Advisory Committee (ICAC) and was established during ICAC's 65th Plenary Meeting, held in Goiânia, Brazil, in September 2006. The SEEP Panel currently has fifteen members and reflects a broad cross-section of nationalities, expertise, and experience. The members of SEEP serve without compensation. Members belong to research or development organizations, national cotton organizations, or private sector associations. SEEP has a powerful collaborative capacity and substantially broadens ICAC's resource base. The primary objective of the Panel is to collect and review independent, science-based information on the negative and positive social, environmental, and economic aspects of global cotton production. Over the years, SEEP has reviewed existing information – using its internal expertise – and has commissioned and supervised scientific studies. Based on the available information, SEEP has formulated recommendations for further action as and when appropriate to improve the overall sustainability of cotton production.

SEEP began working on this report in 2023 in close collaboration with Dr. Kater Hake, a former panel member. At the 81st ICAC Plenary Meeting in Mumbai, India, delegates discussed the draft report and provided valuable insights and recommendations for its enhancement. SEEP integrated the feedback from the Plenary Meeting into this final version of the report. Allan Williams (SEEP Chair, CRDC) and Lorena Ruiz (ICAC) served as overall coordinators of the report. SEEP members, Bruno Bachelier(CIRAD), Fábio Carneiro (ABRAPA), Ryan Kurtz (Cotton Incorporated), Chad Brewer (NCC), Jens Soth (Helvetas), Elke Hortmeyer (Bremen Cotton Exchange) Leon Picon (Consultant), Damien Sanfilippo (BCI), Marcelo Paytas (INTA), and Keshav Kranthi (ICAC), provided important contributions, and extensive review and comments

EXECUTIVE SUMMARY

Can Cotton Producers Adopt Regenerative Agriculture Practices?

Multiple organizations have provided principles, outcomes, and/or practices of regenerative agriculture (RA) with the goal of encouraging farmers to adopt these RA practices. It is practices that are adopted by farmers. This document is designed to stimulate a discussion of RA practices and their feasibility for farms resourced at different levels and sizes.

The farming practices claimed to be RA are diverse, as are the global farms growing cotton. Twelve RA frameworks were identified, their practices categorized, and then counted to create a list of 25 common RA practices based on their inclusion in these frameworks.

Cover crops and tillage (reduced, minimum, no-till or zero-till) are the most frequent practices referenced in RA frameworks. The next most referenced practices are crop rotation, livestock grazing, and reduction in synthetic inputs (pesticides and fertilizers). All 25 practices were examined with regard to adoption feasibility and implications by 12 categories of farms representing the global diversity of size, water, mechanization, and livestock. Adoption feasibility is based on readily available technologies and equipment in 2024 and without external subsidies. Innovations on the horizon, such as small autonomous equipment, remote soil sensing, gene editing pest tolerance, and expanded RA subsidies, could lower barriers to adoption for all farm categories.

The chart on next page summaries whether specific practices are:

Very Feasible

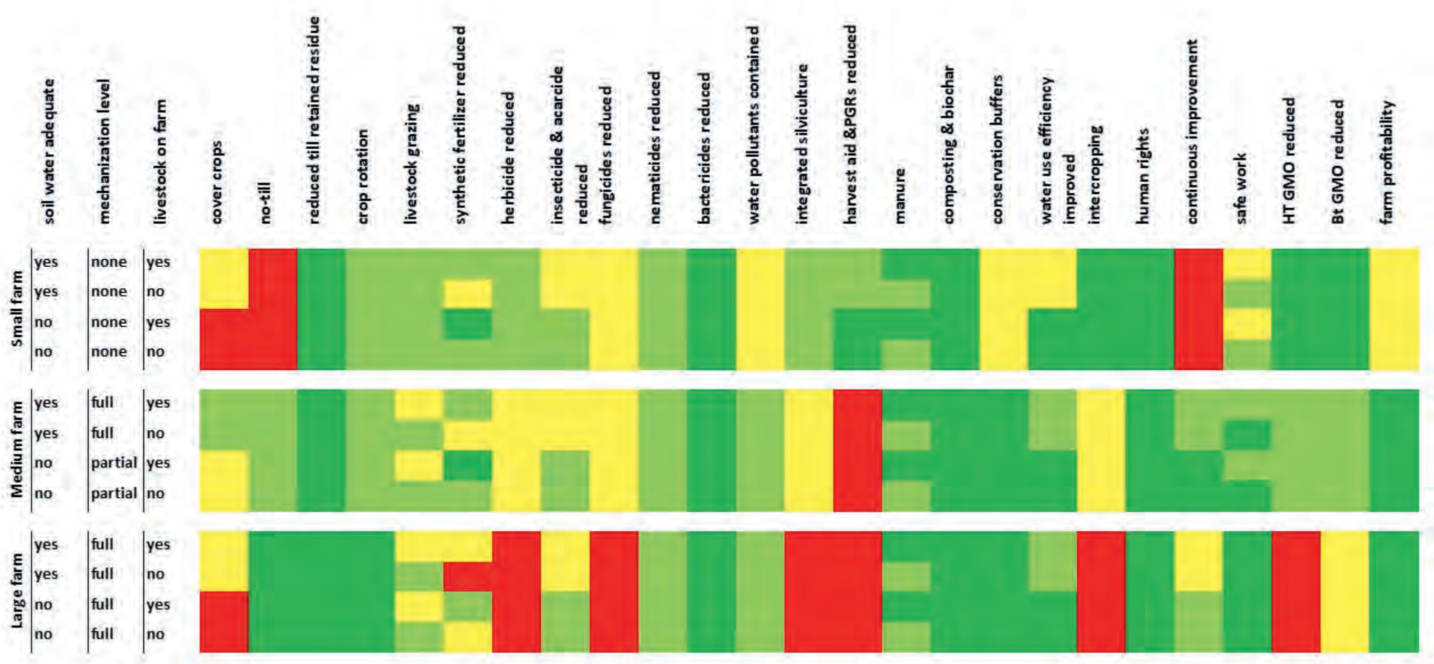
Feasible

Challenging

Very Challenging

From this chart it is apparent that most of the claimed RA practices are not uniformly feasible by all 12 farm categories. For example, only 6 of the 25 practices are considered feasible or very feasible for all 12 farm categories. On average, the practices are more feasible in medium size farms – those with 10 to 50 hectares of cotton per adult worker. Small farms rely on hand labor, which limits adoption of no-till, continuous improvement, and safe working environments. Large fully mechanized farms are more dependent on off-farm purchased inputs such as fertilizer and pesticides. Another dimension is the adequacy of soil water. Inadequate water limits the adoption of cover crops but enhances water use and tolerance to insects and diseases. Livestock also present tradeoffs, they produce manure but make worker safety more challenging.

Since many interactions exist between RA practices and farm categories, comprehension of the RA practices requires greater scrutiny which is provided over the following pages along with implications (benefits, risks, and needed changes). Risks include both recognized and some unintended adverse consequences. Based on this summary, many of the claimed RA practices can feasibly be adopted by the world's diverse cotton farms.



INTRODUCTION

Multiple organizations have provided principles, outcomes and/or practices of Regenerative Agriculture (RA) with the goal of encouraging farmers to adopt these RA practices. Although principles and outcomes convey direction, it is practices that are adopted by farmers - if feasible and economic on their own farms. This document is designed to stimulate a discussion around the feasibility of diverse RA practices by farms resourced at different levels and sizes. Guidance regarding the economic impact, farm business risk, or environmental outcomes of each RA practice is beyond the scope of this document.

Many organizations present RA practices that are intermingled with principles and outcomes. For example, addressing climate change is a principle; sequestering carbon in the soil is an outcome, and no-till is a practice that can, under certain conditions, sequester carbon and thus address climate change.

The farming practices claimed to be regenerative are diverse, as are the farms growing cotton globally. This document includes a wide range of claimed RA practices. The list of 25 RA practices were selected based on frequency of inclusion in 12 RA frameworks and listed in order of frequency.

Table 1. Practices Associated with Regenerative Agriculture Frameworks

"X" denotes inclusion as a practice by each RA framework.

		REGENERATIVE AGRICULTURE FRAMEWORKS													
	REGENERATIVE AGRICULTURE PRACTICES	1	2	3	4	5	6	7	8	9	10	11	12	13	COUNT
1	Cover Crops	X	X	X	X	X	X		X	X	X	X	X	X	12
2	No-Till Or Zero-Till	X	X	X	X	X		X	X	X		X	X		10
3	Reduced Tillage With Retained Residue	X	X	X		X		X		X	X	X	X	X	10
4	Crop Rotation	X	X	X			X	X			X	X	X	X	9
5	Livestock Grazing	X	X	X	X	X			X		X	X			8
6	Synthetic Fertilizer Reduced	X	X		X	X	X		X		X			X	8
7	Herbicides Reduced	X	X		X	X	X		X		X			X	8
8	Insecticides And Acaricides Reduced	X	X		X	X	X		X		X			X	8
9	Fungicides Reduced	X	X		X	X	X		X		X			X	8
10	Nematicides Reduced	X	X		X	X	X		X		X			X	8
11	Bactericides Reduced	X	X		X	X	X		X		X			X	8
12	Water Pollutants Contained		X	X	X	X	X				X	X		X	8
13	Integrated Silviculture		X		X	X	X				X	X			6
14	Plant Growth Regulators And Harvest Aids Reduce	X	X		X		X		X						5
15	Manure		X	X			X		X		X				5
16	Composting And Biochar	X	X		X		X				X				5
17	Conservation Buffers				X	X	X				X	X			5
18	Water Use Efficiency Improved		X			X	X				X	X		X	6
19	Intercropping	X	X				X				X				4
20	Human Rights					X	X	X			X				4
21	Continuous Improvement						X	X			X	X			4
22	Safe Work						X	X			X				3
23	Gmos With Herbicide Tolerance Reduced		X			X	X								3
24	Gmos With Insect Tolerance Reduced		X			X	X								3
25	Farm Profitability						X					X			2

These claimed Regenerative Ag (RA) Practices are not uniform across frameworks. Some such as “cover crops” and “no-till” are frequently mentioned. Others such as “safe work”, “GMOs” and “profitability” are rarely mentioned as RA practices. The following chart provides links to 12 different RA framework websites used to identify the 25 RA practices. The RA practice terminology was standardized in this document and thus does not match each framework precisely.

RA Framework	Web Sources
Science publication	https://doi.org/10.3390/su15032338
Science publication*	https://doi.org/10.3389/fsufs.2020.577723
Field-to-Market	https://fieldtomarket.org/defining-sustainability
NRDC	https://www.nrdc.org/stories/regenerative-agriculture-101?gad_source=1&gclid=CjwKCAiAp5qsBhAPEiwAP0qeJtHU82Cixg1OOzm2tOvmst80uRvOqM0omSWuZ0zJnPG0HbhJD1lYeRoCHpMQAvD_BwE#what-is
Textile Exchange	https://textileexchange.org/app/uploads/2023/07/Regen-Ag-Framework-Overview.pdf
AbTF	https://regenerative-cotton.org/wp-content/uploads/Regenerative_Cotton_Standard_0.0-1.pdf
Better Cotton	https://bettercotton.org/better-cotton-principles-and-criteria-how-the-revised-pc-informs-our-approach-to-regenerative-agriculture/
reNature	https://www.renature.co/what-is-regenerative-agriculture/
Cargill RegenConnect	https://www.cargill.com/2022/cargill-regenconnecttm-regeneratively-sourced-cotton-program-wo
RegenAgri	https://regenagri.org/wp-content/uploads/2024/01/regenagri-standard-criteria-v3.1-1.pdf
SAI Platform	https://saiplatform.org/regenerative-agriculture-programme/
Regrow	https://www.regrow.ag/

* Dimensions of Regenerative Agriculture. This publication reported the frequency of "Processes" in "Practitioner websites". Only those with 10% or higher were included here.

To allow a manageable feasibility assessment, 12 categories of farms were selected to represent the diversity of global cotton farms. Categories are based on farm size and resources: water adequacy, mechanization availability, and livestock presence on the farm. Three farm sizes (small, medium, and large) are quantified by the average number of cotton hectares managed from planting through harvest by one adult. This removes confusion regarding labor status (owner, family, full-time employee, seasonal employee, etc.). Not all factorial combinations of farm size and resources were considered. For example, large farms are considered fully mechanized. The 12 farm categories derive from the following six farm characteristics:

Small farms with less than 2 hectares of cotton per adult	**Medium farms with 10 to 50 hectares of cotton per adult**	**Large farms with greater than 200 hectares of cotton per adult**
Water supply greater than 100% cotton ET from irrigation, rain and soil storage	**Mechanization availability: none, partial, or full for planting, in-season through harvesting**	**Ruminant livestock (cattle, sheep, and goats) continuously being raised on the farm**

The feasibility of farmer adoption for the 12 farm categories was estimated for each of the 25 claimed regenerative practices to be either very feasible, feasible, challenging, or very challenging. This 12 by 25 matrix is color coded and presented in the table at the end of the document. Each of the 25 practices is covered in an Explanatory Section which details the claimed regenerative practice along with the implications (benefits, risks, and needed changes for greater adoption) of each practice. These explanatory sections provide most of the information conveyed in the document. Many of the 25 practices are synergistic and farmers adopt a set based on their region, farming operation, and their journey towards regenerative agriculture. Because of the synergy and connectedness between RA practices, references may be applicable to multiple sections.

REGEN AG PRACTICES

1 Cover Crops

Cover crops grow during the interval between cotton harvest and planting of the next season's crop and extend the coverage of soil with living plants year-round. If well-distributed annual moisture and heat units exceed cotton's needs, then native vegetation (often just winter weeds) can cover the ground after harvest. Native vegetation does not require technical training or off-farm inputs and provides benefits of live roots and soil covering. Alternatively, cover crops that are locally tested, adapted, and seed available can be planted either before cotton harvest or soon thereafter. Commonly planted cover crop species include: Barley *Hordeum vulgare*, Black Oats *Avena strigose*, Black Seeded Oats *Avena sativa*, Cereal *Rye Secale cereale*, Common Wheat *Triticum aestivum*, Cowpea *Vigna unguiculata*, Crimson Clover, *Trifolium incarnatum,* Daikon Radish *Raphanus sativus,* Faba Bean *Vicia faba*, Hairy Vetch *Vicia villosa*, Rapeseed *Brassica napus*, Red Clover *Trifolium pratense*, Serradella *Ornithopsus sativua*, Sunn Hemp *Crotalaria juncea* and Winter/Field Peas *Pisum sativum*[1].

BENEFITS

Cover crops provide multiple farm and off-farm benefits to their communities. Some of the intended on-farm benefits include earthworm population, erosion control, livestock forage[2,3], microbial population[4] including pathogen suppression, nutrient scavenger to avoid winter loss, nitrogen source[5], nutrient availability[6,7], organic matter addition[8,9], soil hydraulic properties[10,11] (infiltration, storage, release and losses), soil structure including compaction amelioration, soil temperature moderation, weed suppression[12,13]and yield[14,15]. Community benefits of cover crops include dust abatement, water pollution and turbidity minimization, flood water, siltation, carbon sequestration[16,17,18], weed herbicide resistance development[19], pollinator, and wildlife habitat. Although cover crops have been utilized for decades to address soil erosion[20], their widespread use is uncovering multiple benefits related to soil physical, biological and chemical health[21].

RISKS

Winter weeds used for cover can host overwintering insect pests and diseases (e.g. Henbit *Lamium amplexicaule*), inhibit cotton germination via allelopathy[22], soil cooling[23], and persist to compete with crops (e.g. Annual Ryegrass *Lolium multiflorum*). Cover crops also pose management challenges since some may be difficult to terminate without foliar herbicides or heavy roller crimpers or may release N_2O if immature at termination[24]. Native vegetation cover crops may reseed thus persisting to the detriment of future cropping decisions unless carefully designed. Where irrigation and rainfall are less than annual ET cotton, cover crops utilize some of the limited planting moisture which may decrease cotton stand establishment but is often compensated for with higher rainwater infiltration and reduced surface evaporation[25,26,27].

NEEDED CHANGES

To fully utilize cover crops requires local research to evaluate optimum species and cultivars[28], species mixtures, planting methods/timing[29], agronomy, termination methods/timing, and a local seed supply of cover crop seed uncontaminated with weed seeds. The requirements for successful management of cover crops make their adoption challenging in small farms unless the research, education, and seed access are all installed locally. Cover crops are feasible in medium sized farms with access to technology and off-farm inputs. Where each adult is responsible for many hectares (>200) there may be insufficient labor to plant and harvest (or terminate) both the cotton crop and the cover crop. Regardless of the farm size, cover crop adoption is more challenging where soil moisture (rain, storage, or irrigation) is insufficient for full cotton production. Improved long range weather forecasts along with tools to precisely monitor soil moisture and abruptly terminate the cover crop would mitigate some of the cover crop risk in low moisture environments by allowing growers to preserve necessary soil moisture in response to unanticipated winter drought.

2 No-Till

No-till or zero-till farming does not disturb the soil other than to place seed. The residue is retained on the soil surface. Weeds are not cultivated or hoed. No-till is very challenging to practice on small farms because of the difficulty of controlling weeds without disturbing the soil during cultivation or hand weeding. No-till farmers usually rely on herbicide weed control. Non-herbicidal, no-till is challenging since it requires long-term strategies to manage the existing weed seed bank and prevent introduced weed seeds or escape weeds. Examples of non-herbicidal, no-till weed control include high residue (>6 MT per hectare of Cereal *Rye Secale cereale*) cover crops [30] , weed suppressing rotational crops, solarization and summer flooding. Farms with greater than 200 hectares per adult have predominately shifted to herbicide weed control versus more labor-intensive cultivation and hand weeding. No-till complements this shift since one adult operating a large precision application ground sprayer can treat 200 hectares per day. Thus, labor savings have been a significant driver for both no-till adoption and the engineering of equipment capable of covering large hectares in one day.

BENEFITS

The driving benefits for no-till adoption are labor availability and production costs[31,32]. Farmers realize savings in capital, fuel, and labor by eliminating both primary tillage (moldboard plows, subsoils, rippers, etc.) and secondary tillage (disc plows, field cultivators, harrows, etc.). Much of these tillage operations were self-inflicting cycles: heavy equipment traffic on soils with poor physical structure leads to deep compaction that requires heavy primary tillage equipment to loosen the compacted soil[33]; mechanical cultivation to uproot weeds disturbs the soil, bringing new weed seeds to the surface where they germinate during the next rain and require more cultivation; seedbed preparation creates fine soil aggregates that are vulnerable to wind erosion and melting after a rain which then requires more tillage to roughen the soil surface and increase water infiltration.

Although the benefits of no-till (zero-till) often take 3 to 7 years to be fully realized on the farm[34], they allow farmers to break out of these vicious cycles: no-till fields are less vulnerable to deep compaction and any shallow compaction can be addressed by crop and cover crop roots; weeds seeds on the surface deteriorate more rapidly and deep placed seeds do not sprout[35,36]; no-till fields have residue on the surface that protects crops from wind erosion; undisturbed macropores left by earthworms [37], and decaying roots permit rapid water infiltration. Other benefits of no-till parallel those of cover crops and reduced tillage: surface residue stabilizes daily soil temperature range promoting root and fungal growth; no-till slows the oxidation of soil organic matter which promotes carbon sequestration [38,39]; soil organic matter promotes beneficial microbial populations [40] and nutrient retention in organic material [41]; cotton yields are higher especially under rainfed water-limited fields [42,43,44]; soil loss is curtailed [45]. The extent of benefits from no-till is still being explored [46].

RISKS

No-till introduces multiple crop production risks. Getting a stand in high residue (often cooler at planting) soils with a higher fungal pathogen spore load requires vigorous cotton planting seed, fungicide seed treatments, occasionally supplemental fungicides, no-till planters, and planter/planting expertise [47]. Stratification of immobile nutrients or toxicant from surface applied fertilizer [48], especially P and K [49], can restrict uptake when surface roots are inactive or organic matter buffering of toxicants is low [50]. The abrupt transition to no-till on farms without access to foliar selective herbicides poses additional risks of crop failure from perennial weed competition.

NEEDED CHANGES

The expansion of no-till on small farms requires either adoption of herbicides or non-mechanical weed control. Currently, selective foliar herbicides combined with soil residual herbicides are a cost-effective option to control weeds in no-till cotton without accelerating herbicide resistance in weeds. Laser weeders are commercially available for high value vegetable crops but are not economically feasible for cotton. Significant research and development are needed to find additional non-herbicidal weed control strategies for no-till farming. Controlled traffic is an important component of long-term no-till systems as mechanization is adopted [51,52].

3 Reduced till with surface residue retained

Reduced tillage is very feasible on small farms where crop residue is not removed because hand hoeing only disturbs the surface soil near the weed. Animal drawn field cultivators generally undercut weeds, leaving the subsoil intact and uncompacted with plant residue on the surface. Tillage equipment for medium to large, mechanized farms has been developed that creates a narrow seed bed planting zone leaving most of the plant residue on the surface. Even where subsoils become compacted or consolidated, strip till equipment can loosen the subsoil without burying plant residue.

BENEFITS

Reduced tillage offers similar yield[53,54,55,56,57,58], and surface soil benefits of no-till (zero-till) but without the full labor savings and soil benefits[59]. Surface residues protect the soil and crop from wind erosion, sun baking, surface evaporation, and soil aggregate breakdown from rain impacts. Surface residues improve infiltration rates, shade small-seeded weeds and slow plant decomposition which stabilizes the nutrient and carbon cycle to the benefit of the crop and soil microbes.

RISKS

Reduced tillage precludes sanitation (mixing of crop residue with soil) to destroy pathogen propagules (infectious spores). Depending on the pathogen and environment, reduced tillage may increase or decrease pathogen propagules[60]. Soil borne insects are more likely to damage seedling cotton in reduced till and no till cotton fields [61]. Crop rotation is a viable alternative to sanitation.

NEEDED CHANGES

Soil compaction sensing tools that allow limited resource farmers to determine if primary tillage is required to loosen consolidated root zone soils. Also needed is greater awareness of the long-term benefits from reduced tillage.

4 Crop Rotation

Crop rotation is common on small farms since family nutrition derives from crops other than cotton. The ability to sell their food and feed crops is dependent on the post-harvest infrastructure and markets. Crop rotation is also common in medium and large farms to diversity farm income and provide agronomic benefits[62] .

BENEFITS

Farmers of all sizes rotate crops to benefit the farm operation and individual crops[63]. The diverse markets for crops such as vegetables, fiber, forage[64],feed grains, and food grains result in independent income streams that do not rise and fall in tandem. Due to the diverse tolerances to pests and weather and the spread in planting dates, crop diversity further stabilizes income. Rotation enhances crop performance for both cotton[65,66] and its rotational crops[67]. For example, cotton suppresses soil borne diseases for peanuts[68] and cotton lowers the weed seed bank for subsequent vegetable crops where cultivation and herbicides are challenging[69] . Rotation is an effective tool to suppress pathogenic nematodes[70,71]. Legume and grain crops provide both residual nutrients[72] and weed suppression to subsequent cotton crops. Crop rotation in a field expands the soil microbial biodiversity benefiting pest management, plant nutrition and water availability.

RISKS

If farmers have experience with locally adapted rotational crops and their markets, risks are minimal for small, medium, and large farms. New crops pose uncertainty in pest management since insects and diseases can build unforeseen in a new crop and threaten cotton fields. For example, Whitefly *Bemisia* species build in harvested and abandoned cucurbit fields, then move to cotton[73], creating sticky cotton and transmitting viruses[74]. When adjacent host crops are harvested, Miridae (e.g. *Lygus* and *Creontiades* species) can move into cotton causing square injury[75]. Maize (corn) planted next to cotton can build insect pest populations that do not cause damage to the maize but devastate cotton fruit when they move out of drying maize into cotton[76,77] .




NEEDED CHANGES

Many rotational crops require post-harvest infrastructure and markets. Larger farms are less dependent on the existing post-harvest infrastructure and markets than smaller farms because they can individually or collectively install the necessary processing facilities and establish new markets. To enhance adoption by small and medium farms, greater investment in post-harvest infrastructure and markets is needed. With all size farms, experience with locally tested and well adapted rotational crops is critical to lower the agronomic risks. Expanded knowledge of whole farm IPM interactions between neighboring crops and rotational crops would minimize unintended adverse consequences and hopefully identify beneficial Integrated Pest Management (IPM) synergies between crops.

5 Livestock grazing

Optimal ruminant grazing patterns for Regenerative Agriculture follow managed grazing standards such as mob grazing or cell grazing which limit the grazing time and allow plant recovery after animal removal. These optimal practices require physical or virtual fencing. Failure to use optimal grazing patterns promotes unpalatable weed dominance and when high stocking rates are employed also degrade the soil. The ability to provide optimal grazing on farms without livestock depends on the availability of off-farm animals. RA grazing may be achieved at lower labor to the farmer with temporarily introduced animals since herd size can be matched to the field size. Short term grazing can improve plant recovery compared to long term stocking once the animals are removed [78,79].

BENEFITS

Cattle grazing on harvested cotton fields was a common practice to capture value from the seed cotton left in the field. Currently, livestock grazing of either cotton's rotational crops or cover crops is the dominant use of grazing in cotton. Soil benefits may exceed that of applied dry manure since fresh manure has a vibrant microflora, includes urine and is soil incorporated with trampling [80,81].

RISKS

Grazing a few draft or meat animals on a small farm poses few risks of environmental damage since they will likely graze non-crop areas. However, they pose a risk to irrigation and other farm infrastructures. For small farms, bringing nearby livestock to a farm poses a minimal risk of introducing exotic weed seeds since the livestock likely come from farms with similar weed species.

NEEDED CHANGES

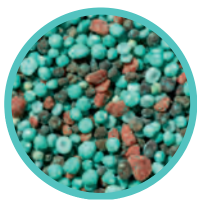
Research and education are needed to better understand seed viability of common weed species passing through grazing animal manure. On medium to large farms with livestock, grazing requires fencing to avoid degrading pastures or crops. Virtual fences offer a potentially valuable solution that can be managed by a smart phone and hopefully will decline in price [82,83]. Research is needed to understand the impacts to cotton of fresh manure and urine compared with the dry product sourced from off the farm.

6 Synthetic Fertilizer Reduced

Cotton can be produced without synthetic (manufactured) fertilizers if yield expectations match the nutrient supplying capacity of the soil[84,85]. After decades of removing plant material from a field in the harvested crop without replenishing nutrients, yield potential declines[86,87]. Non synthetic fertilizer nutrient sources include manure, legumes, cottonseed meal, rock phosphate, and wood ash[88]. Cotton can receive N without off farm inputs when grown following legumes or in areas with significant electrical storm activity which adds reactive N to the rainwater[89]. These two combined can contribute to the N removed in the seed of approximately 2 bales per hectare[90]. If all the cottonseed meal is returned to the field (not recommended) adequate soil nutrition can be sustained (calculated from[91]). Soil reserves are a source of P and K which are eventually depleted if not replenished with manure and rock phosphate (P), wood ash (K) or synthetic fertilizer (P and K). Cotton's nutritional needs are farm size independent. Whether the hectares managed per adult are small, medium, or large, a high cotton yield requires an adequate nutrient supply from the soil. Where yield expectations are severely limited by moisture availability, cotton's nutritional needs are lower. Natively fertile soils that have only recently been farmed can be sustained for more seasons without added nutrients than similar fields with irrigation. Soil and rotational crop residuals and manure are the most common nutrient sources where farmers do not use synthetic fertilizer.

BENEFITS
Prohibiting synthetic fertilizers reduces input costs without sacrificing yield where soils remain high in all required nutrients or organic nutrients are readily available at low costs. The primary benefits from limiting synthetic fertilizer are reduced costs, environmental contamination[92,93], greenhouse gas emissions associated with current N fertilizer manufacture, and meeting the requirements of a specific market.





RISKS

Relying solely on residual fertility contributes to a steady decline in yield potential while relying solely on manure poses nutrient imbalance risks that damage either the crop or environment. Nutrient content of manure varies widely based on its handling and storage. When farmers rely solely on manure for high yields of non-legume crop nutrition (such as cotton) environmental damage can occur from the excess P applied to meet N needs from manure[94] . Secondary risks of relying solely on manure derive from the logistics of transport, storing and spreading plus the slow N mineralization (release) which can lead to excess N during boll opening which stimulates vegetative growth during wet harvest seasons and causes insect and quality challenges. When soil available N remains high during boll opening, harvest preparation requires precise control of water supply such as with drip irrigation in desert environments or high rates of Harvest Aids.

NEEDED CHANGES

There is a substantial need for low cost and easy to use soil and plant nutrient testing tools for farmers to evaluate the nutritional status of their soils and crops. This need is especially critical when farmers adopt higher-yielding cultivars that partition more nutrients into fruit[95]. These tools need to be combined with farmer education about plant nutrition and nutrient management. Despite decades of fertilizer field trials in cotton, recent research shows that substantial improvements in fertilizer efficiency can still be achieved [96,97].

7 Herbicide Reduced

Access to herbicides is not essential for small hectare cotton farms which one adult can typically keep weed free during the critical first 6 to 8 week period after planting[98,99]. Mechanical cultivation can relieve some of this hand weeding time burden in medium size farms especially if skills and equipment allow close cultivation that covers or uproots in-row weeds. On large farms, access to herbicides is essential where the cotton hectares to labor ratio precludes even mechanical cultivation. Modern large ground sprayers can cover more than 50 hectares per hour compared with 10 hectares per hour for mechanical cultivation. Compounding the labor challenges of mechanical cultivation is their weekly or biweekly requirement if pernicious weeds are present or frequent rains germinate new weed flushes. This compares with herbicides which typically are applied in 2 to 5 applications per growing season. Thus, large hectare farms per adult rely on herbicides for weed control.

BENEFITS

Reducing herbicides saves input costs without sacrificing yield where soils are weed free and weed seed inputs from planting seed, equipment, manure, birds, water, and wind can be managed with isolation, cultivation, and/or hand weeding. The primary benefit from reducing herbicides is to meet the requirements of a specific market.

RISKS

Reduced use of herbicides carries multiple risks: Weed resistance to herbicides can be triggered by low rates of herbicides and/or single herbicide modes of action. Delaying herbicide application or hand weeding for 6 to 8-weeks after cotton planting allows severe weed competition that can reduce yields by 60%[100]. Delayed herbicide application later in the season allows weed growth that then requires higher herbicide rates or contributes to the weed seed bank in the soil. The elimination of herbicides and reliance on mechanical weed cultivation can lead to adverse consequences: reduced tillage cotton is challenging without herbicides[101,102], soil is readily compacted which reduces root density and depth when farm equipment traffics previously tilled soil near cotton plants[103], frequent rains after planting prevent cultivation and stimulate multiple weed flushes that may be difficult to control even for hand weeding. No-till cotton where the soil surface is not disturbed, except to place seed, is nearly impossible without herbicides[104].

NEEDED CHANGES
There is a substantial need for education regarding the use of herbicides in no-till and reduced-tillage agriculture and management practices that avoid weed resistance to herbicides[105]. Long term investment in novel weed control strategies is essential to avoid hand weeding costs[106] .

8 Insecticide and Acaracide Reduced

Unlike weeds, insects cannot be fully hand removed and thus the impact of reducing insecticides and acaracides is independent of farm size; small, medium, and large farms are equally impacted if insect pests exceed economic thresholds[107,108]. Insects rarely cut yields below 50% when season length is adequate because most insect pests are mobile selective feeders and their populations cycle out after depleting preferred food sources or due to expansion of biological pest control[109]. Host Plant Resistance (aka Native Traits) provides protection to specific insect pests; for example, hairy leaf cotton suppresses jassids *Amrasca* and *Empoasca*, and smooth leaf cotton limits Whitefly *Bemisia*[110]. Cultural control provides partial protection to insect pests; for example, short-season management minimizes late-season injury to Lepidopteran, Miridae, and Boll Weevil *Anthonomous grandis* feeding, and surface cereal residue at planting suppresses early-season injury from Thrips *Frankliniella* species[111]. Miridae are suppressed by surrounding cotton with natural areas that do not contribute to invasive insects[112]. However, high yielding cultivars with multiple Host Plant Resistances against all the insect pests damaging cotton in a region have not been commercialized on substantial acreage. Drought and low humidity that severely limits cotton yields also provide protection against most insect pests since their early life stages (eggs and neonates) are vulnerable to desiccation and intense sunlight[113,114,115]. However, some insect pests can still further reduce yield and delay harvest in dry, low humidity conditions (e.g., Thrips *Frankliniella* species)[116].

BENEFITS
Reducing insecticides and acaracides lowers human exposure and input costs without sacrificing yield where fields remain below economic thresholds for insect pests. Avoiding early broad-spectrum applications allows beneficial insects to accumulate in the field. Reducing insecticides and acaracides meets the requirements of specific markets.

RISKS

The negative impacts of limiting access to insecticides and acaracides are generally sporadic since cotton has a high tolerance to many insect pests which when exceeded can trigger an urgent need for pesticidal remediation. Managing cotton without access to insecticides and acaracides requires a tolerance for yield loss of 35% in dry climates that are favorable for organic cotton[117] and likely substantially more in wet less favorable climates. Since season long drought predictions are regional in scope and low in forecast precision, relying on drought/heat stress to control insect pests is risky. Unforeseen timely rains in droughted regions generally increase yield potential and allow farms to recover from previous low yield years. Thus, the inability to capture rain augmented yield benefits due to insect damage is economically harmful where farms rely on multiyear profitability to sustain operations.

NEEDED CHANGES

Since early Bt GMO traits have lost efficacy to some lepidopteran pests in some regions (e.g. Cry1Ac against Pink Bollworm in South Asia), additional Host Plant Resistance either from Native Traits or gene manipulation (editing or GMO) is urgently needed. Also needed is farmer expertise to anticipate the specific insect pests prior to seed selection supported by a professional seed industry to reliably test, identify, accurately advise farmers and deliver the seeds. With climate change, growers in historically low or high rainfall areas may need to adopt more proactive pest management strategies to protect from rainfall uncertainty.

9 Fungicide Reduced

Fungi are a global threat to crops[118]. Most soil borne fungi can be controlled with crop rotation and sanitation (tillage that fully incorporates previous crop residue)[119]. Some soil borne and air borne fungal pathogens of cotton can move long distances and infect cotton grown in fields that do not have a history of these pathogens. The fungal pathogens Areolate Mildew (*Ramulariopsis gossypii*)[120,121], Target Spot (*Corynespora cassicola*)[122] and Fusarium Wilt (*Fusarium oxysporum vas infectans*)[123] cannot be easily controlled with commercially available fungicides or with commercial Host Plant Resistant varieties in all regions where these pathogens occur. These three fungal pathogens can reduce cotton yields by more than 50%. Seedling fungal diseases can only be partially controlled with vigorous seed planted at optimum times and depths thus, non-access to seed treatment fungicides is challenging. Access to seed treatment fungicides is more critical in no-till fields on large farms, since surface residue can slow soil warming in the spring and significant time is often required to plant the greater hectarage per person.

BENEFITS

Prohibiting fungicides reduces input costs without sacrificing yield where fields are free of fungal pathogens. The primary benefit to prohibit fungicides is to meet the requirements of a specific market.

RISKS

The presence of foliar fungal pathogens upwind poses yield risk to cotton fields when fungicides are prohibited[124]. Since seed treatment pathogens are ubiquitous, not using seed treatment fungicides poses risk of stand failure if post planting weather is cold or wet[125]. Replanting cotton seed into fungal infected stands is challenging since soil inoculum can be elevated and the resulting crop is delayed.

NEEDED CHANGES

Local knowledge is required to avoid rotating cotton with crops that sustain pathogenic fungi. Since cotton tolerates skippy stands (low-density gaps), a high level of farm expertise is needed to carefully assess which parts of each damaged field need to be replanted, how to achieve a replant stand, and how best to manage either a late or a skippy cotton crop. A successful replant assessment incorporates many factors: anticipated season length and end of season biotic and abiotic risks, moisture supply, cultivar planted, cultivars available for replanting, subsequent cropping intentions, etc. Host Plant Resistance to seedling disease pathogens is needed [126].

10 Nematicides Reduced

Pathogenic nematodes (microscopic soil worms) of cotton are not known to be either seed borne or air borne and thus can be controlled with crop rotation[127] and Host Plant Resistance[128]. Different nematode pests have different host ranges (some to the cultivar level) and need specific Host Plant Resistance genes for control thus precise identification of the nematodes in a specific field is required. Some nematodes can be moved in soil or water so containment is required if nematodes are present in an area. For example, Reniform nematode *Rotylenchus reniformis* can be spread in dried soil on farm equipment. Nematodes can be successfully managed without nematicides on small, medium, and large farms if identified to species[129] and appropriate rotation and Host Plant Resistance is employed.

BENEFITS

Nematicides are expensive inputs and, other than fumigant nematicides, provide only partial control of Root Knot *Meloidogyne incognita* and Reniform *Rotylenchus reniformus* nematodes[130]. Reducing nematicide use on fields below economic thresholds for pathogenic nematodes saves input costs without sacrificing yield.

RISKS

Nematodes can reduce yield to near zero in heavily infested fields. Many commercially popular cultivars do not contain effective Host Plant Resistance against local nematodes resulting in yield loss in infested fields. Since nematode populations build over time, impact the roots, and are difficult to diagnose, removing prophylactic nematicide applications (seed treatment or in-furrow) can lead to unanticipated yield loss.

NEEDED CHANGES

Although Host Plant Resistance traits are available for some pathogenic nematodes, continual investment is needed to create nematocidal traits for all cotton damaging nematodes and to delay development of resistance to currently available traits[131]. Soil sampling and analysis for pathogenic nematodes requires field and laboratory expertise along with specialized equipment. This capability is not available to many low resource farmers.

11 Bactericides Reduced

Only one bacterial pathogen of cotton is widespread, *Xanthomonas citri pv. Malvacearum*, causal agent of Bacterial Blight of Cotton. This pathogen resides in the soil on plant debris and can be spread by contaminated seed[132] and splashing water. Host Plant Resistance to Bacterial Blight, not bactericides, are widely employed in commercial cultivars by small, medium, and large farms[133].

BENEFITS

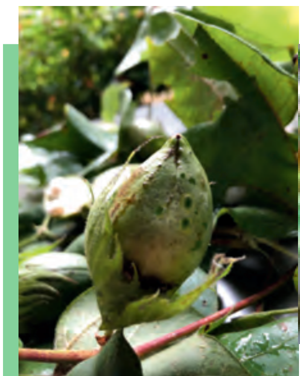
Other than broad spectrum biocides, fiber production fields do not currently utilize bactericides. Eliminating the use of bactericides in cotton production would save input costs without sacrificing yield if fields are planted to disease free resistant cultivars.

RISKS

Prohibiting access to bactericides during seed production could allow planting seed to be infected during the ginning and processing stages.

NEEDED CHANGES

Unless a continuous effort is made to incorporate Bacterial Blight Host Plant Resistance in new varieties, fields without a recent history of infestation may become infested. Investment in novel Host Plant Resistance for Bacterial Blight needs to be accelerated since a single trait is currently used on millions of acres and thus exposed to selection pressure for resistance breaking strains.




12 Water Pollutants Contained

Where nutrients and pesticides are applied, there is a need to contain them to the field. Movement of these expensive inputs off the field or below the root zone wastes valuable resources and can contaminate areas away from the field[134,135]. Surface and shallow subsoil water movement of nutrients to streams, rivers, lakes, and oceans is the predominant concern since N and P can lead to eutrophication and toxicity [136]. Another concern is the movement of nitrates and pesticides to ground water which once contaminated are difficult to remediate in situ[137] or process in water treatment facilities. When new land is brought into production it is easier to include water pollutant containment structures such as tail water return systems and holding ponds that address surface water movement. Land that has been farmed for multiple decades, especially when subdivided, presents greater challenges to retrofit with containment structures. Ground water contamination is also more challenging in smaller farming units since structures such as safe well heads and contained pesticide storage/mixing facilities require resources and engineering.

BENEFITS

The benefits of containing non-point agricultural water pollutants on farms are many. Non-point source pollution is more difficult to identify than point sources such as from factories or mines. Thus, proactive steps to contain farm pollutants are preferred instead of the monitoring, enforcement and abatement used with point-source pollution. In addition to the off-farm benefits from reducing water pollution, farmers realize on-farm profitability when purchased inputs (fertilizer, pesticides, amendments, manure) are not lost. Since hundreds and thousands of fields feed into common water bodies, just a few highly contaminating fields can go unnoticed until downstream levels are high enough to trigger an alert. Groundwater is even more challenging since monitoring is expensive and focused primarily on drinking water concerns at the point of delivery, not in the ground.

RISKS
Pollution containment structures are expensive to design and build. Other than these sizeable costs, risks are not identified.

NEEDED CHANGES
Substantial investments are needed in the design and management of pollutant containment systems for existing and small farms[138,139].

13 Integrated Silviculture

Like intercropping, the planting of trees in cotton fields is feasible when hand labor is adequate to manage and harvest trees, along with all the cotton operations. Silviculture is challenging in medium size farms (10-50 hectares per adult) due to the use of herbicides in cotton that can injure interplanted trees. Even in farms that use mechanical weed control instead of herbicides, growing trees interfere with cultivation equipment. Large farms would find silviculture very challenging due to the size of field equipment and the divergence between horticultural/silvicultural practices and cotton agronomy.

BENEFITS

Silviculture provides economic benefits and biological diversity similar to intercropping. When farmers are transitioning a field out of row crops, such as cotton, and into slow growing trees they can cultivate saplings until the trees interfere with the row crops. Low density silviculture may allow row crops and trees to coexist longer and gain nutritional benefits in nutrient depleted soils from symbiotic nitrogen fixing trees and recovery of deep nutrients from tree roots back to the surface via tree shoot biomass[140].

RISKS

When trees are small the risks of silviculture in cotton fields are similar to intercropping. However, trees continue to grow and compete with understory annual crops for sunlight and water. Eventually, the farmer will need to decide whether to convert the cotton field into managed forest or remove the trees. Mechanized cotton planting and harvesting will be prevented within 2 to 5 years after planting trees into a cotton field. Thus, silviculture for medium to large farms is a short-term practice.

NEEDED CHANGES

Expanded knowledge of the interactions between adjacent trees and cotton could identify biotic and abiotic benefits that might be exploited by farmers adopting integrated silviculture. Substantial mechanization research and development (likely with small autonomous equipment) would be required to extended silviculture into large farms.

14 Plant Growth Regulators & Harvest Aid Reduced

PGRs widely used in cotton slow the expansion of leaves, branches, and stems [141,142]. This plant canopy containment may have ancillary benefits in reducing boll rot [143], facilitating spray penetration into the canopy, machine harvesting, and managing the crop when excess nitrogen and/or water is unavoidable[144]. Harvest Aids facilitate machine harvest and can improve fiber quality if used in coordination with machine or labor availability for harvesting [145].

BENEFITS
Prohibiting PGR's reduces input costs without sacrificing yield and quality where fields are reliably short, water and nitrogen can be controlled precisely to manage plant height, or where rank growth is not deleterious. Prohibiting Harvest Aids reduces input costs without sacrificing yield and quality where hand harvesting predominates or in the rare fall environment with temperatures that reliably defoliate the crop. The primary benefit to prohibit PGR's and Harvest Aids is to meet the requirements of a specific market.

RISKS
Non access to PGRs and Harvest Aids is very challenging in large and mediums farms where harvest is fully mechanized[146].

NEEDED CHANGES
Innovative harvest machinery is needed that ideally can gather the crop without Harvest Aids.

15 Manure

On farms with livestock, the capture and spreading of manure is common and presents limited risks to small, medium, and large cotton farms when the manure provides only part of cotton's nutrition. Sourcing cattle manure from off-farm locations is expensive due to its low nutrient density and poses some risk from feedlot salts and weed seeds[147]. Poultry manure is more nutrient dense and thus more cost effective to transport, plus salt is not considered a risk with poultry manure. Since poultry manure is high in phosphate it complements nitrogen and potassium from other sources such as legumes, nitrogen and potassium fertilizers, and high potassium soils.

BENEFITS

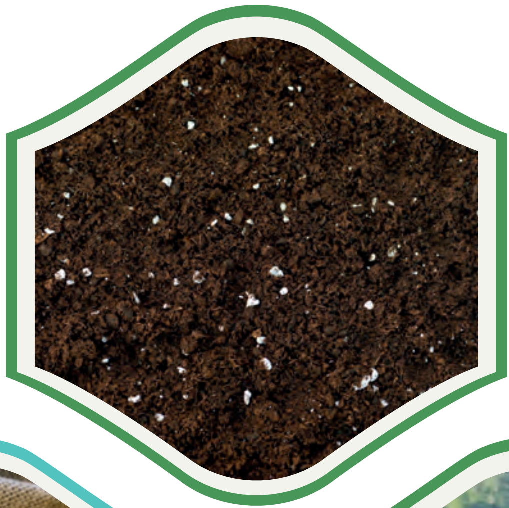
Prior to Haber Bosch production of reactive nitrogen from inert nitrogen gas, manure was the dominant source of nutrients to support crops by utilizing animals (birds, bats, and ruminants) to forage nutrients from non-cultivated areas in a manner that they could be accessed and applied to the farm. Manure provides essential plant nutrients but predominately P and N. Manure provides microbes that may be beneficial and in combination synergizes other soil amendments[148,149]. For cotton, manure is an excellent source of available P since single applications can meet multiyear crop needs. Poultry manure combined with minimum tillage improves both soil health and cotton yield[150]. When manure is applied judiciously to crops such as cotton it mitigates the environmental damage from excess N and P created in confined feeding operations. Combinations of manure and fertilizer can provide high yielding cotton nutrition programs [151,152,153,154].

RISKS

The major risk of surface applied manure is excess P which can move into nearby surface waters causing eutrophication. When manure is the sole long-term source for crop nutrition soil organic carbon stocks are at risk [155] and nitrogen deficiencies are evident [156]. Climate change risks include nitrous oxide emissions from excessive manure application [157].

NEEDED CHANGES

There is a need for greater awareness of the global and farm benefits from a balanced nutrient program along with availability of low cost and locally calibrated soil/plant tissue testing services.



16 Composting and Biochar

Composting organic material to retain nutrients while reducing pathogens requires more than piling up refuse for later application to fields. Ideally, the temperature, moisture, and aeration of the compost pile is manipulated with the addition of water and stirring to promote aerobic bacterial consumption of organic material which concentrates the nutrients and more recalcitrant organic molecules. The common sources of organic material composted on cotton farms are plant residue, gin waste, and manure. Biochar results from anaerobic composting at high temperature and provides benefits similar to aerobic composting but retains a higher fraction of the organic matter in recalcitrant molecules. Composting can be conducted on any size farm.

BENEFITS

Composting organic material creates a nutrient rich soil amendment that applied to the soil surface or soil incorporated will benefit most crops, including cotton. Compost that is incorporated into the soil supports carbon sequestration and nutrient retention, especially biochar. During the composting process, bacteria generate heat which reduces fungal pathogens levels and weed seed viability [158]. Composting of city organic waste is an opportunity to transfer nutrients to the farm and dispose of food waste. Multiyear biochar applications increase cotton yields, drought tolerance[159], soil physical characteristics[160], nutrient use efficiency[161], greenhouse gas mitigation [162,163], and can utilize agricultural waste products [164] .
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RISKS

Eradicating pathogens from compost [165] and gin waste is not feasible in farm settings, thus some spread of pathogens between farms can occur when applying composted gin waste. Excess moisture to run off on compost results in nutrient loss since they are now more available for both plant uptake and loss. The nutrient concentration of compost varies based on source material and composting methods which creates uncertainty in the seasonal fertility of cotton fields. Compared with synthetic fertilizers, compost releases nutrients slower which can lead to excess N late during boll opening aggravating late season pests and excess vegetation. Indiscriminate applications of products that cannot be removed once applied to a field, such as biochar, can lead to adverse impacts [166].

NEEDED CHANGES

Guidance on optimum blending and composting diverse organic material along with access to easy, low-cost tools that access nutrient density and temperature are needed. Funding is needed to establish city-to-farm linkages that recycle nutrients back to the farm. Research is needed to better understand and apply the impact of organic amendments on the complex soil biology [167,168].

17 Conservation Buffers

Conservation buffers are non-cropped and non-grazed areas in and around fields that help retain rainwater in the field[169,170,171]. Conservation buffers include grass waterways in natural drainage channels and grass buffers around fields. Perennial grasses are preferred in conservation buffers because they do not interfere with farm equipment and their growth is stimulated by N and P retaining these nutrients in roots and shoots. The retention benefit of conservation buffers is a function of their width[172]. Thus, a greater proportion of a small field will be removed from crop production than a larger field when surrounded by a conservation buffer.

BENEFITS

Conservation buffers around fields retard the movement of rainwater, soil, and dissolved chemicals (fertilizers, manure, and pesticides) allowing them to infiltrate into the buffer instead of flowing to sensitive habitats and water bodies. Grass waterways retard rill soil erosion. Grass buffers slow sheet soil erosion. With the intense rainfall triggered by climate change, these permanent buffers will be important in preventing downstream movement of water, soil, and dissolved chemicals. They can also mitigate climate change[173].

RISKS

Conservation buffers provide no harvested or grazed product yet occupy productive farmland and require planting and maintenance.

NEEDED CHANGES

Conservation Buffers are permanent structures designed by drainage and soil conservation engineers[174]. The selection of grass species and planting seed availability is critical to ensure success and avoid creating problems such as invasive weeds.

18 Water Use Efficiency Improved

Capturing more harvested cotton from the available water is the goal of Water Use Efficiency Improvement. This goal encompasses many metrics and practices depending on the irrigation infrastructure and water sources. Some of these practices include irrigation scheduling, water conveyance canals/pipes, on-farm water storage with return systems, and soil conditions that capture rainwater, reduce evaporation, and store water in the root zone. Where in-season soil water is inadequate RA practices improve the capture, storage, and delivery of rainwater to the crop and improve Water Use Efficiency. Where soil water is adequate, the harvested cotton to water ratio must be increased by either boosting yield or restricting water. The optimal design and management of irrigation systems require engineering expertise and infrastructure investment. For this reason, improving irrigated water efficiency is challenging in small, poorly resourced irrigated farms.

BENEFITS

Water is the most limiting input for global agriculture. Improving water use efficiency leads to more total agricultural output or beneficial water use elsewhere. For cotton farmers, water use efficiency reduces the chance of inadequate or excess applied water, both of which reduce yield and profit[175]. Where total water is limited improvements in water use efficiency allow focusing of this resource to the crop stage most responsive to water (early boll development)[176,177]. Since cotton is a highly drought tolerant crop with a near linear yield response to transpired water (evaporated out of the leaves) it allows high water use efficiencies over a broad range of water inputs. This adaptability derives from the cotton plant's ability to adjust its growth to the available water. Water supply uncertainty at planting is a common occurrence in rainfed agriculture or where irrigation relies on seasonal storage. Climate change exacerbates this uncertainty[178].

RISKS

Improving water use efficiency in cotton carries no risks to the local community, since both too much and too little water applied to cotton as rain or irrigation reduces yield. Excess water leaches nutrients, cools the plant and promotes disease and pests. Too little water reduces plant transpiration and yield. Salt accumulation in the root zone from lack of leaching is one field level risk of high water use efficiency. Downstream communities may be adversely impacted by high water use efficiency upstream if there water access is diminished.

NEEDED CHANGES

Substantial capital and training investments are needed in the design, installation, and management of efficient water delivery for small farms.

19 Intercropping

Intercropping (also called relay cropping since plants with different life stages are grow adjacent to cotton) has land use benefits and is feasible when hand labor is adequate to plant, weed, and harvest the alternative crops [179,180]. These are planted in the same row or in rows adjacent to cotton. The labor requirements make intercropping desirable in small farms with limited land resources, however as mechanization or land increases and hand labor supply relative to hectares declines intercropping becomes challenging. Intercropping will likely remain very challenging for large farms.

BENEFITS

Intercropping extends the diversity and duration that a field can grow a harvestable product. Intercropping also provides economic stability and soil biological diversity similar to crop rotation[181]. As with cover crops, plant diversity can have positive or negative impacts. For example, harvested small grains left standing in seedling cotton protects from wind and Thrips *Frankliniella* [182] and provides a resource for beneficial insects [183], while intercropped corn outcompetes cotton for sunlight, water, and nutrients.

RISKS

Intercropping poses some of the same risks as rotation in adjacent fields [184].

NEEDED CHANGES

Expanded knowledge of the interactions between adjacent crops could provide IPM benefits to cotton and could revive intercropping in the scale of previous trap cropping.

20 Human Rights

Human rights policies address worker health and safety, compensation and profitability, diversity, inclusion, and forced labor. Farms, individually and collectively, regardless of size, can develop and adopt locally appropriate human rights policies. This practice is not dependent on farm size, water availability, mechanization, or the presence of livestock.

BENEFITS
Beyond the basic benefits of human rights to those engaged in agriculture and downstream processing, proactive steps by the cotton industry to recognize and redress past human rights violations in both production and processing can improve our reputation with consumers[185] .

RISKS
The adoption of Human Rights Policies by farms has no apparent risks.

NEEDED CHANGES
Agricultural communication regarding basic human rights should be expanded along with guidance in establishing culturally relevant human rights policies for farms.

21 Continuous Improvement

As climate, agricultural technology, crop markets, and governmental policies evolve, profitable farmers continue to improve and adapt. Farmers willing to invest in continuous improvement will be able to access diverse innovations that will address many common objectives of RA [186]. Continuous improvement requires time away from day-to-day farm chores and thus is best achieved where mechanization reduces labor and hectarage per adult are moderate. The ability to allocate sufficient time for continuous improvement is low in farming units reliant on hand labor. On mechanized dryland farms, time for continuous improvement is greater than where irrigation water needs to be managed. In general, the more hectarage per adult the less time for continuous improvement.

BENEFITS
Broad static metrics have limited value in agriculture where each farm is different and at various stages of improvement. Continuous improvement with benchmarking, self-assessment, and educational tools allows farmers to expand expertise, profitability, and responsiveness to changing climate, pests, and markets.

RISKS
There are no apparent risks associated with farmers continually improving.

NEEDED CHANGES
There is a substantial need for farmer education and information tools that reaches farms of all sizes, farmers of all skills levels, and in their local languages and customs.

22 Safe Work

Agricultural workers are exposed to numerous physical and mental safety challenges. Close contact with livestock exposes workers to pathogens and physical harm. Pesticide applications, other than in fully enclosed and air filtered mixing-loading-application systems, present exposure risks. Long term stoop labor for planting and weeding has musculoskeletal impacts. Hand harvesting cotton is a repetitive motion that is abrasive on the skin[187]. Field work can lead to sun and heat exposure[188,189]. Farm work is solitary and stressful from the inability to control key components of success – weather, pests, and markets.

BENEFITS

Beyond the substantial human benefits of safe work, agriculture needs to attract young workers and sustain experienced workers[190]. A safe work environment is essential to attract new farmers to an agricultural life.

RISKS

There are no apparent risks associated with improving work safety.

NEEDED CHANGES

Since worker safety standards and their compliance are regional there is a need to share expertise gained in countries with more robust data collection with countries that lag in their reporting of worker safety incidents. Education regarding worker safety needs to be broadly and repeatedly disseminated. Mechanization of planting, tilling, weed control, and harvesting removes much of the physical safety challenges in agriculture associated with long term exposure to sun, heat, and stoop labor. Handling large animals and farm equipment presents the risk of accidents; which can be mitigated with safety protocols, training and compliance.

23 GMOs with Herbicide Tolerance Reduced

Currently available cotton GMOs include multiple Herbicide Tolerance (HT) traits providing crop tolerance to glyphosate, glufosinate, dicamba, and 2,4-D herbicides. Where these herbicides are not sprayed on cotton, the HT GMO traits provide a defensive value from herbicide use on other crops that drift onto cotton fields. This is a concern when grain and cotton are grown together as many grain herbicides severely damage cotton[191] especially when drift occurs around early bloom[192]. All herbicides paired with HT GMO cotton are effective without soil incorporation which makes them useful in no-till cotton fields. Where some weeds are susceptible to just one of the 4 paired herbicides their use on HT GMO cotton can greatly reduce the need for hand weeding, cultivation, and tillage that incorporates soil active herbicides. Non access to HT GMO cotton cultivars leads to one of three outcomes: a) farmers are dependent on hand weeding, b) cultivation is used to control weeds which degrades soil health, and/or 3) farmers develop the expertise and purchase the equipment to apply and incorporate pre-1997 herbicide regimens. Each of these 3 options becomes less viable as farm size increases.

BENEFITS

Restricting HT GMO seeds may reduce input costs in some markets without sacrificing yield where labor is abundant, or fields are weed free. Restricting HT GMO seeds also delays the development of weed resistance to the 4 paired herbicides by preventing their frequent use during the growing season and selection for invasive tolerant weeds[193]. This is especially true for highly efficacious broad-spectrum herbicides.

RISKS

Herbicides other than the 4 associated with HT GMO cotton can be used to create a viable weed control program that does not require hand weeding and frequent cultivation, since this was the status quo prior to 1997 in the Americas and Australia. However, the herbicide regime required machine operator expertise, weed science research, a tolerance for crop injury, and access to now discontinued herbicides. In some markets, non-access to GMO traited seeds limits access to the highest yielding germplasm since seed companies, in general, limit their commercialization to only traited cultivars[194].

NEEDED CHANGES

There is a need for education regarding the role of HT GMO herbicides in no-till and reduced-tillage agriculture and management practices that avoid weed resistance. Long term investment in novel weed control strategies is essential for productive agriculture[195,196].

24 GMOs with Insect Tolerance Reduced

Currently available cotton GMOs include multiple *Bacillus thuringiensis* protein expressing (Bt) GMO traits against worms, mirids and Thrips (Lepidopterans, Miridae and *Frankinellia*) pests. The Bt GMO traits provide value where some of their target pests remain susceptible to these Bt toxins and periodically damage non-Bt GMO cotton.

BENEFITS

Restricting access to Bt GMO seeds may reduce input costs in some regions if fields remain below economic thresholds for Bt targeted insect pests. When target pests develop resistance to the Bt trait, benefits are degraded and restricting access less onerous [197] .

RISKS

Non-access to current Bt GMO cotton traits in regions with susceptible target pests forces farmers to accept either of the following outcomes (a) cotton must be closely scouted and treated with insecticides based on locally researched and relevant IPM guidelines or (b) farmers must accept periodic cotton yield loss. As hectares per adult increases, adequate insect pest scouting becomes challenging. In some markets, non-access to GMO traited seeds limits access to the highest yielding germplasm since seed companies, in general, limit their commercialization to only traited cultivars [198].

NEEDED CHANGES

Long term investment in novel and regionally coordinated insect control strategies is essential for productive agriculture [199] .

25 Farm Profitability

Unlike salaried wage earners, farmers invest their labor with no stable return on investment. Only when field production coincides with market strength do farmers earn an income. Thus, farmers rely on these occasional profitable years to offset the many years when expenses exceed receipts. Since farms are complex businesses, successful farmers track and forecast expenses and receipts to avoid profitability surprises that could be mitigated with timely management. Key components to profitability are beyond a farmer's control: weather, markets, and invasive insects, weeds, and diseases. They control only the on-farm decisions such as crop management, capital investments and market timing. Unless farmers are profitable in the long run, they will fail, and the land will be idled or managed by a more efficient farmer.

BENEFITS

Farm profitability is essential to the supply of food, feed, and fiber that the world's population depends on. Reliable profitability allows farmers to make long term investments in irrigation, equipment, and farm practices that generally lead to further farm profitability and crop supply. RA practices generally improve profitability through increased soil health and yield [200,201], and lower capital equipment costs [202].

RISKS

There are no apparent risks associated with stable farm profitability. However, sharp rises in cotton prices lead to textile demand destruction, substitution with synthetic fibers, over planting and subsequent fiber price reduction [203].

NEEDED CHANGES

Closing productivity yield gaps (potential or research plot yields minus average farms yields in a locality) can substantially improve profitability since higher cotton yields may only require further expense in harvesting and ginning. Yield gap closure requires intensive research to ascertain the local causes of yield gaps along with extension and infrastructure to address these constraints[204] . Market access and potentially higher prices for farmers implementing RA practices, could promote further adoption of RA practices on an individual farm and to other farmers [205] .

FARMING UNIT CHARACTERISTICS

Farm size	soil water adequate for cotton	mechanization level	livestock on farm	#1 cover crops	#2 no-till	#3 reduced till retained residue	#4 crop rotation	#5 livestock grazing	#6 synthetic fertilizer reduced	#7 herbicide reduced	#8 insecticide & acaricide reduced	#9 fungicides reduced
Small (< 2 ha/person)	yes	none	yes	challenging	very challenging	very feasible	feasible	feasible	feasible	feasible	challenging	challenging
	yes	none	no	challenging	very challenging	very feasible	feasible	feasible	challenging	feasible	challenging	challenging
	no	none	yes	very challenging	very challenging	very feasible	feasible	feasible	very feasible	feasible	feasible	challenging
	no	none	no	very challenging	very challenging	very feasible	feasible	feasible	feasible	feasible	feasible	challenging
Medium (10-50 ha/person)	yes	full	yes	feasible	feasible	very feasible	feasible	challenging	challenging	challenging	challenging	challenging
	yes	full	no	feasible	feasible	very feasible	feasible	feasible	challenging	challenging	challenging	challenging
	no	partial, some hand weeding	yes	challenging	feasible	very feasible	feasible	challenging	very feasible	challenging	feasible	challenging
	no	partial, some hand weeding	no	challenging	feasible	very feasible	feasible	feasible	feasible	challenging	feasible	challenging
Large (≥ 200 ha/person)	yes	full	yes	challenging	very feasible	very feasible	very feasible	challenging	challenging	very challenging	challenging	very challenging
	yes	full	no	challenging	very feasible	very feasible	very feasible	feasible	very challenging	very challenging	challenging	very challenging
	no	full	yes	very challenging	very feasible	very feasible	very feasible	challenging	feasible	very challenging	feasible	very challenging
	no	full	no	very challenging	very feasible	very feasible	very feasible	feasible	challenging	very challenging	feasible	very challenging

FARMING UNIT CHARACTERISTICS

	soil water adequate for cotton	mechanization level	livestock on farm	#10 nematicides reduced	#11 bactericides reduced	#12 water pollutants contained	#13 integrated silviculture	#14 harvest aid &PGRs reduced	#15 manure	#16 composting & biochar	#17 conservation buffers	#18 water use efficiency improved
Small (< 2 ha/person)	yes	none	yes	feasible	very feasible	challenging	feasible	feasible	very feasible	very feasible	challenging	challenging
	yes	none	no	feasible	very feasible	challenging	feasible	feasible	feasible	very feasible	challenging	challenging
	no	none	yes	feasible	very feasible	challenging	feasible	very feasible	very feasible	very feasible	challenging	very feasible
	no	none	no	feasible	very feasible	challenging	feasible	very feasible	feasible	very feasible	challenging	very feasible
Medium (10-50 ha/person)	yes	full	yes	feasible	very feasible	feasible	challenging	very challenging	very feasible	very feasible	very feasible	feasible
	yes	full	no	feasible	very feasible	feasible	challenging	very challenging	feasible	very feasible	very feasible	feasible
	no	partial, some hand weeding	yes	feasible	very feasible	feasible	challenging	very challenging	very feasible	very feasible	very feasible	very feasible
	no	partial, some hand weeding	no	feasible	very feasible	feasible	challenging	very challenging	feasible	very feasible	very feasible	very feasible
Large (≥ 200 ha/person)	yes	full	yes	feasible	very feasible	feasible	very challenging	very challenging	very feasible	very feasible	very feasible	feasible
	yes	full	no	feasible	very feasible	feasible	very challenging	very challenging	feasible	very feasible	very feasible	feasible
	no	full	yes	feasible	very feasible	feasible	very challenging	very challenging	very feasible	very feasible	very feasible	very feasible
	no	full	no	feasible	very feasible	feasible	very challenging	very challenging	feasible	very feasible	very feasible	very feasible

FARMING UNIT CHARACTERISTICS

	soil water adequate for cotton	mechanization level	livestock on farm	#19 intercropping	#20 human rights	#21 continuous improvement	#22 safe work	#23 HT GMO reduced	#24 IT GMO prohibited	#25 farm profitability
Small (< 2 ha/person)	yes	none	yes	very feasible	very feasible	very challenging	challengin	very feasible	very feasible	challenging
	yes	none	no	very feasible	very feasible	very challenging	feasible	very feasible	very feasible	challenging
	no	none	yes	very feasible	very feasible	very challenging	challenging	very feasible	very feasible	challenging
	no	none	no	very feasible	very feasible	very challenging	feasible	very feasible	very feasible	challenging
Medium (10-50 ha/person)	yes	full	yes	challenging	very feasible	feasible	feasible	feasible	feasible	very feasible
	yes	full	no	challenging	very feasible	feasible	very feasible	feasible	feasible	very feasible
	no	partial, some hand weeding	yes	challenging	very feasible	very feasible	feasible	feasible	feasible	very feasible
	no	partial, some hand weeding	no	challenging	very feasible	very feasible	very feasible	feasible	feasible	very feasible
Large (≥ 200 ha/person)	yes	full	yes	very challenging	very feasible	challenging	very feasible	very challenging	challenging	very feasible
	yes	full	no	very challenging	very feasible	challenging	very feasible	very challenging	challenging	very feasible
	no	full	yes	very challenging	very feasible	feasible	very feasible	very challenging	challenging	very feasible
	no	full	no	very challenging	very feasible	feasible	very feasible	very challenging	challenging	very feasible

REFERENCES

[1] U.S. Department of Agriculture, Natural Resources Conservation Service. 2020. Plant Materials Technical Note no. 3: Evaluation of Cool Season Cover Crops in the Southeast Region. East National Technology Support Center, Greensboro, NC.
[2] Schomberg, H.H., Fisher, D.S., Reeves, D.W., Endale, D.M., Raper, R.L., Jayaratne, K.S.U., Gamble, G.R. and Jenkins, M.B., 2014. Grazing winter rye cover crop in a cotton no-till system: Yield and economics. Agronomy Journal, 106(3), pp.1041-1050.
[3] Santos, E.R., Dubeux Jr, J.C., Sollenberger, L.E., Mackowiak, C.L., Wright, D.L., Dilorenzo, N., Siqueira, M.C., Garcia, C.C., D. Queiroz, L.M., van Cleef, F.O. and Garcia, L., 2022. Grazing management effects on cover crop responses and cotton lint yield. Crop Science, 62(6), pp.2523-2536.
[4] Orrù, L., Canfora, L., Trinchera, A., Migliore, M., Pennelli, B., Marcucci, A., Farina, R. and Pinzari, F., 2021. How tillage and crop rotation change the distribution pattern of fungi. Frontiers in Microbiology, p.1469.
[5] Mitchell, C.C., Delaney, D.P. and 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), pp.1493-1498.
[6] Ye, R., Parajuli, B., Ducey, T.F., Novak, J.M., Bauer, P.J. and Szogi, A.A., 2020. Cover cropping increased phosphorus stocks in surface sandy Ultisols under long-term conservation and conventional tillage. Agronomy Journal, 112(4), pp.3163-3173.
[7] Adeli, A., Brooks, J.P., Read, J.J., Miles, D.M., Shankle, M.W. and Jenkins, J.N., 2021. Impact of cover crop on nutrient losses in an upland soil. Communications in Soil Science and Plant Analysis, 52(5), pp.536-550.
[8] Lewis, K.L., Burke, J.A., Keeling, W.S., McCallister, D.M., Delaune, P.B. and Keeling, J.W., 2018. Soil benefits and yield limitations of cover crop use in Texas High Plains cotton. Agronomy Journal, 110(4), pp.1616-1623.
[9] Sainju, U.M., Singh, B.P. and Yaffa, S., 2002. Soil organic matter and tomato yield following tillage, cover cropping, and nitrogen fertilization. Agronomy Journal, 94(3), pp.594-602.
[10] Adetunji, A.T., Ncube, B., Mulidzi, R. and Lewu, F.B., 2020. Management impact and benefit of cover crops on soil quality: A review. Soil and Tillage Research, 204, p.104717.
[11] Basche, A. and DeLonge, M., 2017. The impact of continuous living cover on soil hydrologic properties: A meta-analysis. Soil Science Society of America Journal, 81(5), pp.1179-1190.
[12] Price, A.J., Monks, C.D., Culpepper, A.S., Duzy, L.M., Kelton, J.A., Marshall, M.W., Steckel, L.E., Sosnoskie, L.M. and Nichols, R.L., 2016. High-residue cover crops alone or with strategic tillage to manage glyphosate-resistant Palmer amaranth (Amaranthus palmeri) in southeastern cotton (Gossypium hirsutum). Journal of Soil and Water Conservation, 71(1), pp.1-11.
[13] Toler, H.D., Augé, R.M., Benelli, V., Allen, F.L. and Ashworth, A.J., 2019. Global meta-analysis of cotton yield and weed suppression from cover crops. Crop Science, 59(3), pp.1248-1261.
[14] Decker, H.L., Gamble, A.V., Balkcom, K.S., Johnson, A.M. and Hull, N.R., 2022. Cover crop monocultures and mixtures affect soil health indicators and crop yield in the southeast United States. Soil Science Society of America Journal, 86(5), pp.1312-1326.
[15] Billman, E.D. and Campbell, B.T., 2023. Cover cropping history affects cotton boll distribution, lint yields, and fiber quality. Crop Science.
[16] Peng, Y., Rieke, E.L., Chahal, I., Norris, C.E., Janovicek, K., Mitchell, J.P., Roozeboom, K.L., Hayden, Z.D., Strock, J.S., Machado, S. and Sykes, V.R., 2023. Maximizing soil organic carbon stocks under cover cropping: insights from long-term agricultural experiments in North America. Agriculture, Ecosystems & Environment, 356, p.108599.
[17] Acharya, P., Ghimire, R. and Acosta-Martínez, V., 2024. Cover crop-mediated soil carbon storage and soil health in semi-arid irrigated cropping systems. Agriculture, Ecosystems & Environment, 361, p.108813.
[18] Vendig, I., Guzman, A., De La Cerda, G., Esquivel, K., Mayer, A.C., Ponisio, L. and Bowles, T.M., 2023. Quantifying direct yield benefits of soil carbon increases from cover cropping. Nature Sustainability, pp.1-10.

REFERENCES

[19] Hand, L.C., Randell, T.M., Nichols, R.L., Steckel, L.E., Basinger, N.T. and Culpepper, A.S., 2021. Cover crops and residual herbicides reduce selection pressure for Palmer amaranth resistance to dicamba-applied postemergence in cotton. Agronomy Journal, 113(6), pp.5373-5382.
[20] Rogers, T.H. and Giddens, J.E., 1957. Green manure and cover crops. Soil, the, pp.252-257.
[21] https://soilhealthinstitute.org/
[22] Shekoofa, A., Safikhan, S., Raper, T.B. and Butler, S.A., 2020. Allelopathic impacts of cover crop species and termination timing on cotton germination and seedling growth. Agronomy, 10(5), p.638.
[23] McNellis, R., van Gestel, N., Thomas, Q. and Smith, N.G., 2020, December. Winter cover cropping increases albedo and latent heat flux in the Texas High Plains. In AGU Fall Meeting Abstracts (Vol. 2020, pp. GC101-0016).
[24] Abalos, D., Rittl, T.F., Recous, S., Thiébeau, P., Topp, C.F., van Groenigen, K.J., Butterbach-Bahl, K., Thorman, R.E., Smith, K.E., Ahuja, I. and Olesen, J.E., 2022. Predicting field N2O emissions from crop residues based on their biochemical composition: A meta-analytical approach. Science of the Total Environment, 812, p.152532.
[25] Burke, J.A., Lewis, K.L., Ritchie, G.L., DeLaune, P.B., Keeling, J.W., Acosta-Martinez, V., Moore, J.M. and McLendon, T., 2021. Net positive soil water content following cover crops with no tillage in irrigated semi-arid cotton production. Soil and Tillage Research, 208, p.104869.
[26] Burke, J.A., Lewis, K.L., DeLaune, P.B., Cobos, C.J. and Keeling, J.W., 2022. Soil water dynamics and cotton production following cover crop use in a semi-arid ecoregion. Agronomy, 12(6), p.1306.
[27] Baumhardt, R.L., Schwartz, R., Howell, T., Evett, S.R. and Colaizzi, P., 2013. Residue management effects on water use and yield of deficit irrigated cotton. Agronomy journal, 105(4), pp.1026-1034.
[28] DeLaune, P.B., Mubvumba, P., Fan, Y. and Bevers, S., 2020. Agronomic and economic impacts of cover crops in Texas rolling plains cotton. Agrosystems, Geosciences & Environment, 3(1), p.e20027.
[29] Balkcom, K.S., Read, Q.D. and Gamble, A.V., 2023. Rye planting date impacts biomass production more than seeding rate and nitrogen fertilizer. Agronomy Journal, 115(5), pp.2351-2368.
[30] Camargo Silva, G. and Bagavathiannan, M., 2023. Mechanisms of weed suppression by cereal rye cover crop: A review. Agronomy Journal, 115(4), pp.1571-1585.
[31] Fan, Y., Liu, Y., DeLaune, P.B., Mubvumba, P., Park, S.C. and Bevers, S.J., 2020. Economic analysis of adopting no-till and cover crops in irrigated cotton production under risk. Agronomy Journal, 112(1), pp.395-405.
[32] Das, T.K., Bhattacharyya, R., Sudhishri, S., Sharma, A.R., Saharawat, Y.S., Bandyopadhyay, K.K., Sepat, S., Bana, R.S., Aggarwal, P., Sharma, R.K. and Bhatia, A., 2014. Conservation agriculture in an irrigated cotton–wheat system of the western Indo-Gangetic Plains: Crop and water productivity and economic profitability. Field Crops Research, 158, pp.24-33.
[33] Farmaha, B.S., Sekaran, U. and Franzluebbers, A.J., 2022. Cover cropping and conservation tillage improve soil health in the southeastern United States. Agronomy Journal, 114(1), pp.296-316.
[34] Grigar, J., Hatfield, J.L. and Reeder, R., 2018. Transitional no-till: What is it and how does it differ from 'true'no-till?. Crops & Soils, 51(6), pp.28-36.
[35] Cechin, J., Schmitz, M.F., Hencks, J.R., Vargas, A.A.M., Agostinetto, D. and Vargas, L., 2020. Burial depths favor Italian ryegrass persistence in the soil seed bank. Scientia agricola, 78, p.e20190078.
[36] Korres, N.E., Norsworthy, J.K., Young, B.G., Reynolds, D.B., Johnson, W.G., Conley, S.P., Smeda, R.J., Mueller, T.C., Spaunhorst, D.J., Gage, K.L. and Loux, M., 2018. Seedbank persistence of Palmer amaranth (Amaranthus palmeri) and waterhemp (Amaranthus tuberculatus) across diverse geographical regions in the United States. Weed Science, 66(4), pp.446-456.
[37] Fonte, S.J., Hsieh, M. and Mueller, N.D., 2023. Earthworms contribute significantly to global food production. Nature Communications, 14(1), p.5713.

REFERENCES

[38] JOSEPH, A., Bhattacharyya, R., Biswas, D.R., Das, T.K., Bandyopadhyay, K.K., DEY, A., Ghosh, A., Roy, P., NARESH KUMAR, S.O.O.R.A., Jat, S.L. and Casini, R., 2023. Long-term adoption of bed planted conservation agriculture based maize/cotton-wheat system enhances soil organic carbon stabilization within aggregates in the Indo-Gangetic Plains. Frontiers in Environmental Science, 11, p.1216242.

[39] Abreu, S.L., Godsey, C.B., Edwards, J.T. and Warren, J.G., 2011. Assessing carbon and nitrogen stocks of no-till systems in Oklahoma. Soil and Tillage Research, 117, pp.28-33.

[40] Acosta-Martinez, V., Cotton, J., Slaughter, L.C., Ghimire, R. and Roper, W., 2023. Soil health assessment to evaluate conservation practices in semiarid cotton systems at producer site scale. Soil Systems, 7(3), p.72.

[41] Jayaraman, S., Sinha, N.K., Mohanty, M., Hati, K.M., Chaudhary, R.S., Shukla, A.K., Shirale, A.O., Neenu, S., Naorem, A.K., Rashmi, I. and Biswas, A.K., 2021. Conservation tillage, residue management, and crop rotation effects on soil major and micro-nutrients in semi-arid Vertisols of India. Journal of Soil Science and Plant Nutrition, 21, pp.523-535.

[42] Pittelkow, C.M., Linquist, B.A., Lundy, M.E., Liang, X., Van Groenigen, K.J., Lee, J., Van Gestel, N., Six, J., Venterea, R.T. and Van Kessel, C., 2015. When does no-till yield more? A global meta-analysis. Field crops research, 183, pp.156-168.

[43] Bauer, P.J., Fortnum, B.A. and Frederick, J.R., 2010. Cotton responses to tillage and rotation during the turn of the century drought. Agronomy Journal, 102(4), pp.1145-1148.

[44] Burke, J.A., Lewis, K.L., Ritchie, G.L., DeLaune, P.B., Keeling, J.W., Acosta-Martinez, V., Moore, J.M. and McLendon, T., 2021. Net positive soil water content following cover crops with no tillage in irrigated semi-arid cotton production. Soil and Tillage Research, 208, p.104869.

[45] Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences, 104(33), pp.13268-13272.

[46] Vezzani, F.M., Anghinoni, I., Cherubin, M.R. and Mendes, I.C., 2024. Soil Health and Modern Brazilian Agriculture. Soil Health and Sustainable Agriculture in Brazil, 196, p.1.

[47] Wheeler, T.A., Gannaway, J.R., Kaufman, H.W., Dever, J.K., Mertley, J.C. and Keeling, J.W., 1997. Influence of tillage, seed quality, and fungicide seed treatments on cotton emergence and yield. Journal of production agriculture, 10(3), pp.394-400.

[48] Wright, A.L., Hons, F.M., Lemon, R.G., McFarland, M.L. and Nichols, R.L., 2007. Stratification of nutrients in soil for different tillage regimes and cotton rotations. Soil and Tillage Research, 96(1-2), pp.19-27.

[49] Ye, R., Parajuli, B., Ducey, T.F., Novak, J.M., Bauer, P.J. and Szogi, A.A., 2020. Cover cropping increased phosphorus stocks in surface sandy Ultisols under long-term conservation and conventional tillage. Agronomy Journal, 112(4), pp.3163-3173.

[50] Souza, J.L.B., Antonangelo, J.A., Zhang, H., Reed, V., Finch, B. and Arnall, B., 2023. Impact of long-term fertilization in no-till on the stratification of soil acidity and related parameters. Soil and Tillage Research, 228, p.105624.

[51] Khalilian, A., Jones, M.A., Bauer, P.J. and Marshall, M.W., 2017. Comparison of five tillage systems in coastal plain soils for cotton production. Open Journal of Soil Science, 7(10), pp.245-258.

[52] Blanco-Canqui, H., Claassen, M.M. and Stone, L.R., 2010. Controlled traffic impacts on physical and hydraulic properties in an intensively cropped no-till soil. Soil Science Society of America Journal, 74(6), pp.2142-2150.

[53] Ahmad, S., Hussain, I., Ghaffar, A., Rahman, M.H.U., Saleem, M.Z., Yonas, M.W., Hussnain, H., Ikram, R.M. and Arslan, M., 2022. Organic amendments and conservation tillage improve cotton productivity and soil health indices under arid climate. Scientific Reports, 12(1), p.14072.

[54] Khan, N.U., Khan, A.A., Goheer, M.A., Shafique, I., Hussain, S., Hussain, S., Javed, T., Naz, M., Shabbir, R., Raza, A. and Zulfiqar, F., 2021. Effect of zero and minimum tillage on cotton productivity and soil characteristics under different nitrogen application rates. Sustainability, 13(24), p.13753.

REFERENCES

[55] Sonune, B.A., Kharche, V.K., Gabhane, V.V., Jadhao, S.D., Mali, D.V., Katkar, R.N., Kadu, P.R., Konde, N.M., Deshmukh, D.P. and Goramnagar, H.B., 2021. Sustaining soil health and cotton productivity with tillage and integrated nutrient management in Vertisols of Central India. Indian Journal of Soil Conservation, 49(1), pp.1-11.
[56] Idowu, O.J., Sultana, S., Darapuneni, M., Beck, L., Steiner, R. and Omer, M., 2020. Tillage effects on cotton performance and soil quality in an irrigated arid cropping system. Agriculture, 10(11), p.531.
[57] Karamanos, A.J., Bilalis, D. and Sidiras, N., 2004. Effects of reduced tillage and fertilization practices on soil characteristics, plant water status, growth and yield of upland cotton. Journal of Agronomy and Crop Science, 190(4), pp.262-276.
[58] Joseph, A.M., Bhattacharyya, R., Das, T.K., Sharma, D.K., Roy, P. and Jat, S.L., 2023. Conservation agriculture impacts on soil carbon sequestration under a cotton (Gossypium hirsutum)-wheat (Triticum aestivum) system in the Indo-Gangetic plains. The Indian Journal of Agricultural Sciences, 93(8), pp.925-929.
[59] Nafi, E., Webber, H., Danso, I., Naab, J.B., Frei, M. and Gaiser, T., 2020. Interactive effects of conservation tillage, residue management, and nitrogen fertilizer application on soil properties under maize-cotton rotation system on highly weathered soils of West Africa. Soil and Tillage Research, 196, p.104473.
[60] Wheeler, T.A., Bordovsky, J.P., Keeling, J.W., Keeling, W. and McCallister, D., 2020. The effects of tillage system and irrigation on Verticillium wilt and cotton yield. Crop Protection, 137, p.105305.
[61] https://www.aces.edu/wp-content/uploads/2019/10/IPM-0415_Cotton2023_012523L-G.pdf
[62] Bennett, A.J., Bending, G.D., Chandler, D., Hilton, S. and Mills, P., 2012. Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations. Biological reviews, 87(1), pp.52-71.
[63] Sehgal, A., Singh, G., Quintana, N., Kaur, G., Ebelhar, W., Nelson, K.A. and Dhillon, J., 2023. Long-term crop rotation affects crop yield and economic returns in humid subtropical climate. Field Crops Research, 298, p.108952.
[64] Maltais-Landry, G., James, M., Wilson, C., Schumacher, L., Grabau, Z., Sidhu, S. and George, S., 2024. Long-term integration of bahiagrass into a cover-cropped and strip-tilled peanut–cotton rotation has a limited effect on soil carbon and other soil properties. Soil Science Society of America Journal, 88(1), pp.185-191.
[65] Praharaj, C.S. and Sankaranarayanan, K., 2015. Sustainability of cotton based crop rotations under long-term management of genotypes and integrated nutrient schedules in South Zonein India-A decadal study. Current Advances in Agricultural Sciences (An International Journal), 7(1), pp.1-10.
[66] Katsvairo, T.W., Wright, D.L., Marois, J.J., Hartzog, D.L., Balkcom, K.B., Wiatrak, P.P. and Rich, J.R., 2007. Performance of peanut and cotton in a bahiagrass cropping system. Agronomy journal, 99(5), pp.1245-1251.
[67] Khaitov, B. and Allanov, K., 2014. Crop rotation with no-till methods in cotton production of Uzbekistan. Eurasian Journal of Soil Science, 3(1), pp.28-32.
[68] Jordan, D.L., Barnes, J.S., Corbett, T., Bogle, C.R., Johnson, P.D., Shew, B.B., Koenning, S.R., Ye, W. and Brandenburg, R.L., 2008. Crop response to rotation and tillage in peanut-based cropping systems. Agronomy Journal, 100(6), pp.1580-1586.
[69] https://ipm.ucanr.edu/agriculture/tomato/
[70] Davis, R.F. and Kemerait, R.C., 2021. Integrated management of Meloidogyne incognita, the most economically damaging pathogen of cotton in the south-eastern United States. In Integrated Nematode Management: State-of-the-art and visions for the future (pp. 87-93). Wallingford UK: CABI.
[71] Stetina, S.R., Young, L.D., Pettigrew, W.T. and Bruns, H.A., 2007. Effect of corn-cotton rotations on reniform nematode populations and crop yield. Nematropica, pp.237-248.

REFERENCES

[72] Mitchell, C.C., Delaney, D.P. and 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), pp.1493-1498.

[73] Ellsworth, P.C. and Martinez-Carrillo, J.L., 2001. IPM for Bemisia tabaci: a case study from North America. Crop protection, 20(9), pp.853-869.

[74] Singh, J.A., Sohi, S., Brar, D.S., Denhdm, I., Russel, D. and Briddon, R., 1999. Management of cotton leaf curl virus disease in India. Proc. ICAC regional consultation insecticide resistance management in cotton. CCRI, Multan, pp.277-284.

[75] https://ipm.ucanr.edu/agriculture/cotton/

[76] Jackson, R.E., Allen, K.C., Snodgrass, G.L., Krutz, L.J., Gore, J., Perera, O.P., Price, L.D. and Mullen, R.M., 2014. Influence of maize and pigweed on tarnished plant bug (Hemiptera: Miridae) populations infesting cotton. Southwestern Entomologist, 39(3), pp.391-400.

[77] https://www.mississippi-crops.com/insect-control-guide/cotton-insect-management/

[78] Bartley, R., Abbott, B.N., Ghahramani, A., Ali, A., Kerr, R., Roth, C.H. and Kinsey-Henderson, A., 2023. Do regenerative grazing management practices improve vegetation and soil health in grazed rangelands? Preliminary insights from a space-for-time study in the Great Barrier Reef catchments, Australia. The Rangeland Journal, 44(4), pp.221-246.

[79] Mosier, S., Apfelbaum, S., Byck, P., Ippolito, J. and Cotrufo, M.F., 2022. Improvements in soil properties under adaptive multipaddock grazing relative to conventional grazing. Agronomy Journal, 114(4), pp.2584-2597.

[80] Döbert, T.F., Bork, E.W., Apfelbaum, S., Carlyle, C.N., Chang, S.X., Khatri-Chhetri, U., Sobrinho, L.S., Thompson, R. and Boyce, M.S., 2021. Adaptive multi-paddock grazing improves water infiltration in Canadian grassland soils. Geoderma, 401, p.115314.

[81] Teague, R. and Kreuter, U., 2020. Managing grazing to restore soil health, ecosystem function, and ecosystem services. Frontiers in Sustainable Food Systems, p.157.

[82] Campbell, D.L.M., Marini, D., Lea, J.M., Keshavarzi, H., Dyall, T.R. and Lee, C., 2021. The application of virtual fencing technology effectively herds cattle and sheep. Animal Production Science, 61(13), pp.1393-1402.

[83] Goliński, P., Sobolewska, P., Stefańska, B. and Golińska, B., 2022. Virtual Fencing Technology for Cattle Management in the Pasture Feeding System—A Review. Agriculture, 13(1), p.91.

[84] Mitchell, C.C., Delaney, D.P. and 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), pp.1493-1498.

[85] Singh, J., Gamble, A.V., Brown, S., Campbell, B.T., Jenkins, J., Koebernick, J., Bartley III, P.C. and Sanz-Saez, A., 2023. 65 years of cotton lint yield progress in the USA: Uncovering key influential yield components. Field Crops Research, 302, p.109058.

[86] Sanchez, P.A., 2015. En route to plentiful food production in Africa. Nature Plants, 1(1), pp.1-2.

[87] https://www.fao.org/global-soil-partnership/resources/highlights/detail/en/c/1601502/

[88] Crystal-Ornelas, R., Thapa, R. and Tully, K.L., 2021. Soil organic carbon is affected by organic amendments, conservation tillage, and cover cropping in organic farming systems: A meta-analysis. Agriculture, Ecosystems & Environment, 312, p.107356.

[89] Keresztesi, Á., Nita, I.A., Boga, R., Birsan, M.V., Bodor, Z. and Szép, R., 2020. Spatial and long-term analysis of rainwater chemistry over the conterminous United States. Environmental research, 188, p.109872.

[90] Pabuayon, I.L.B., Lewis, K.L. and Ritchie, G.L., 2020. Dry matter and nutrient partitioning changes for the past 30 years of cotton production. Agronomy Journal, 112(5), pp.4373-4385.

[91] Main, C.L., Barber, L.T., Boman, R.K., Chapman, K., Dodds, D.M., Duncan, S., Edmisten, K.L., Horn, P., Jones, M.A., Morgan, G.D. and Norton, E.R., 2013. Effects of nitrogen and planting seed size on cotton growth, development, and yield. Agronomy Journal, 105(6), pp.1853-1859.

[92] Maggi, F., Tang, F.H. and Tubiello, F.N., 2023. Agricultural pesticide land budget and river discharge to oceans. Nature, 620(7976), pp.1013-1017.

REFERENCES

[93] Schulte-Uebbing, L.F., Beusen, A.H.W., Bouwman, A.F. and De Vries, W., 2022. From planetary to regional boundaries for agricultural nitrogen pollution. Nature, 610(7932), pp.507-512.
[94] Zangarini, S., Pepè Sciarria, T., Tambone, F. and Adani, F., 2020. Phosphorus removal from livestock effluents: recent technologies and new perspectives on low-cost strategies. Environmental Science and Pollution Research, 27, pp.5730-5743.
[95] Lewis, K., Morgan, G., Frame, W.H., Fromme, D., Dodds, D.M., Edmisten, K.L., Robertson, B., Boman, R., Cutts, T., Delaney, D.P. and Burke, J.A., 2021. Cotton yield response to soil applied potassium across the US Cotton Belt. Agronomy Journal, 113(4), pp.3600-3614.
[96] Scheer, C., Rowlings, D.W., Antille, D.L., De Antoni Migliorati, M., Fuchs, K. and Grace, P.R., 2023. Improving nitrogen use efficiency in irrigated cotton production. Nutrient Cycling in Agroecosystems, 125(2), pp.95-106.
[97] Sažinas, R., Li, K., Andersen, S.Z., Saccoccio, M., Li, S., Pedersen, J.B., Kibsgaard, J., Vesborg, P.C., Chakraborty, D. and Chorkendorff, I., 2022. Oxygen-enhanced chemical stability of lithium-mediated electrochemical ammonia synthesis. The Journal of Physical Chemistry Letters, 13(20), pp.4605-4611.
[98] Douti, P.Y., Djagni, K. and Jallas, E., 1997. Cotton crops versus weeds: when is the competition period?.
[99] Buchanan, G.A. and Burns, E.R., 1970. Influence of weed competition on cotton. Weed Science, 18(1), pp.149-154.
[100] Bukun, B., 2004. Critical periods for weed control in cotton in Turkey. Weed Research, 44(5), pp.404-412.
[101] Chauhan, B.S., Singh, R.G. and Mahajan, G., 2012. Ecology and management of weeds under conservation agriculture: a review. Crop Protection, 38, pp.57-65.
[102] Sivakumar, K., Babu, R., Venkataraman, N.S., Kumutha, K. and Thiyageshwari, S., 2021. Effects of conservation agricultural practices on soil microbial population and yield of cotton.
[103] Jamali, H., Nachimuthu, G., Palmer, B., Hodgson, D., Hundt, A., Nunn, C. and Braunack, M., 2021. Soil compaction in a new light: Know the cost of doing nothing–A cotton case study. Soil and Tillage Research, 213, p.105158.
[104] Colbach, N. and Cordeau, S., 2022. Are no-till herbicide-free systems possible? A simulation study. Frontiers in Agronomy, 4, p.823069.
[105] Norsworthy, J.K., Ward, S.M., Shaw, D.R., Llewellyn, R.S., Nichols, R.L., Webster, T.M., Bradley, K.W., Frisvold, G., Powles, S.B., Burgos, N.R. and Witt, W.W., 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed science, 60(SP1), pp.31-62.
[106] Norsworthy, J.K., Green, J.K., Barber, T., Roberts, T.L. and Walsh, M.J., 2020. Seed destruction of weeds in southern US crops using heat and narrow-windrow burning. Weed Technology, 34(4), pp.589-596.
[107] Rosenheim, J.A., Cluff, E., Lippey, M.K., Cass, B.N., Paredes, D., Parsa, S., Karp, D.S. and Chaplin-Kramer, R., 2022. Increasing crop field size does not consistently exacerbate insect pest problems. Proceedings of the National Academy of Sciences, 119(37), p.e2208813119.
[108] Kennedy, G.G. and Huseth, A.S., 2022. Pest species respond differently to farm field size. Proceedings of the National Academy of Sciences, 119(39), p.e2214082119.
[109] Bordini, I., Ellsworth, P.C., Naranjo, S.E. and Fournier, A., 2021. Novel insecticides and generalist predators support conservation biological control in cotton. Biological Control, 154, p.104502.
[110] Frisbie, R.E., El-Zik, K.M. and Wilson, L.T. eds., 1989. Integrated pest management systems and cotton production (pp. xvi+-437).
[111] Manley, D.G., DuRant, J.A., Bauer, P.J. and Frederick, J.R., 2002. Rye cover crop, surface tillage, crop rotation, and soil insecticide impact on thrips numbers in cotton in the southeastern coastal plain.

REFERENCES

[112] Gagic, V., Holding, M., Venables, W.N., Hulthen, A.D. and Schellhorn, N.A., 2021. Better outcomes for pest pressure, insecticide use, and yield in less intensive agricultural landscapes. Proceedings of the National Academy of Sciences, 118(12), p.e2018100118.

[113] Fye, R.E. and Surber, D.E., 1971. Effects of several temperature and humidity regimens on eggs of six species of lepidopterous pests of cotton in Arizona. Journal of Economic Entomology, 64(5), pp.1138-1142.

[114] Tellez, I., 2022. Resistance to Bacillus thuringiensis Cotton and a Possible Alternate Control for Helicoverpa zea in Okra-Leaf Cotton (Doctoral dissertation, New Mexico State University).

[115] Fisher, J.J., Rijal, J.P. and Zalom, F.G., 2021. Temperature and humidity interact to influence brown marmorated stink bug (Hemiptera: Pentatomidae), survival. Environmental Entomology, 50(2), pp.390-398.

[116] https://extensionentomology.tamu.edu/wp-content/uploads/2018/03/ENTO075.pdf

[117] Swezey, S.L., Goldman, P., Bryer, J. and Nieto, D., 2007. Six-year comparison between organic, IPM and conventional cotton production systems in the Northern San Joaquin Valley, California. Renewable Agriculture and Food Systems, 22(1), pp.30-40.

[118] Stukenbrock, E. and Gurr, S., 2023. Address the growing urgency of fungal disease in crops. Nature, 617(7959), pp.31-34.

[119] Hillocks, R.J. 1992. Seedling diseases in R. J. Hillocks (ed) Cotton Diseases. CAB International, Wallingford. Pp. 1-38.

[120] da Silva, J.C., Bettiol, W. and Suassuna, N.D., 2019. Ramularia leaf spot: an emergent disease of cotton in Brazil. Tropical Plant Pathology, 44, pp.473-482.

[121] Silva, A.S.D., Renno, M.H.L., Quitania, A.C.R., Café Filho, A.C., Miller, R.N., Araújo, A.E.D. and Pinho, D.B., 2023. Ramularia leaf spot: PCR based methods reveal widespread distribution of Ramulariopsis pseudoglycines and limited presence of R. gossypii in Brazil.

[122] Mehl, H.L., Dufault, N.S., Allen, T.W., Hagan, A.K., Price, P., Kemerait, R.C., Kelly, H., Mulvaney, M.J. and Nichols, R.L., 2020. Multiyear regional evaluation of foliar fungicide applications for cotton target spot management in the Southeastern United States. Plant disease, 104(2), pp.438-447.

[123] Doan, H.K. and Davis, R.M., 2015. Efficacy of seed treatments on viability of Fusarium oxysporum f. sp. vasinfectum race 4 in infected cotton seed. Crop Protection, 78, pp.178-184.

[124] Van der Heyden, H., Dutilleul, P., Charron, J.B., Bilodeau, G.J. and Carisse, O., 2021. Monitoring airborne inoculum for improved plant disease management. A review. Agronomy for Sustainable Development, 41(3), p.40.

[125] Rothrock, C.S., Winters, S.A., Miller, P.K., Gbur, E., Verhalen, L.M., Greenhagen, B.E., Isakeit, T.S., Batson Jr, W.E., Bourland, F.M., Colyer, P.D. and Wheeler, T.A., 2012. Importance of fungicide seed treatment and environment on seedling diseases of cotton. Plant disease, 96(12), pp.1805-1817.

[126] Suassuna, N.D., Morello, C.D.L., Silva Filho, J.L.D., Pedrosa, M.B., Perina, F.J., Magalhães, F.O.D.C., Sofiatti, V. and Lamas, F.M., 2020. BRS 372 and BRS 416: high-yielding cotton cultivars with multiple disease resistance. Crop Breeding and Applied Biotechnology, 20.

[127] Stetina, S.R., Young, L.D., Pettigrew, W.T. and Bruns, H.A., 2007. Effect of corn-cotton rotations on reniform nematode populations and crop yield. Nematropica, pp.237-248.

[128] McCarty Jr, J.C., Jenkins, J.N., Wubben, M.J., Hayes, R.W., Callahan, F.E. and Deng, D., 2017. Registration of six germplasm lines of cotton with resistance to the root-knot and reniform nematodes. Journal of Plant Registrations, 11(2), pp.168-171.

[129] Faske, T.R., Kandel, Y., Allen, T.W., Grabau, Z.J., Hu, J., Kemerait, R.C., Lawrence, G.W., Lawrence, K.S., Mehl, H.L., Overstreet, C. and Thiessen, L.D., 2022. Meta-analysis of the field efficacy of seed-and soil-applied nematicides on Meloidogyne incognita and Rotylenchulus reniformis across the US cotton belt. Plant Disease, 106(8), pp.2228-2238.

[130] Davis, R.F. and Kemerait, R.C., 2021. Integrated management of Meloidogyne incognita, the most economically damaging pathogen of cotton in the south-eastern United States. In Integrated Nematode Management: State-of-the-art and visions for the future (pp. 87-93). Wallingford UK: CABI.

REFERENCES

[131] Nolan, R., Lege, K., Fuchs, S., and McCulloch, M. 2024. Sequence of crop species and genetic resistance to manage reniform nematode in cotton. 2024 Proceedings of the Beltwide Cotton Conferences.

[132] Mijatović, J., Severns, P.M., Kemerait, R.C., Walcott, R.R. and Kvitko, B.H., 2021. Patterns of seed-to-seedling transmission of Xanthomonas citri pv. malvacearum, the causal agent of cotton bacterial blight. Phytopathology®, 111(12), pp.2176-2184.

[133] Zhang, J., Bourland, F., Wheeler, T. and Wallace, T., 2020. Bacterial blight resistance in cotton: genetic basis and molecular mapping. Euphytica, 216, pp.1-19.

[134] Maggi, F., Tang, F.H. and Tubiello, F.N., 2023. Agricultural pesticide land budget and river discharge to oceans. Nature, 620(7976), pp.1013-1017.

[135] Downing, J.A., Polasky, S., Olmstead, S.M. and Newbold, S.C., 2021. Protecting local water quality has global benefits. Nature communications, 12(1), p.2709.

[136] Paerl, H.W. and Huisman, J., 2009. Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. Environmental microbiology reports, 1(1), pp.27-37.

[137] Zhao, B., Sun, Z. and Liu, Y., 2022. An overview of in-situ remediation for nitrate in groundwater. Science of The Total Environment, 804, p.149981.

[138] Morillo, E. and Villaverde, J., 2017. Advanced technologies for the remediation of pesticide-contaminated soils. Science of the Total Environment, 586, pp.576-597.

[139] Raffa, C.M. and Chiampo, F., 2021. Bioremediation of agricultural soils polluted with pesticides: A review. Bioengineering, 8(7), p.92.

[140] Sanchez, P.A., Buresh, R.J. and Leakey, R.R., 1997. Trees, soils, and food security. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 352(1356), pp.949-961.

[141] Kerby, T.A., Hake, K. and Keeley, M., 1986. Cotton Fruiting Modification with Mepiquat Chloride 1. Agronomy Journal, 78(5), pp.907-913.

[142] Liao, B., Ren, X., Du, M., Eneji, A.E., Tian, X. and Li, Z., 2021. Multiple applications of mepiquat chloride enhanced development of plant-wide fruits from square initiation to boll opening in cotton. Crop Science, 61(4), pp.2733-2744.

[143] Chambers, A.Y. and McCutchen, T.C., 1977. Use of BAS 083 growth regulator in cotton boll rot control. In Proc. Beltwide Cotton Production Res. Conf., Atlanta, Ga. to-12 Jan (pp. 28-29).

[144] Dodds, D.M., Banks, J.C., Barber, L.T., Boman, R.K., Brown, S.M., Edmisten, K.L., Faircloth, J.C., Jones, M.A., Lemon, R.G., Main, C.L. and Monks, C.D., 2010. Beltwide evaluation of commercially available plant growth regulators. Journal of Cotton Science, 14(3), pp.119-130.

[145] Singh, K., Rathore, P. and Gumber, R.K., 2015. Impact of harvest-aid defoliants on yield of American cotton and their monetary evaluation. Int. J. Plant Sci, 28, pp.41-46.

[146] Gwathmey, C.O. and Hayes, R.M., 1997. Harvest-aid interactions under different temperature regimes in field-grown cotton. J. Cotton Sci, 1, pp.1-28.

[147] Pleasant, J.M. and Schlather, K.J., 1994. Incidence of weed seed in cow (Bos sp.) manure and its importance as a weed source for cropland. Weed technology, 8(2), pp.304-310.

[148] Adeli, A., Brooks, J.P., Miles, D., Mlsna, T., Quentin, R. and Jenkins, J.N., 2023. Effectiveness of Combined Biochar and Lignite with Poultry Litter on Soil Carbon Sequestration and Soil Health. Open Journal of Soil Science, 13(2), pp.124-149.

[149] Adeli, A., Brooks, J.P., Miles, D., Misna, T., Feng, G. and Jenkins, J.N., 2022. Combined effects of organic amendments and fertilization on cotton growth and yield. Agronomy Journal, 114(6), pp.3445-3456.

[150] Sonune, B.A., Kharche, V.K., Gabhane, V.V., Jadhao, S.D., Mali, D.V., Katkar, R.N., Kadu, P.R., Konde, N.M., Deshmukh, D.P. and Goramnagar, H.B., 2021. Sustaining soil health and cotton productivity with tillage and integrated nutrient management in Vertisols of Central India. Indian Journal of Soil Conservation, 49(1), pp.1-11.

REFERENCES

[151] Franzluebbers, A.J., 2021. Soil health conditions under cotton production in North Carolina. Agronomy Journal, 113(2), pp.2132-2149
[152] Chen, X., Xi, K., Yang, Z., Lu, J., Zhang, Q., Wang, B., Wang, K. and Shi, J., 2023. Long-term increases in continuous cotton yield and soil fertility following the application of cotton straw and organic manure. Agronomy, 13(8), p.2133.
[153] Iqbal, S., Luqman, M., Nasrullah, H.M., Ullah, A. and Akram, H.M., 2020. Response of cotton to application of organic and inorganic source of nutrients in semi-arid climate. Sarhad Journal of Agriculture, 36(3), pp.929-938.
[154] Blaise, D., Singh, J.V., Venugopalan, M.V. and et al., 2003. Effect of continuous application of manures and fertilizers on productivity of cotton-sorghum rotation. Acta agronomica hungarica, 51(1), pp.61-67.
[155] Gaudaré, U., Kuhnert, M., Smith, P., Martin, M., Barbieri, P., Pellerin, S. and Nesme, T., 2023. Soil organic carbon stocks potentially at risk of decline with organic farming expansion. Nature Climate Change, 13(7), pp.719-725.
[156] Barbieri, P., Pellerin, S., Seufert, V., Smith, L., Ramankutty, N. and Nesme, T., 2021. Global option space for organic agriculture is delimited by nitrogen availability. Nature Food, 2(5), pp.363-372.
[157] Shakoor, A., Shahzad, S.M., Chatterjee, N., Arif, M.S., Farooq, T.H., Altaf, M.M., Tufail, M.A., Dar, A.A. and Mehmood, T., 2021. Nitrous oxide emission from agricultural soils: Application of animal manure or biochar? A global meta-analysis. Journal of Environmental Management, 285, p.112170.
[158] Liu, T., Wang, M., Awasthi, M.K., Chen, H., Awasthi, S.K., Duan, Y. and Zhang, Z., 2020. Measurement of cow manure compost toxicity and maturity based on weed seed germination. Journal of Cleaner Production, 245, p.118894.
[159] Adeli, A., Brooks, J.P., Miles, D., Misna, T., Feng, G. and Jenkins, J.N., 2022. Combined effects of organic amendments and fertilization on cotton growth and yield. Agronomy Journal, 114(6), pp.3445-3456.
[160] Adeli, A., Brooks, J.P., Miles, D., Mlsna, T., Quentin, R. and Jenkins, J.N., 2023. Effectiveness of Combined Biochar and Lignite with Poultry Litter on Soil Carbon Sequestration and Soil Health. Open Journal of Soil Science, 13(2), pp.124-149.
[161] Saba, F., Cornelis, J.T., Sawadogo, H., Lefebvre, D., Bacia, R.K., Cisse, D., Bandaogo, A.A., Mamadou, T. and Nacro, H.B., 2023. Nutrient-charged biochars increased nutrient-use efficiency in a cotton–maize rotation in Burkina Faso. Agronomy Journal, 115(2), pp.958-975.
[162] Shakoor, A., Shahzad, S.M., Chatterjee, N., Arif, M.S., Farooq, T.H., Altaf, M.M., Tufail, M.A., Dar, A.A. and Mehmood, T., 2021. Nitrous oxide emission from agricultural soils: Application of animal manure or biochar? A global meta-analysis. Journal of Environmental Management, 285, p.112170.
[163] Shakoor, A., Dar, A.A., Arif, M.S., Farooq, T.H., Yasmeen, T., Shahzad, S.M., Tufail, M.A., Ahmed, W., Albasher, G. and Ashraf, M., 2022. Do soil conservation practices exceed their relevance as a countermeasure to greenhouse gases emissions and increase crop productivity in agriculture?. Science of the Total Environment, 805, p.150337.
[164] Pinnamaneni, S.R., Lima, I., Boone, S.A., Anapalli, S.S. and Reddy, K.N., 2023. Effect of continuous sugarcane bagasse-derived biochar application on rainfed cotton (Gossypium hirsutum L.) growth, yield and lint quality in the humid Mississippi delta. Scientific Reports, 13(1), p.10941.
[165] Wichuk, K.M., Tewari, J.P. and McCartney, D., 2011. Plant pathogen eradication during composting: a literature review. Compost Science & Utilization, 19(4), pp.244-266.
[166] Novak, J.M., Ippolito, J.A., Lentz, R.D., Spokas, K.A., Bolster, C.H., Sistani, K., Trippe, K.M., Phillips, C.L. and Johnson, M.G., 2016. Soil health, crop productivity, microbial transport, and mine spoil response to biochars. BioEnergy Research, 9, pp.454-464.
[167] Allsup, C.M., George, I. and Lankau, R.A., 2023. Shifting microbial communities can enhance tree tolerance to changing climates. Science, 380(6647), pp.835-840.
[168] Coban, O., De Deyn, G.B. and van der Ploeg, M., 2022. Soil microbiota as game-changers in restoration of degraded lands. Science, 375(6584).

REFERENCES

[169] Lovell, S.T. and Sullivan, W.C., 2006. Environmental benefits of conservation buffers in the United States: Evidence, promise, and open questions. Agriculture, ecosystems & environment, 112(4), pp.249-260.
[170] Alagele, S.M., Anderson, S.H. and Udawatta, R.P., 2022. Conservation buffers and soil water. Soil hydrology in a changing climate, pp.133-156.
[171] Mekonnen, M., Keesstra, S.D., Stroosnijder, L., Baartman, J.E. and Maroulis, J., 2015. Soil conservation through sediment trapping: a review. Land degradation & development, 26(6), pp.544-556.
[172] Dosskey, M.G., Helmers, M.J. and Eisenhauer, D.E., 2008. A design aid for determining width of filter strips. Journal of soil and water conservation, 63(4), pp.232-241.
[173] Schoeneberger, M., Bentrup, G., De Gooijer, H., Soolanayakanahally, R., Sauer, T., Brandle, J., Zhou, X. and Current, D., 2012. Branching out: Agroforestry as a climate change mitigation and adaptation tool for agriculture. Journal of Soil and Water Conservation, 67(5), pp.128A-136A.
[174] https://www.nrcs.usda.gov/sites/default/files/2022-09/Filter_Strip_393_CPS.pdf
[175] Barnes, E.M., Campbell, B.T., Vellidis, G., Porter, W., Payero, J., Leib, B., Sui, R., Fisher, D.K., Anapalli, S., Colaizzi, P. and Bordovsky, J., 2020. Forty years of increasing cotton's water productivity and why the trend will continue. Applied Engineering in Agriculture, 36(4), pp.457-478.
[176] Himanshu, S.K., Ale, S., Bell, J., Fan, Y., Samanta, S., Bordovsky, J.P., Gitz III, D.C., Lascano, R.J. and Brauer, D.K., 2023. Evaluation of growth-stage-based variable deficit irrigation strategies for cotton production in the Texas High Plains. Agricultural Water Management, 280, p.108222.
[177] Herritt, M.T., Thompson, A. and Thorp, K., 2022. Irrigation management impacts on cotton reproductive development and boll distribution. Crop Science, 62(4), pp.1559-1572.
[178] Yang, Y., Jin, Z., Mueller, N.D., Driscoll, A.W., Hernandez, R.R., Grodsky, S.M., Sloat, L.L., Chester, M.V., Zhu, Y.G. and Lobell, D.B., 2023. Sustainable irrigation and climate feedbacks. Nature Food, 4(8), pp.654-663.
[179] Gesch, R.W., Berti, M.T., Eberle, C.A. and Weyers, S.L., 2023. Relay cropping as an adaptive strategy to cope with climate change. Agronomy Journal.
[180] Ali, H., Sarwar, N., Ahmad, S., Farooq, O., Nahar, K. and Hasanuzzaman, M., 2020. Cotton-based intercropping systems. Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies, pp.321-340.
[181] Bennett, A.J., Bending, G.D., Chandler, D., Hilton, S. and Mills, P., 2012. Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations. Biological reviews, 87(1), pp.52-71.
[182] Billman, E.D., Campbell, B.T. and Reay-Jones, F.P., 2023. Using perennial groundcover crops to suppress weeds and thrips in the southeast cotton belt. Crop Science, 63(5), pp.3037-3050.
[183] Parajulee, M.N., Montandon, R. and Slosser, J.E., 1997. Relay intercropping to enhance abundance of insect predators of cotton aphid (Aphis gossypii Glover) in Texas cotton. International Journal of Pest Management, 43(3), pp.227-232.
[184] Singh, J.A., Sohi, S., Brar, D.S., Denhdm, I., Russel, D. and Briddon, R., 1999. Management of cotton leaf curl virus disease in India. Proc. ICAC regional consultation insecticide resistance management in cotton. CCRI, Multan, pp.277-284.
[185] Beckert, Sven, Empire of Cotton: A Global History. New York, Alfred A. Knopf, 2014.
[186] Northrup, D.L., Basso, B., Wang, M.Q., Morgan, C.L. and Benfey, P.N., 2021. Novel technologies for emission reduction complement conservation agriculture to achieve negative emissions from row-crop production. Proceedings of the National Academy of Sciences, 118(28), p.e2022666118.
[187] Bakhsh, K., Ahmad, N., Kamran, M.A., Hassan, S., Abbas, Q., Saeed, R. and Hashmi, M.S., 2016. Occupational hazards and health cost of women cotton pickers in Pakistani Punjab. BMC Public Health, 16(1), pp.1-11.
[188] Priyadarshani, W.V.D., de Namor, A.F.D. and Silva, S.R.P., 2023. Rising of a global silent killer: critical analysis of chronic kidney disease of uncertain aetiology (CKDu) worldwide and mitigation steps. Environmental Geochemistry and Health, 45(6), pp.2647-2662.

REFERENCES

[189] Almaguer, M., Herrera, R. and Orantes, C.M., 2014. Chronic kidney disease of unknown etiology in agricultural communities. MEDICC review, 16(2), pp.09-15.

[190] White, B., 2012. Agriculture and the generation problem: rural youth, employment and the future of farming. ids Bulletin, 43(6), pp.9-19.

[191] Marple, M.E., Al-Khatib, K. and Peterson, D.E., 2008. Cotton injury and yield as affected by simulated drift of 2, 4-D and dicamba. Weed Technology, 22(4), pp.609-614.

[192] Byrd, S.A., Collins, G.D., Culpepper, A.S., Dodds, D.M., Edmisten, K.L., Wright, D.L., Morgan, G.D., Baumann, P.A., Dotray, P.A., Manuchehri, M.R. and Jones, A., 2016. Cotton stage of growth determines sensitivity to 2, 4-D. Weed technology, 30(3), pp.601-610.

[193] Gaines, T.A., Slavov, G.T., Hughes, D., Küpper, A., Sparks, C.D., Oliva, J., Vila-Aiub, M.M., Garcia, M.A., Merotto Jr, A. and Neve, P., 2021. Investigating the origins and evolution of a glyphosate-resistant weed invasion in South America. Molecular Ecology, 30(21), pp.5360-5372.

[194] Zeng, L., Wu, J., Bourland, F.M., Campbell, B.T., Dever, J.K., Hague, S., Myers, G.O., Raper, T.B., Smith, W. and Zhang, J., 2021. Comparative study of transgenic and nontransgenic cotton. Crop Science, 61(4), pp.2467-2477.

[195] Vulchi, R., Bagavathiannan, M. and Nolte, S.A., 2022. History of herbicide-resistant traits in cotton in the US and the importance of integrated weed management for technology stewardship. Plants, 11(9), p.1189.

[196] Westwood, J.H., Charudattan, R., Duke, S.O., Fennimore, S.A., Marrone, P., Slaughter, D.C., Swanton, C. and Zollinger, R., 2018. Weed management in 2050: Perspectives on the future of weed science. Weed science, 66(3), pp.275-285.

[197] Kranthi, K.R. and Stone, G.D., 2020. Long-term impacts of Bt cotton in India. Nature plants, 6(3),
[198] pp.188-196.

[199] Zeng, L., Wu, J., Bourland, F.M., Campbell, B.T., Dever, J.K., Hague, S., Myers, G.O., Raper, T.B., Smith, W. and Zhang, J., 2021. Comparative study of transgenic and nontransgenic cotton. Crop Science, 61(4), pp.2467-2477.

[199] Henneberry, T.J., 2007. Integrated systems for control of the pink bollworm Pectinophora gossypiella in cotton. In Area-wide control of insect pests: from research to field implementation (pp. 567-579). Dordrecht: Springer Netherlands.

[200] Zhou, X.V., Larson, J.A., Sykes, V.R., Ashworth, A.J. and Allen, F.L., 2021. Crop rotation, cover crop, and poultry litter effects on no-tillage cotton profitability. Agronomy Journal, 113(3), pp.2648-2663.

[201] Nouri, A., Lee, J., Yin, X., Tyler, D.D. and Saxton, A.M., 2019. Thirty-four years of no-tillage and cover crops improve soil quality and increase cotton yield in Alfisols, Southeastern USA. Geoderma, 337, pp.998-1008.

[202] Varner, B.T., Epplin, F.M. and Strickland, G.L., 2011. Economics of no-till versus tilled dryland cotton, grain sorghum, and wheat. Agronomy Journal, 103(5), pp.1329-1338.

[203] Johnson, J., MacDonald, S., Meyer, L. and Stone, L., 2018. Cotton outlook (No. 2072-2018-3490).

[204] Lobell, D.B., Cassman, K.G. and Field, C.B., 2009. Crop yield gaps: their importance, magnitudes, and causes. Annual review of environment and resources, 34, pp.179-204.

[205] Schulte, L.A., Dale, B.E., Bozzetto, S., Liebman, M., Souza, G.M., Haddad, N., Richard, T.L., Basso, B., Brown, R.C., Hilbert, J.A. and Arbuckle, J.G., 2022. Meeting global challenges with regenerative agriculture producing food and energy. Nature Sustainability, 5(5), pp.384-388.

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