**Can Cotton Producers Adopt Regenerative Agriculture Practices?**

**Executive Summary**

Multiple organizations have provided principles, outcomes and/or practices of regenerative agriculture (RA) with the goal of influencing farmer decisions. 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 or standards were identified, their practices categorized, and then counted to create a list of 25 common RA practices based on their inclusion in these frameworks/standards.

Cover crops and tillage (reduced, minimum, no-till or zero-till) are the most frequent practices referenced in RA frameworks/standards. The next most referenced practices are crop rotation, livestock grazing and reduction in synthetic inputs (pesticides and fertilizers). All 25 practices were examined with regards to adoption feasibility and implications by 12 categories of farms representing the global diversity of size, water, mechanization and livestock.

The colored graphic summaries whether specific practices are very feasible, feasible, challenging or very challenging. From this graphic it is apparent that most of the claimed regenerative practices are not uniformly feasible to all 12 farm categories. For example, only 5 of the 25 practices are colored the same. On average, the practices are more feasible in medium size farms – those with 10 to 50 hectares of cotton per person. 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 exists 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, unintended adverse consequences and needed changes). Based on this summary, it is clear that many of the claimed RA practices can feasibly be adopted by the diverse cotton farms around the world.



**Introduction**

Multiple organizations have provided principles, outcomes and/or practices of Regenerative Agriculture (RA) with the goal of influencing farmer decisions. 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 and challenges 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/standards and listed in order of frequency.



These claimed Regenerative Ag (RA) Practices are not standardized across frameworks/standards. 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/standards websites used to identify the 25 RA practices. The RA practice terminology was standardized and thus does not match each framework/standard precisely.



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: adequacy of water, availability of mechanization and presence of livestock 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 full grown person. 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 6 farm characteristics.

1. Small farms with less than 2 hectares of cotton per adult
2. Medium farms with 10 to 50 hectares of cotton per adult
3. Large farms with greater than 200 hectares of cotton per adult.
4. Water supply greater than 100% cotton ET from irrigation, rain and soil storage.
5. Mechanization availability: none, partial or full for planting, in-season operations and harvesting.
6. 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 unintended adverse consequences 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. References for each RA practice’s explanatory sections are included as footnotes. Because of the synergy and connectedness between RA practices, references may be applicable to multiple sections.

**Explanatory Sections**

1. **Cover Crops.** *[[1]](#footnote-1)[[2]](#footnote-2)[[3]](#footnote-3)*[[4]](#footnote-4)[[5]](#footnote-5)[[6]](#footnote-6)[[7]](#footnote-7)[[8]](#footnote-8)[[9]](#footnote-9)[[10]](#footnote-10)[[11]](#footnote-11)[[12]](#footnote-12)[[13]](#footnote-13)[[14]](#footnote-14)[[15]](#footnote-15)[[16]](#footnote-16) Cover crops grow during the interval between cotton harvest and planting of the next season’s crop and extend the coverage of soil 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 on 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.*

**Implications (Benefits).** Cover crops provide multiple farm and off farm benefits to their communities. Some of the intended benefits include: earthworm population, erosion control, livestock forage, microbial population including pathogen suppression, nutrient scavenger to avoid winter loss, nitrogen source, nutrient availability, organic matter addition, pollinator habitat, soil hydraulic properties (infiltration, storage, release and losses), soil structure including compaction amelioration, soil temperature moderation and weed suppression.

**Implications (Risks and Unintended Adverse Consequences).** Winter weeds used for cover can host overwintering insect pests and diseases (e.g. Henbit *Lamium amplexicaule*), inhibit cotton germination via allelopathy and persist to compete with cotton (e.g. Horseweed *Erigeron canadensis* and Annual Ryegrass *Lolium multiflorum*). Cover crops also pose management risks since some may be difficult to terminate without foliar herbicides or heavy roller crimpers or may release N2O if immature at termination. Some cover crops may reseed thus persisting to the detriment of future cropping decisions. Where irrigation and rainfall are less than annual ET cotton, cover crops utilize the limited moisture without generating a harvestable crop. This moisture risk discourages grower adoption unless the non-harvested benefits of cover crops exceed the risk from reduced availability of water for the harvested crop – for example, wind erosion protection in sandy fields. The greatest risk of cover crops where moisture is limited occurs at planting, if a cover crop has sufficiently depleted soil moisture such that a healthy cotton stand cannot be achieved.

**Implications (Needed Changes).** To fully utilize cover crops requires local research to evaluate optimum species and cultivars, species mixtures, planting methods/timing, 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 makes 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 person 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.

1. **No-till.** [[17]](#footnote-17)[[18]](#footnote-18)[[19]](#footnote-19)[[20]](#footnote-20)[[21]](#footnote-21)[[22]](#footnote-22)[[23]](#footnote-23)[[24]](#footnote-24)[[25]](#footnote-25)[[26]](#footnote-26)[[27]](#footnote-27)[[28]](#footnote-28) No-till or zero-till farming does not disturb the soil other than to place seed. 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, weed suppressing rotational crops, solarization and summer flooding. Farms with greater than 200 hectares per person have predominately shifted to herbicide weed control versus more labor-intensive cultivation and hand weeding. No-till complements this shift since one person operating a large precision application ground sprayer can treat 200 hectares per day. Thus, labor savings has been a major driver for both no-till adoption and the engineering of equipment capable of covering large hectares in one day.

**Implications (Benefits).** The driving benefits for no-till adoption are labor availability and production costs. 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; 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, 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; no-till fields have residue on the surface that protects crops from wind erosion; undisturbed macropores left by earthworms 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 oxygen movement into the soil and the oxidation of soil organic matter which promotes carbon sequestration; soil organic matter promotes beneficial microbial populations and nutrient retention in organic material; cotton yields are higher especially under rainfed water-limited fields. The extent of benefits from no-till is still being explored.

**Implications (Risks and Unintended Adverse Consequences).** 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. Stratification of immobile nutrients from surface applied fertilizer, especially P and K, can restrict uptake when surface roots are inactive. The abrupt transition to no-till on farms without access to foliar selective herbicides poses additional risks of crop failure from weed competition.

**Implications (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 the 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 is needed to find additional non-herbicidal weed control strategies for no-till farming.

1. **Reduced till with surface residue retained.**[[29]](#footnote-29)**[[30]](#footnote-30)[[31]](#footnote-31)**[[32]](#footnote-32)[[33]](#footnote-33)[[34]](#footnote-34)[[35]](#footnote-35) 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.

**Implications (Benefits).** Reduced tillage offers similar surface soil benefits of no-till (zero-till) but without the full labor savings and soil benefits. 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.

**Implications (Risks and Unintended Adverse Consequences).** Reduced tillage precludes sanitation (mixing of crop residue with soil) to destroy pathogen infectious propagules. Depending on the pathogen and environment, reduced tillage may increase or decrease pathogen propagules. Crop rotation is a viable alternative to sanitation.

**Implications (Needed Changes).** Soil compation 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.

1. **Crop Rotation****.** [[36]](#footnote-36)[[37]](#footnote-37)[[38]](#footnote-38)[[39]](#footnote-39)[[40]](#footnote-40)[[41]](#footnote-41)[[42]](#footnote-42) 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.

**Implications (Benefits).** Farmers of all sizes rotate crops to benefit the farm operation and individual crops. The diverse markets for crops such as vegetables, fiber, 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 and its rotational crops. For example, cotton suppresses soil borne diseases for peanuts and cotton lowers the weed seed bank for subsequent vegetable crops where cultivation and herbicides are challenging. Legume and grain crops provide both residual nutrients 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.

**Implications (Risks and Unintended Adverse Consequences).** As long as 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 creating sticky cotton. When adjacent potato fields are dug, Miridae (e.g. *Lygus* and *Creontiades* species) can move into cotton causing square injury. 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.

**Implications (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

1. **Livestock grazing. [[43]](#footnote-43)[[44]](#footnote-44)[[45]](#footnote-45)** 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.

**Implications (Benefits).** Cattle grazing on harvested cotton fields was a common practice to capture value from the cottonseed left in the field. Currently, livestock grazing of either cotton’s rotational crops or cover crops is the dominant use of grazing in cotton. Benefits may exceed that of applied dry manure since fresh manure has a vibrant microflora, includes urine and is soil incorporated with trampling.

**Implications (Risks and Unintended Adverse Consequences).** 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.

**Implications (Needed Changes).** Research is 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. Research is needed to understand the impacts to cotton of fresh manure and urine compared with the dry product sourced from off the farm.

1. **Synthetic Fertilizer Prohibited.** [[46]](#footnote-46)[[47]](#footnote-47)[[48]](#footnote-48)[[49]](#footnote-49)[[50]](#footnote-50)[[51]](#footnote-51)[[52]](#footnote-52)[[53]](#footnote-53)[[54]](#footnote-54)[[55]](#footnote-55)[[56]](#footnote-56)[[57]](#footnote-57)[[58]](#footnote-58)[[59]](#footnote-59) Cotton can be produced without synthetic (manufactured) fertilizers if yield expectations match the nutrient supplying capacity of the soil. After decades of removing plant material from a field in the harvested crop without replenishing nutrients, yield potential declines. Non synthetic fertilizer nutrient sources include manure, legumes, cottonseed meal, rock phosphate and wood ash. 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 rain water. These two combined can contribute the N removed in the seed of approximately 2 bales per hectare. If all the cottonseed meal is returned to the field (not recommended) adequate soil nutrition can be sustained. Soil reserves is a source of P and K which are eventually depleted if not replenished with manure and rock phosphate (P), wood ask (K) or synthetic fertilizer (P and K). Cotton’s nutritional needs are farm size independent. Whether the hectares managed per person are small, medium or large, a high cotton yield requires a high 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 source where farmers do not use synthetic fertilizer.

**Implications (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, greenhouse gas emissions associated with current N fertilizer manufacture, and to meet the requirements of a specific market.

**Risks and Unintended Adverse Consequences.** 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. 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. 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 use efficiency need to be achieved.

1. **Herbicides Reduced. [[60]](#footnote-60)[[61]](#footnote-61)[[62]](#footnote-62)[[63]](#footnote-63)** Access to herbicides is not essential for small hectare cotton farms which one worker can typically keep weed free during the critical first 6-week period after planting. 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 mechanically 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 person rely on herbicides for weed control.

**Implications (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.

**Implications (Risks and Unintended Adverse Consequences)** 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 and hand weeding for 6 weeks after cotton planting allows severe weed competition that can reduce yields to zero. 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: soil is readily compacted which reduces root density and depth when farm equipment traffics previously tilled soil near cotton plants, 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.

**Implications (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. Long term investment in novel weed control strategies is essential to avoid hand weeding costs.

1. **Insecticide and Acaracide Reduced.** [[64]](#footnote-64)[[65]](#footnote-65)[[66]](#footnote-66)[[67]](#footnote-67)[[68]](#footnote-68)[[69]](#footnote-69) Unlike weeds, insects cannot be 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. 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. 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*. Cultural control provides partial protection to insect pests, for example, short season management minimize late season injury to Lepidopteran, Miridae and boll weevil *Anthonomous grandis* feeding and surface cereal residue at planting suppresses early season injury from *Frankliniella* species. 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. However, some insect pests can still further reduce yield and delay harvest in dry, low humidity conditions (e.g., *Frankliniella* species).

**Implications (Benefits).** Reducing insecticides and acaracides application lowers human exposure and input costs without sacrificing yield where fields remain all season below economic thresholds for insect pests. Avoiding early broad-spectrum insecticide and acaracide applications allows beneficial insects to accumulate in the field. Reducing insecticides and acaracides meets the requirements of specific markets.

**Implications (Risks and Unintended Adverse Consequences)** The negative impacts of limiting access to insecticides and acaracides is 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 in wet environments requires a tolerance for yield loss up to 50%. 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.

**Implications (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.

1. **Reduce Fungicides.** [[70]](#footnote-70)[[71]](#footnote-71)[[72]](#footnote-72)[[73]](#footnote-73)[[74]](#footnote-74) Fungi that damage cotton can come from the soil and other fields. Most soil borne fungi can be controlled with crop rotation and sanitation (tillage that fully incorporates previous crop residue). 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 pathogen. The fungal pathogens *Ramulariopsis gossypii*, *Corynespora cassicola* and *Fusarium oxysporum vas infectans* 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.

**Implications (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.

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

**Implications (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.

1. **Nematicide access.** [[75]](#footnote-75)[[76]](#footnote-76)[[77]](#footnote-77)[[78]](#footnote-78) 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 and Host Plant Resistance. 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 field sanitation 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 and appropriate rotation and Host Plant Resistance is employed.

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

**Implications (Risks and Unintended Adverse Consequences)** 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 nematodes 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.

**Implications (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. 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.

1. **Bactericide access.** [[79]](#footnote-79)[[80]](#footnote-80) Only one bacterial pathogen of cotton is widespread, *Xanthomonas citri pv. Malvacearum*, causal agent Bacterial Blight of Cotton. This pathogen resides in the soil on plant debris and can be spread by contaminated seed and splashing water. Host Plant Resistance to Bacterial Blight, not bactericides, are widely employed in commercial cultivars by small, medium and large farms.

**Implications (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.

**Implications (Risks and Unintended Adverse Consequences)** Prohibiting access to bactericides during seed production could allow planting seed to be infected during the ginning and processing stages.

**Implications (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*.*

1. **Water Pollutants Contained. [[81]](#footnote-81)[[82]](#footnote-82)[[83]](#footnote-83)[[84]](#footnote-84)** Where nutrients and pesticides are applied, there is a need to contain them to the fields. Movement of these expensive inputs off the field or below the root zone wastes valuable resources and can contaminate areas away from the field. Surface and shallow subsoil water movement of nutrients to down-stream streams, rivers, lakes and oceans is the predominant concern since N and P can lead to eutrophication and toxicity. Another concern is the movement of nitrates and pesticides to ground water which once contaminated are difficult to remediate *in situ* 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 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 small farms since structures such as safe well heads and contained pesticide storage/mixing facilities require resources and engineering.

**Implications (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 pollutants by farmers 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.

**Implications (Risks and Unintended Adverse Consequences).** Pollution containment structures are expensive to design and build. Other than these sizeable costs, risk and unintended adverse consequences are not identified.

**Implications (Needed Changes)** Substantial investments are needed in the design and management of water pollutant containment systems for existing and small farms.

1. **Integrated Silviculture.** [[85]](#footnote-85) Similar to 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 person) 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 practices and cotton agronomy.

**Implications (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.

**Implications (Risks and Unintended Adverse Consequences).** 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 manage 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.

**Implications (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.

1. **PGRs and Harvest Aid access. [[86]](#footnote-86)[[87]](#footnote-87)[[88]](#footnote-88)[[89]](#footnote-89)[[90]](#footnote-90)[[91]](#footnote-91)** Plant Growth Regulators (PGRs) widely used in cotton slow the expansion of leaves, branches and stems. This plant canopy reduction may have ancillary benefits in reducing boll rot, facilitating spray penetration into the canopy, machine harvesting, and managing the crop when excess nitrogen and/or water is unavoidable. Harvest Aids facilitate machine harvest and can improve fiber quality if used in coordination with machine or labor harvesting.

**Implications (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 fall temperatures reliably defoliate the crop or hand harvesting predominates. The primary benefit to prohibit PGR’s and Harvest Aids is to meet the requirements of a specific market.

**Implications (Risks and Unintended Adverse Consequences)** Non access to PGRs and Harvest Aids is very challenging in large and mediums farms where harvest is fully mechanized.

**Implications (Needed Changes)** Innovative harvest machinery are needed that ideally can gather the crop without Harvest Aids.

1. **Manure.** [[92]](#footnote-92)[[93]](#footnote-93)[[94]](#footnote-94)[[95]](#footnote-95)[[96]](#footnote-96)[[97]](#footnote-97)[[98]](#footnote-98)[[99]](#footnote-99) 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. 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.

**Implications (Benefits).** Prior to Haber Bosch production of reactive nitrogen from inert nitrogen, manure was the dominant source of nutrients to support crops by utilizing animals (predominately 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 most essential plant nutrients but predominately P and N. Manure provides microbes that may be beneficial and in combination synergizes other soil amendments. For cotton, manure is an excellent source of available P since single applications meet multiyear crop needs. 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.

**Implications (****Risks and Unintended Adverse Consequences).** 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 cotton’s nutrition, nitrogen deficiencies will be evident or P contamination will be damaging. Secondary risks include nitrous oxide emissions from manure application.

**Implications (Needed Changes).** There is a need for greater awareness of the global and field benefits from a balanced nutrient program along with availability of low cost and locally calibrated soil/plant tissue testing services.

1. **Composting and Biochar. [[100]](#footnote-100)[[101]](#footnote-101)[[102]](#footnote-102)[[103]](#footnote-103)[[104]](#footnote-104)[[105]](#footnote-105)[[106]](#footnote-106)[[107]](#footnote-107)[[108]](#footnote-108)** 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 composed on cotton farms is food waste, 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.

**Implications (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. Composting of city organic waste is an opportunity to transfer nutrients nutrition and dispose of food waste (and perhaps human waste, if adequate safety procedures are employed).

**Implications (Risks and Unintended Adverse Consequences)**. Anaerobic composting at low to moderate temperatures can generate methane and nitrous oxide - both potent greenhouse gases. Eliminating pathogens from 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. Compost releases nutrients slower than synthetic fertilizers which can release excess N late during boll opening which aggravates late season pests and excess vegetation.

**Implications (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. Start-up funding is needed to establish city-to-farm linkages that safely handle, compost, transport and apply as needed the city sourced organic waste.

1. **Conservation Buffers. [[109]](#footnote-109)[[110]](#footnote-110)[[111]](#footnote-111)[[112]](#footnote-112)** Conservation buffers are non-cropped and non-grazed areas in and around fields that help retain rainwater in the field. 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.

**Implications (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 also retard rill soil erosion and 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.

**Implications (Risks and Unintended Adverse Consequences)** Conservation buffers provide no harvested or grazed product yet occupy productive farm land and require planting and maintenance.

**Implications (Needed Changes)** Conservation Buffers are permanent structures designed by drainage and soil conservation engineers. The selection of grass species and planting seed availability is critical to ensure success and avoid creating problems such as invasive weeds.

1. **Water Use Efficiency Improvement.** [[113]](#footnote-113)[[114]](#footnote-114)[[115]](#footnote-115)[[116]](#footnote-116)[[117]](#footnote-117) 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 also 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.

**Implications (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. Since cotton is a highly drought tolerant crop with a positive 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 plants 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.

**Implications (Risks and Unintended Adverse Consequences)** Improving water use efficiency in cotton carries no known risks, 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.

**Implications (Needed Changes)** Substantial capital and training investments are needed in the design, installation and management of efficient water delivery for small farms.

1. **Intercropping.** [[118]](#footnote-118)[[119]](#footnote-119)[[120]](#footnote-120)[[121]](#footnote-121)[[122]](#footnote-122)[[123]](#footnote-123)  Intercropping with cotton (also called relay planting since crops with different life stages are growing adjacent to each other) is feasible when hand labor is adequate to plant, weed and harvest the alternative crops. 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.

**Implications (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. As with cover crops, biological diversity can have positive or negative impacts. For example, harvested small grains left standing in seedling cotton protects from wind and thrips, while intercropped corn outcompetes cotton for sunlight, water and nutrients.

**Implications (Risks and Unintended Adverse Consequences).** Intercropping poses some of the same risks as rotation in adjacent fields. Intercropping will likely remain very challenging for large farms.

**Implications (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.

1. **Human Rights.** Human rights policies address worker health and safety, compensation and profitability, diversity, inclusion and forced labor. Farms, individually and collectively, can develop and adopt locally appropriate human rights policies.

**Implications (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.

**Implications (Risks and Unintended Adverse Consequences).**  The adoption of Human Rights Policies by farms has no apparent risks or unintended adverse consequences. This practice is not dependent on farm size, water availability, mechanization or the presence of livestock.

**Implications (Needed Changes).** Agricultural communication regarding basic human rights should be expanded along with guidance in establishing culturally relevant human rights policies for farms.

1. **Continuous Improvement.** [[124]](#footnote-124) As climate, agricultural technology, crop markets and governmental policy evolve and abruptly change, 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 Regenerative Agriculture. Continuous improvement requires time away from the day-to-day farm chores and thus is best achieved where mechanization reduces labor and hectarage per person 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 person the less time for continuous improvement.

**Implications (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.

**Implications (Risks and Unintended Adverse Consequences).** There are no apparent risks or unintended adverse consequences associated with farmers continually improving.

**Implications (Needed Changes).** There is a substantial need for farmer education and information tools that reaches farms of all sizes, farmers of all skills levels, in their local languages and customs.

1. **Safe Work. [[125]](#footnote-125)[[126]](#footnote-126)[[127]](#footnote-127)**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 fingers. Field work can lead to sun and heat exposure. Farm work is solitary and stressful from the inability to control key components of success – weather, pests and markets.

**Implications (Benefits).** Beyond the substantial human benefits of safe work, agriculture needs to attract young workers and sustain experienced workers. A safe work environment is essential to attract new farmers to an agricultural life.

**Implications (Risks and Unintended Adverse Consequences).** 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 present the risk of accidents; which can be mitigated with safety protocols, training and compliance.

**Implications (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 worder safety incidents. Education regarding worker safety needs to be broadly and repeatedly disseminated.

1. **HT GMO access.** [[128]](#footnote-128) Currently available cotton GMOs include multiple Herbicide Tolerance (HT) traits providing crop tolerance to glyphosate, glufosinate, dicamba, 2,4-D and HPPD herbicides. Where these herbicides are not employed in season, 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. All of the herbicides paired with HT GMO cotton are effective without soil incorporation which makes them useful in no-till cotton fields. Where weeds have not yet gained resistance to all 5 of these herbicides their use on HT GMO cotton can greatly reduce the need for hand weeding, cultivation and tillage that incorporates soil active herbicides.

**Implications (Benefits)** Restricting HT GMO seeds may reduce input costs in some markets without sacrificing yield where fields are weed free and imported weed seeds on bird, animals, water, seed can be controlled with other methods. Restricting HT GMO seeds also delays the development of weed resistance to the HT paired herbicides by preventing their frequent use during the growing season. This is especially true for highly efficacious and broad spectrum herbicides.

**Implications (Risks and Unintended Adverse Consequences)** Herbicides other than the 5 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, and a tolerance for crop injury. Non access to HT GMO cotton cultivars leads to one of three outcomes: farmers are dependent on hand weeding, cultivation is used to control weeds which degrades soil health, farmers develop the expertise and purchase the equipment to apply and incorporate pre-1997 herbicide regimens. None of these 3 options are viable when one person is farming a large hectarage.

**Implications (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.

1. **Bt GMO access.** [[129]](#footnote-129)[[130]](#footnote-130) 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 their specific target pests remain susceptible to these Bt toxins and periodically damage non-Bt GMO cotton.

**Implications (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 or target pests develop resistance to the Bt trait.

**Implications (Risks and Unintended Adverse Consequences)** 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 person increases, adequate insect pest scouting becomes challenging. In some markets, non-access to GMO traited seeds limits access to well-adapted high-yielding cultivars since multinational seed companies, in general, limit commercialization of their best germplasm in non-traited cultivars.

**Implications (Needed Changes)** Long term investment in novel insect control strategies is essential for productive agriculture.

1. **Profitability/Productivity. [[131]](#footnote-131)[[132]](#footnote-132)[[133]](#footnote-133)[[134]](#footnote-134)[[135]](#footnote-135)[[136]](#footnote-136)[[137]](#footnote-137)[[138]](#footnote-138)** Unlike salaried wage earners farmers invest their savings and 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 exceeded 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; 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.

**Implications (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 increase soil health and lead to greater productivity.

**Implications (Risks and Unintended Adverse Consequences)**. High cotton farm profitability leads to textile demand destruction, substitution with synthetic fibers, subsequent over planting and rapid fiber price reduction.

**Implications (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 yield only requires 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.







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