The ICAC Recorder

A Change in Plant Architecture Can Break Yield Barriers in Africa

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Over the past 30 years, cotton yields in Africa have been stagnant at an average of 350 kg of lint per hectare (ha). Cotton in Africa is grown mainly in the tropical regions, where abundant sunlight, adequate rainfall and fertile soils (in many countries) should have resulted in high yields and good crop growth. A critical analysis shows that it is paradoxical that the unabated crop growth could be the main factor that is responsible for low yields.

It would be possible to enhance yields by breeding 'compact-architecture' cultivars coupled with 'canopy management' in which excessive vegetative plant growth is curtailed at a critical stage — either through mechanical methods or with the use of plant growth regulators — to ensure a proper nutrient source-sink relationship. Apart from compact architecture, yield improvement in Africa requires best practices for plant mapping, canopy management, soil reclamation, soil conservation, cropping systems, conservation tillage, water-use efficiency, nutrient-use efficiency, pest management, and weed management.

In developed countries such as USA, Australia and Brazil, plant breeders aim to develop cultivars that retain an optimum number of bolls, generally at 15 to 20 bolls per plant, with a population of 80,000 to 110,000 plants per hectare. However, in Africa and Asia, plant breeders traditionally have been developing plant types that produced the highest number of bolls (80 to 150) per plant. Agronomists recommended wider spacing for such varieties to cater to their potential for tall, wide growth.

Producing more bolls per plant takes a longer time for higher yields, and if terminated prematurely, result in low yields. Cotton plants need about 80% water and nutrients during the flowering and boll-formation stage, which is referred as 'the critical window'. Incidentally, the critical window is the period most vulnerable to bollworms. Any stress during this time adversely affects the yields depending on the level of stress. The critical window is about 40 to 50 days in a short-duration, high-density crop, whereas it ranges from 80 to 120 days in a long-duration crop like those in Africa or India.

If the plants have to be kept in the field for longer than six to eight months to obtain high yields, the crop would need adequate water, nutrients during the longer (80 to 120 day) critical window of 'flowering and fruiting' to obtain higher yields. A long-duration crop becomes vulnerable not only to stresses from water and nutrients but also from insect pests and diseases, thereby warranting proper management.

In all other countries that harvest high yields of 1,000 to 2,500 kg/ha, emphasis is placed on high-density planting (more than 75,000 plants per hectare) coupled with canopy management to terminate the crop at four or five sympodial nodes (fruiting branches) above the white flower (generally at a total of 12 to 16 sympodial nodes per plant below the white flower). Care is taken to ensure 80% square retention, and/or retention of 60% to 70% of the bolls formed, to obtain high yields in a short season.

To achieve a breakthrough in yields and to increase input-use efficiency of water and nutrients, Africa needs to seriously consider the development and evaluation of the following systems:

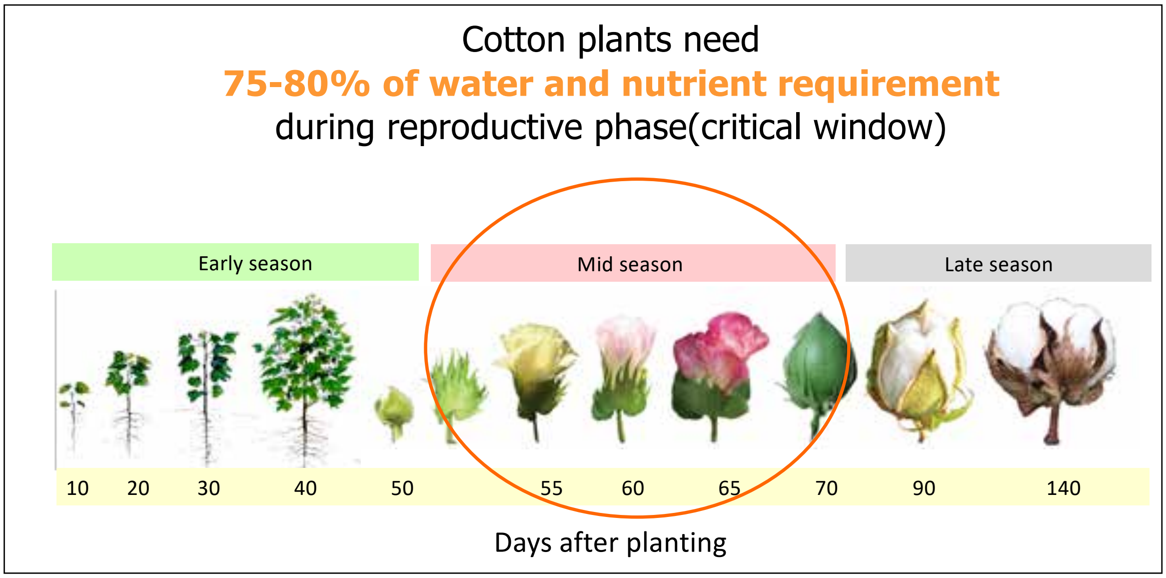
- A new system of plant architecture;
- New planting geometry;
- Canopy management;
- Soil health management; and
- Ecological engineering for pest management.

Development of Efficient Cultivars

Plant breeders must seriously consider developing cultivars with the following plant features: 1. Compact, short-statured; 2. Zero-monopodial; 3. Short season (140 to 150 days); 4. Resistant to sap-sucking insects and local pathogens; 5. High initial shoot and root vigour; and 6. High ginning out-turn and good quality fibre.

Compact statured plants with short internodal length are known to be more efficient in channeling water and nutrients to fruiting parts such as flowers and bolls. Canopy management becomes easier with plants that are genetically designed to be compact.

Zero-monopodial plants have a single main stem that bears sympodial branches with short internodes, which makes it very efficient in energy dynamics for boll development, thereby resulting in higher harvest index (ratio of seed cotton to plant biomass). A higher number of monopodial branches with longer internodes will require more energy in the form of nutrients and water for their growth and development.



Short-season, compact cotton cultivars planted in a high density of >110,000 plants per hectare are expected to retain at least 14 to 15 bolls per plant for high yields, which needs less time for development, maturation and opening. In a short-season crop, the critical window of squaring, flowering and early green boll formation extends for about 50 to 60 days. This critical window is most vulnerable for bollworm attack and is also most vulnerable to water and nutrient stresses. High yields depend on how well the critical window is managed. Effective pest management, weed management, water and nutrient management during this crucial phase determines yield levels. With timely sowing, a short-season crop escapes water stress and bollworms to a great extent, thereby significantly easing management stress. Currently, Africa has a very long critical window of 100 to 120 days during which the cotton crop is highly vulnerable to insect pests, water, nutrients and abiotic stress for a longer period of time. A short, critical window of boll formation makes it easier for management even for illiterate farmers, if trained properly, whereas a long critical window is a nightmare — even for experts and resource-rich producers.

Sap-sucking pests infest the crop in the early vegetative stage. Naturally occurring biological control consolidates itself in the early stages of the crop. Cultivars that are resistant to sap-sucking insects will not warrant the need for chemical insecticides for management, which results in the conservation of generalist natural enemies that protect the crop against bollworms later in the season. Biopesticides and biological control strategies work well under ecosystems that are minimally disrupted by chemical pesticides.

Cultivars with high initial shoot and root vigour have competitive advantage over weeds and will also be able to produce adequate number of sympodial branches in a short time to synchronise the critical fruiting window with available soil moisture. They could also have the ability to withstand abiotic stress and possess capabilities to compensate early damage by pathogens, nematodes and insect pests.

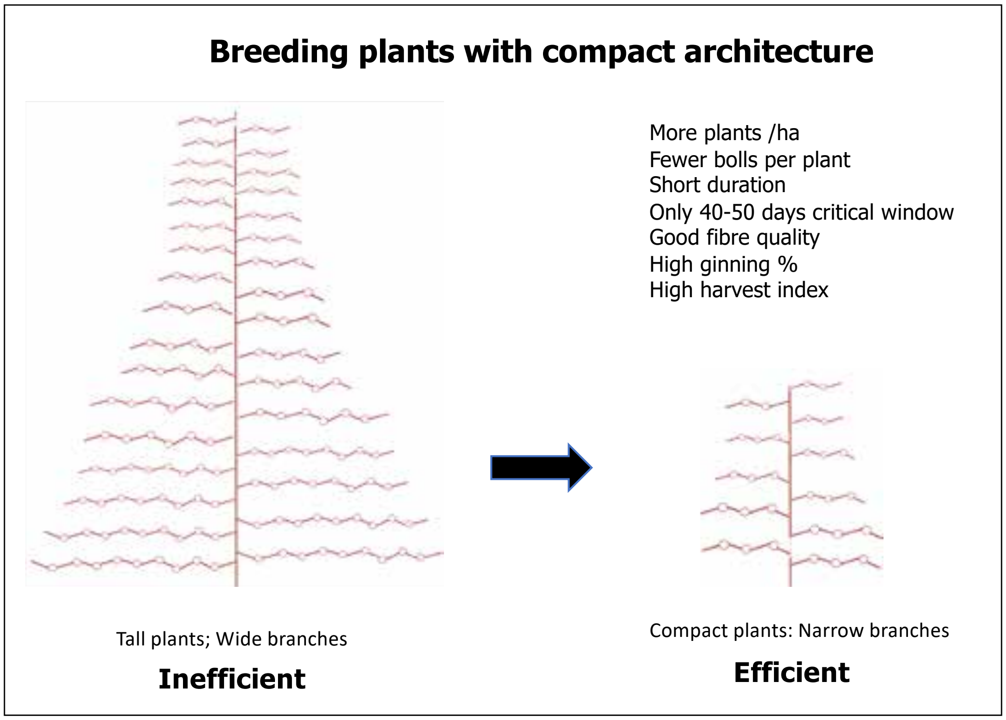
High ginning out-turn results in higher lint yields. High-quality fibre fetches higher prices and thereby produces better profits.

Planting Geometry

Agronomists should seriously consider standardising optimum plant spacing and try a geometry of 8 to 10 cm between plants in a row, with row-to-row spacing at 30 cm, 45 cm, 60 cm, 75 cm or 90 cm, depending on plant architecture, soil type and environment. High yields can be obtained with precision seeding at 1 to 4 cm depth at a spacing of 8 to 10 cm within rows, and 43 to 76 cm between rows, to get 8 to 10 plants per metre and more than 100,000 plants per hectare. The time of sowing must be adjusted to synchronise the boll formation phase with the monsoon. Cotton is highly sensitive to waterlogging and leads to low yields in poorly drained soils. Therefore, planting on ridges or raised beds protects the crop against water-logging. Planting on raised beds improves drainage and enhances soil warmth to minimise seedling pathogens. Gaps between plants must be strictly avoided. Wide spacing causes delayed maturity as more bolls are formed on the outer position and on the higher nodes.

Canopy Management

Agronomists must explore plant growth regulators and mechanical techniques of canopy management to ensure optimum plant growth and to avoid unproductive vegetative growth. Removal of unproductive branches and biomass facilitates proper 'source to sink' channelling of nutrients into fruiting parts, without any wastage into unproductive plant biomass.



Crop monitoring is crucial prior to canopy management. Initially, plant population must be monitored to ensure good plant stand. At the squaring stage from first square to first bloom, it is important to record plant height, number of nodes and node of first fruiting branch, and fruit retention at first position. At flowering stage, there is a need to monitor the plant height, number of nodes above the first position white flower (NAWF), when 25% of plants have their first position flower. At cut-out stage, when 4 to 5 nodes are present above the white flower, it is important to ensure that the number of fruiting parts below the white flower are adequate for high yields. Protecting squares from insect damage and stress contribute significantly to high yields. Retention of 80% of the first position bolls and 9 to 10 nodes above first position white flower is crucial for good yields. Less than 80% retention delays maturity and reverts back to excessive vegetative growth. High retention of fruiting parts plus good plant structure results in high yields. Determining a proper cut-out stage, when all input supplies are stopped, ensures proper source to sinking of nutrients.

Canopy management is done by restricting plant height to 70 to 80 cm by using growth-regulating chemicals coupled with proper management of water and nutrients. Vegetative branches are removed manually after the appearance of the first fruiting branch. This is known to reduce boll shedding, increase boll size, increase the number of fruiting nodes, enhance the dry mass of fruiting parts, and increase seed-cotton yields. This practice is followed in 50% to 70% of the farms in China. Growth tips on the main stem are clipped when an adequate number of fruiting branches are produced, depending on the plant density. Early fruiting branches, generally the lowermost 2 to 3 fruiting branches of the main stem, are removed at peak squaring stage. Apical points of vegetative branches are removed after peak flowering, and those of fruiting branches are removed at peak boll-setting. Removing apical buds of vegetative and fruiting branches is known to enhance root growth, reduce premature senescence, limit horizontal growth of branches and canopy closure/shading and to improve yield, lint percentage and earliness. Empty fruiting branches, and old and yellow diseased leaves, are removed after full flowering for improvement in ventilation and light penetration, as well as a reduction in soil humidity and boll rotting.

It is possible to inhibit lateral growth of vegetative branches by high-density planting, growth regulators and manual clipping to achieve a balance between vegetative and reproductive growth without decreasing yield and fibre quality. The plant height and architecture are generally controlled through timely application of chemical growth regulators. Growth regulation starts from squaring. Apply growth regulators (mepiquat chloride) to restrict vegetative growth or curb excessive growth, after the growth curve when the top third inter-node length is more than 7.5 cm or the length of the top five inter-nodes is more than 18 to 23 cm. Multiple, low-rate applications of growth regulators reduce risks. Do not apply growth regulators when the crop is under stress. Plant height must be maintained equivalent (±10%) to the row width. About 70% to 80% of squares and harvestable bolls across 10 to 14 nodes must be retained. About 80% of the bolls

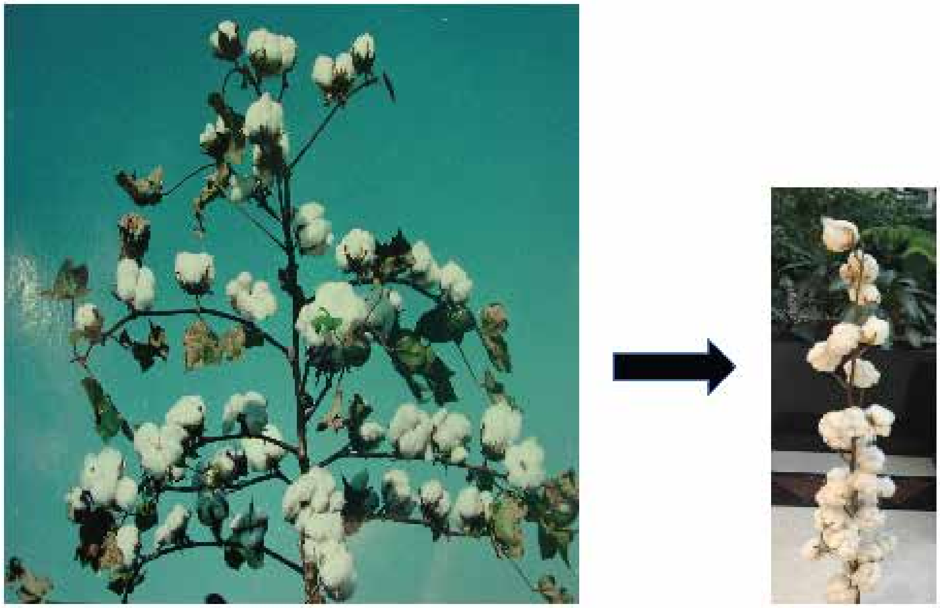


Photo courtesy: Mr. Mubvekeri

must be in the first position. The flowering period is best restricted to 30 to 40 days.

Soil Health Management

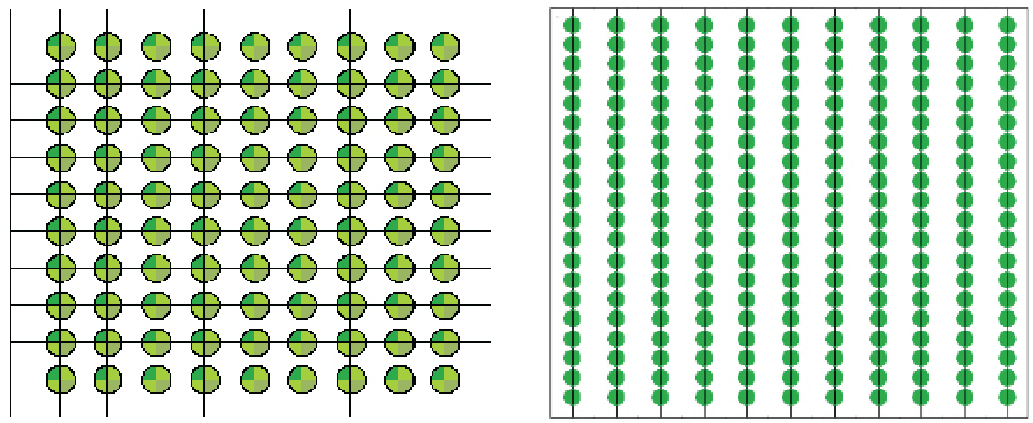
Water and nutrients play a crucial role in plant growth and yields. Uptake of available NPK (nitrogen, phosphorus and potash), secondary and micronutrients in the soil depends on soil health that is based on organic carbon content and the microbial environment. Soil health is mostly a function of good soil management practices that include cropping systems, soil management, nutrient management, soil-moisture management, minimising chemical toxicants, nitrogen fixation by plants, and organic matter that is returned back to the soil as crop residue biomass — which, in turn, is microbially converted to organic manure. Improvement of soil health is crucial for good yields.

Agronomists must conduct experiments to identify the best conservation tillage options for local conditions. Minimum tillage or zero tillage, crop residue management, and choice of appropriate cover crops and crop rotation would play a crucial role in conservation agriculture. Cover crops with legumes such as (*Trifolium incarnatum*) and hairy vetch (*Vicia cillosa*) can provide up to 70 kg N/ha to the subsequent cotton crop. Cover crops improve soil texture, increase soil organic matter, reduce erosion and provide weed control. Crop rotation with legumes such as beans or vetch was found to be profitable in Africa. Mulching with crop residues of cover crops and post-harvest shredding and mulching enhances soil health.

If tillage is required to solve the problem of soil compaction, in-row subsoiling (40 to 45 cm depth) or para ploughing and planting into old crop residue of winter crop can be done to reduce soil compaction. Inter-culture at 15 to 20 days after sowing (DAS) and 40 to 50 DAS can be combined with weeding, earthing up and top dressing of fertiliser.

Ideal soil pH for cotton is 5.8 to 8.0 and adjustments are critical for good yields. Soils in many African countries are slightly acidic and may need reclamation with dolomite lime. Acidic soils do not facilitate proper nutrient uptake, which results in an unhealthy crop that does not have proper capabilities to combat insects and pathogens. Soil reclamation can also be done with biochar that can easily be produced by using cotton stalks and residues obtained from cotton fields. For best effects, amendments with gypsum or lime should be done 5 to 6 months before sowing, which also take care of Ca and Mg requirements.

A significant portion of the chemical fertilisers applied in Africa and elsewhere in the world are lost due to improper application. Precision usage is crucial in resource-poor countries like those in Africa. Soil sampling must be done for less mobile nutrients such as P, K, Ca, Mg and pH. Boron is a key element and should be applied based on soil tests. Optical sensors (such as those form GreenSeeker) that emit light of a specific wavelength to estimate leaf nitrogen may be used for precision N application. Neem-coated urea can be used in Africa for slow release and reduction of losses. Placement of fertilisers, split application, foliar application during blooming, use of growth regulators, use of urease inhibitors and nitrification inhibitors have the potential to prevent nutrient losses. Nitrogen deficiency can be detected by petiole nitrate estimation and visual symptoms. Nitrate content in soil should not be below 25 ppm. Apply N when nitrate is below 50 ppm. Nitrogen and water demands are highest during squaring to the green



boll formation stage. Avoid excessive N in the early stages of the crop (before squaring) to prevent excess vegetative growth and a delay in maturity. The crop needs potash (K) during boll formation stage. Initial soil application and foliar sprays of K during boll formation stage are beneficial. Phosphorus is relatively immobile and should be broadcasted and incorporated so that roots can get a chance to absorb the nutrient. *Arbuscular mycorrhiza* (AM) is important for P absorption. It improves solubilisation of soil-bound P to enhance its uptake through efficient interception. Frequent tillage destroys AM. Yields are always higher due to improved soil structure. The presence of an active soil microbial biomass coupled with restoration of *arbuscular mycorrhiza* (AM) improves nutrient availability, uptake and efficiency.

Ecological Engineering for Pest Management

Integrated pest management (IPM) depends largely on cultivars that are resistant to sap-sucking pests. Seed treatment protects seedlings from pests and diseases. Avoidance of chemical insecticides to control sap-sucking insects prevents disruption in the stabilisation of naturally occurring biological control in the cotton ecosystems. Concomitant with sap-sucking pest infestations, naturally occurring biological control of insect pests starts early in the season and gets consolidated as the season progresses. Populations of insect parasites such as *Eretmocerus* spp., *Trichogramma* spp., and predators such as green lace wing bugs, syrphids, spiders, ladybird beetles, etc., start building up early in the season and survive by feeding on sap-sucking insects and multiply at the expense of a few caterpillars such as semi-loopers, leaf rollers and hairy caterpillars that cause less economic damage. Most of these predators and parasitoids continue to survive and multiply throughout the season. These are detrimental to bollworms and keep them under check. Cultivars that are tolerant to sap-sucking insects do not warrant broad-spectrum insecticides. Botanicals and bio-pesticides or vegetable oils would be adequate for management of sap-sucking pests with minimal harm to biological controls. Cultivars that are susceptible to sap-sucking insects would require application of broad-spectrum insecticides such as those belonging to the organophosphate group, carbamate group, chlorinated hydrocarbons, etc. Just a few applications of these insecticides disrupt ecosystems significantly by destroying naturally occurring biological control that can tilt the ecological balance in favour of insect pests that rebound easily, whereas biological controls takes a much longer time to recuperate.

Intercropping with cowpea or beans helps to attract predatory insects that feed on aphids that occur on the leguminous (nitrogen fixing) intercrops. There are several leguminous crops that do not compete with cotton and can be experimented under ecological engineering as intercrops with cotton to assess the pest-parasite predator ratios under different combinations. Bollworm management becomes easier with biopesticides, if naturally occurring biological control is conserved by avoidance of chemical insecticides early in the season. Marigold serves as an effective trap crop for cotton bollworm. However, if bollworm populations reach economic threshold levels of 5% to 10% damage to fruiting parts, one or two applications of any of insecticides such as spinosad, emamectin benzoate or chlorantraniliprole could be used for effective control. Terminating the crop in 5 to 6 months will provide a closed season for pink bollworm, mealybugs and a few other pests, thereby reducing their infestation significantly in the subsequent season.

It would be worthwhile for researchers in Africa to examine the above-mentioned suggestions to formulate research projects for the development of new cultivars and supporting crop production systems that are most efficient in water use and nutrient use. These efforts will need strong multi-disciplinary research involving good teamwork especially among plant breeders, agronomists, entomologists and extension scientists. Changing the mindset of researchers and farmers for such new approaches, such as compact plants with fewer bolls per plant, would be a great challenge in itself. But these ideas are worth exploring because they have succeeded in countries such as Australia, Brazil, China, Mexico, Turkey and USA, which are placed in divergently different geographical areas, different agro-ecological zones, and with a very different socio-economic and cultural structures. These suggestions are based on success stories and standard practices being followed in developed countries.

It should be remembered that a success story from a developed country may not find resonance in developing or underdeveloped countries, which are located in completely different geographical domains and have very different socio-economic profiles. However, lessons can always be learned from anywhere and adapted to local conditions through rigorous experimentation and validation.

Good scientists never shy away from experimenting with new ideas. If the yield-stagnation jinx is to be broken, new ideas must be tried and tested so effective alternatives can be developed. Success will eventually depend on how determined researchers are to try new things and make a change.

HIGH YIELDS: BASIC CONCEPTS AND TECHNOLOGIES

$$\text{Seed cotton yield (Kg per hectare)} = \frac{\text{No. of bolls per hectare X average boll weight in grams}}{1000}$$

High cotton lint yields can be obtained with a combination of a good cultivar and good management at the mercy of good weather.

The Basics

- Cotton plants are most vulnerable to insects and nutrient stress. Vulnerability increases with the crop duration.
- Flowering and fruiting period (reproductive phase) is most sensitive to bollworms, drought and nutrient stress.
- Cotton plants need about 70-80% of water and nutrient requirements during reproductive phase.
- Longer the reproductive phase, the crop becomes more prone to biotic and abiotic stress.
- A long season crop is a management nightmare.

Good cultivar

High genetic potential:

- The genetic potential for fruiting part formation and boll retention should be high.
- Plants with higher initial shoot and root vigour escape stress.

Sympodial-compact architecture:

- Sympodial short statured plants with short-internodal length and compact architecture are more efficient in 'nutrient-use' and 'water-use'.
- Plants with compact architecture are amenable for high density without compromising on light availability.

High harvest index:

- Breeding for high harvest index enhances water and nutrient use efficiency.

Short duration:

- Plants with a short reproductive window can be efficiently managed for bollworms, water and nutrients.

Resistance to sucking pests:

- Cultivars that are resistant to sap-sucking pests and the major disease of the region, should be preferred. Avoiding insecticide application in early vegetative stage (sucking pest vulnerable stage) helps naturally occurring biological control to establish in the ecosystem.

Good fibre quality plus high ginning out-turn:

- High ginning % (out turn) gives higher lint yield.

Good management

Timely sowing:

- Cotton plants are sensitive to sowing time and degree-day regimens.
- Sowing time in rain-fed regions should coincide with the reproductive phase of peak water need of the crop.

Soil health:

- Nitrogen fixing intercrops, cover crops and rotation crops plus manure or compost enables proper soil health so that plants get a complete complement balanced diet that they need.
- Initial fertilizer dose prior to sowing or at sowing time should be based on soil nutrient analysis to ensure that the plants produce 8-9 sympodial branches in 65-70 days after sowing -before the first flower appears on the first sympodial branch.
- The next split of fertilizer should be applied so that the plants get nutrients during the peak reproductive phase.

Canopy management:

- Plant architecture is managed with plant growth regulating chemicals or physical trimming to ensure proper source-sink flow of water and photosynthates into fruiting parts and also for efficient light penetration into the lower parts of the plant.
- Unproductive branches and vegetative plant parts must be curtailed manually.
- Good boll retention on the first point of the sympodial branches results in high yields.

Water management:

- In rainfed regions, water conservation methods such as water harvesting, ridge planting, mulching, conservation tillage, draining excess water, cover crops etc., are very important to provide adequate soil moisture to the crop, especially during the reproductive phase.

Weed management:

- Creation of a stale seed bed by destroying weeds that emerge in early rains helps cotton seedlings to consolidate initial vigour.
- Appropriate inter-crops, cover-crops and conservation agriculture assist long term weed management.

Pest management:

- Good pest management starts with a cultivar that can tolerate sucking pests and diseases that occur early in the season during vegetative phase.
- Timely sowing helps the crop to escape many insect pests and diseases.
- Timely harvest and residue management practices prevent survival and proliferation of residual pest and pathogen populations.
- A healthy soil greatly enhances crop health thereby enabling the innate crop defenses effectively. Imbalanced nutrient application such as excessive nitrogen and indiscriminate application of broad-spectrum insecticides cause insect pest resurgence.
- Ecosystems get consolidated with naturally occurring biological control organisms, with least application of chemical insecticides on cultivars that are tolerant to sap-sucking insects.
- Implementation of IPM becomes easier and the need for insecticide applications for bollworms gets greatly reduced in ecosystems that contain biocontrol organisms and that are least disrupted with chemicals.