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Introduction

In February 1994, Australia will host the World Cotton Research Conference-1 which is sponsored by the International Cotton Advisory Committee, the Food and Agriculture Organization of the United Nations and the Cotton Research and Development Corporation of Australia. The Conference will discuss all aspects of cotton production research. Early registrations have exceeded 240 and more are arriving. Persons planning to attend the Conference should complete the registration form in the brochure which accompanies this issue of the *ICAC RECORDER*, and return it to the Conference Registrar in Australia along with the appropriate fees. The last date for the receipt of abstracts of papers to be presented in Australia is September 30, 1993. The abstracts will be published before the meeting. Those who are unable to meet this deadline but would like to present a paper may still do so if the Conference Registrar is informed of their intent before the program is finalized. The full papers will be published in the proceedings.

It is interesting to know what differences make Australia one of the highest yielding cotton countries in the world. Cotton production conditions, research organization and important areas of research are discussed in the article on "Research Priorities in Australia." Australia has replaced about 90% of Delta and Pine Land varieties with locally bred Siokra (okra leaf) and Sicala types. Bacterial blight and verticillium wilt have been successfully controlled through host plant resistance. Most insecticide applications are made against *Heliothis* spp. which has developed resistance to insecticides. Resistance management, transgenic cotton, microbial insecticides, variety development and soil compaction are priority areas of research.

The second article is on "Herbicide Weed Control Systems." Weeds compete with the main crop for water, nutrients and light and can even have allelopathic effects. Managing weeds by adopting suitable cultural control methods and removing them manually or mechanically is the preferred method. If labor cost is expensive and farm machinery is inefficient, herbicide use becomes attractive for weed control. Since the chemical method of weed control was invented in the early 1950s, herbicide use has increased, and now many countries apply herbicides on nearly all area. Herbicides act in various ways, but commonly they are absorbed and, in many cases, translocated to their site of activity. Some groups of herbicides are more efficiently absorbed and easily translocated, enhancing the effectiveness of the chemicals involved. Such issues, along with the undesirable effects of herbicides, are discussed in the article.

Cotton has a tap root system which anchors the plant in the soil and provides water and nutrients for development. At an early stage, it is hard to compensate for any root injury. The tap root gives rise to secondary and tertiary roots which explore more area for water and nutrients. Root hairs absorb water and soluble nutrients from the soil and transfer them apoplastically to the upper parts of the plant. A minimum level of oxygen must be maintained in the soil to allow respiration. If pore spaces fill with water, roots are killed and the plant dies. Root functions and the effects of oxygen, temperature and water availability in the soil are discussed in the article "Physiology of the Root System in Cotton."

The Secretariat has updated its publication *Survey of Cotton Production Practices.* A copy is being mailed with this issue of the *ICAC RECORDER*. A limited number of additional copies are available from the ICAC Secretariat.

Research Priorities in Australia

Australia, though not the largest cotton producer, is one of the highest yielding cotton countries in the world. Cotton is produced in two states: New South Wales and Queensland. Cotton production areas are scattered throughout both states. Climatic conditions are similar with the slight advantages of additional sunshine hours and more degree days in Queensland. Queensland produced 364,590 bales from 58,900 hectares in 1992/93. New South Wales (NSW) produced 1,145,410 bales from an area of 177,100 hectares in 1992/93. In NSW and Queensland, 163,200 hectares and 45,700 hectares, respectively, are irrigated. Yield ranges from 1,600 kgs/ha in irrigated areas to 435 kgs/ha in rainfed areas.

Cotton production in Australia is generally characterized by high input use in the form of fertilizers, insecticides and herbicides. Soils are rich in phosphorous and potassium and need only nitrogen for a good harvest. Crops are sprayed at least 10-12 times during normal years, mainly against thrips, *Heliothis armigera* and *Heliothis punctigera*. Poor protection measures against *Heliothis* not only result in huge losses but also in an economically non-viable yield level. Herbicides are applied 2-3 times, before planting, after planting but before germination and at post emergence stage, in addition to the mechanical removal of weeds. Fusarium wilt and bacterial blight have been controlled through built-in resistance of the cultivars. Cultivation practices are fully mechanized.

The Commonwealth Scientific and Industrial Research Organization (CSIRO), funded by the Federal Government, has a mandate to undertake fundamental and applied research on cotton. Two state government organizations, NSW Agriculture and Fisheries Department and Queensland Department of Primary Industries, also do considerable research on cotton and are responsible for the transfer of technology. The Cotton Research and Development Corporation of Australia, an autonomous body owned by growers, sponsors research projects in both states. The Corporation's source of funding is a levy on production which is matched by the Federal Government. Cotton research has the following priorities:

- Australia has grown Delta and Pine Land varieties for years. Locally bred varieties started gaining popularity over the last 4-5 years. Development and adoption of superior varieties with high yield potential and better fiber quality have high priority.

- Insecticides and herbicides are the most expensive component of production costs. It is an aim to protect the crop against pests and diseases with minimal reliance on chemicals. Various aspects of transgenic cotton are being studied.

- The Australian cotton industry is the first in the world to undergo an environmental audit conducted by a neutral agency from outside Australia. A number of areas causing environmental concern were identified and recommendations were made to improve the situation. A main objective of research and development work is to develop and adopt environmentally sound and sustainable farming practices.

- As in many other countries, *Heliothis* has developed resistance to insecticides in Australia. Monitoring resistance, especially to pyrethroids and the endosulfan group of insecticides, is important. One of the main objectives is to find and employ methods which delay resistance in *Heliothis*.

- Through effective research and development efforts, it is endeavored to identify new microbial insecticides which could serve as alternatives to insecticides. Various types of bacteria, fungi and viruses are being tried.
- It is considered important to improve the system of receiving feedback from growers to researchers and transferring technology from researchers to growers.

Development of Varieties

There are only two sources of cotton seed in Australia: Cotton Seed Distributors, a grower-owned, non-profit cooperative, and Delta and Pine Land Company of the USA. Cotton Seed Distributors provides seed at a lower cost than Delta and Pine Land Company to its member and non-member cotton growers. It has won the confidence of growers through the supply of good quality seed. Introduction of commercial seed into Australia is prohibited. Australia has grown Deltapine varieties from seed produced in Australia. Coker 310 and Stoneville types have also been grown to some extent, but they were not able to cater to a major area.

Not until 1985/86 did varieties of Australian origin start replacing Deltapine varieties, mainly by okra leaf and early maturing varieties. Such types are unique in the world. Okra leaf varieties are generally considered to be low yielding compared with broad leaf varieties. Why they are better yielding in Australia is difficult to answer. One possible reason cold be the high light intensity which permits okra leaves to maintain the rate of photosynthetic activities required for a good harvest, but there is no ample proof of this hypothesis. There could be two reasons for such a quick replacement: (1) Deltapine varieties grown in Australia were not matched to environmental requirements and there was really a need for varieties better suited to local conditions; (2) The cotton seed production system, handled by Cotton Seed Distributors, has been streamlined in the last 6-7 years, in consonance with the adoption of Australian varieties. Replacement of Deltapine varieties with local varieties has been very quick. Now Deltapine varieties are estimated to be grown on only 8-10% of the total area in Australia. It is assumed that the area under Deltapine varieties will further decrease, and these types might be eliminated in the next few years or at least restricted to very small area. There might be a turning point with the introduction of

Bt cotton as Deltapine is expected to be the first to release varieties with the Bt gene.

A variety approval process does not exist; growers’ choice is the authority to release any variety for commercial cultivation. Researchers are very particular about the reputation of Australian cotton in the world, and the industry is very proud of quality as 90% of the total production is exported. Hence, two major checks to the release of a variety for general cultivation are farmers’ preference and fiber quality. All local varieties presently in commercial cultivation have been developed by CSIRO with the support of researchers from the NSW Department of Agriculture. The Cotton Research and Development Corporation of Australia provides funds to undertake problem-oriented research. The variety development process is a fairly integrated approach which caters to the needs of the growers. Cotton Seed Distributors conducts multi-location trials on cultivated varieties and promising strains. Data are made available to the growers so that they can select a suitable variety of their own choice. There are no zonal restrictions.

Pest Management

In Australia in early stages, cotton is attacked by thrips, aphids, mirids (green mirid, *Creontiades dilutus*, and apple dimpling bug or yellow mirid, *Campylomma livida*), and tipworm, *Crocidosema plebeiana.* Thrips may continue to be a pest during boll formation stage but do not need stringent pest control. Major pests during the boll formation stage are *Heliothis armigera* and *Heliothis punctigera*. Aphids and mites may also appear but usually remain below the threshold level. Early season spraying is not advised. Experiments (Brook et al 1992) have shown that, presently, locally bred Siokra and Sicala varieties have the ability to recover from early stage damage. The SIRATAC on-line computer-based pest management system gives cotton growers the option of either the earliness strategy or various degrees of compensation strategy.

Because of heavy attack of *Heliothis* spp. and a strong negative correlation of *Heliothis* eggs and larvae with yield, growers in Australia have relied on frequent spraying of cotton. Work on early season recovery and the use of okra leaf types has to some extent minimized the use of insecticides. Expertise is available to keep an eye on the development of resistance to insecticides. Now one of the main objectives of researchers is to minimize the cost of production and develop production technology which is environmentally sound and economically viable. Work is in progress to acquire a deeper knowledge of cotton insect pests and find non-chemical means of insect control. The Plant Industry Division of CSIRO in Canberra, in collaboration with Monsanto Company, is engaged in various aspects of biotechnology. Researchers have noted that insects do have a tendency to develop resistance to transgenic cotton. Furthermore, in the absence of lepidopteran insects, transgenic cotton showed a higher population of sucking pests. Local varieties with the Bt gene are expected to be available to Australian growers in 5-6 years.

The Plant Industry Division of CSIRO is also engaged in developing transgenic cotton tolerant to the herbicides 2,4-dichlorophenoxyacetic acid (2,4-D) and glyphosate. The basic source of gene transfer is Coker 312. It seems possible to transfer herbicide tolerant genes isolated from soil bacterium to cultivated commercial varieties using Coker 312 as a donor. Similar work is underway to impregnate a local variety, Siokra 1-3, with genes resistant to both above mentioned broad-leaf herbicides. Though the material is yet in back cross stages, environmentalists have expressed concerns over herbicide tolerant cotton as it will enhance the use of herbicides.

Transgenic plants, because of the reassortment of genetic material, are usually less adapted than the original highly adapted genotype. However, the Australian variety Siokra 1-3 has proved to be a very elite cultivar. Useful genes can be inserted into this variety without disturbing any of its agronomic characters. The resultant transgenic genotype is not only identical in morphological characters, but has the same requirements for water, nutrition, etc. As mentioned above, Australia has no variety approval process, but in the case of transgenic cotton, such a cotton will not be released for commercial adoption without a proper assessment of its impact on the environment and the approval of the concerned government authorities.

In addition to field studies, laboratory experiments are underway to assess resistance to Bt (as transgenic cotton and as microbial insecticide). Laboratory studies have shown the complete destruction of *Heliothis* larvae fed on transgenic cotton with the Bt gene. Identifying a less expensive method of resistance monitoring is considered important. The top dressing technique is commonly used at the Narrabri Agriculture Research Station to assess resistance to various insecticides. Attempts are also being made to establish a Bt resistant colony of *H. armigera* by further laboratory selection of the survivors of the discriminating dose screens. The mechanisms of resistance in *H. armigera* and *H. punctigera* are being thrashed out.

While the impact of early season thrips attack is monitored very carefully, its management without insecticides and ecology, relating to host preference, is an important aspect of entomological studies. Range and mechanism of plant resistance and the predatory role of thrips on mites are being evaluated.

Disease Control

High crop density (10-12 plants/m) and average monthly rainfall in excess of 10 cm favor the spread of disease. Regular surveys are undertaken twice a year in November (bud stage) and March (late boll opening stage) to assess the incidence of disease, the effect of various cultural practices on disease control and cultivar response. Up to 1985, bacterial blight was the most commonly occurring and damage causing disease of cotton in Australia. Caused predominantly by race 18 of *Xanthomonas campestris* pv. *malvacearum*, it affected up to 20% of leaves as well as bolls during the seasons from 1984/95 to 1987/88. Bacterial blight control has been a high priority area for pathologists. Infested seed was identified to be the main source of the spread of the inoculum. In 1985, a comprehensive program was prepared in collaboration with Cotton Seed Distributors to eradicate this disease. The seed program included shifting seed production sites to comparatively drier areas and blight assessment on pure seed crops to be used for the purpose of seed procurement. Severity of the disease in the field was an important criteria in accepting crops to be used for planting seed purposes. The program has proved its worth as the presence of the disease-causing pathogen in planting seed has decreased from 12.0% to 0.016% in six years. Consequently, the mean incidence of bacterial blight on seedlings and bolls has been reduced from 10.13% to 0.04% and from 19.56% to 0.29%, respectively. All locally bred varieties are almost immune to bacterial blight. The fundamental source of bacterial blight tolerance has been a US variety, Tamcot SP 37, which has been used extensively in crossing by pathologists in Australia.

Cotton growing conditions, reduced tillage practices, permanent bed systems and susceptible cultivars enhance the establishment of verticillium wilt. Yield losses in the range of 20% have been recorded. Developing varieties which resist verticillium wilt is still a challenge for researchers. The only resistant variety available at this time is Sicala V-1. In multi-location variety trials conducted by Cotton Seed Distributors in 1992/93, a newly developed variety, Sicala V-1, out-yielded all other varieties at a number of locations and remained competitive at other locations, with the additional advantages of high tolerance to verticillium wilt and better fiber quality.

Other diseases of insignificant importance are seedling rot, boll rot, black root rot and leaf spot. In 1992/93, there were unconfirmed reports of fusarium wilt from some fields. The whitefly does not exist in Australia, so chances of diseases caused by viruses almost do not exist.

Nutrition

Australian soils are fertile and show very good response to nitrogenous fertilizers. Availability of phosphorus and potassium on the average is enough to meet the needs of the plants. P and K are not usually applied to cotton. Nitrogen is usually applied in the form of anhydrous ammonia under each crop row at the time of seed bed preparation. Although the application rate varies, the average rate of nitrogen application in irrigated and dryland areas is 150 and 50 kg/ha, respectively. P, if applied, varies from 10 to 45 kg/ha. Sound recommendations for nitrogen application are available to growers. The main areas of interest in the field of nitrogen use are precise monitoring of the nitrogen level of the plant, deciding optimum requirements of specific types of soils and minimizing denitrification losses.

Potassic fertilizer in cotton may not show a response if potassium availability is in the range of 80-130 ppm. Australian soils are very rich in potassium as they have as high as 400 ppm potassium. Much like nitrogen, the requirement of potassium for a cotton plant changes with the stage of the plant. The plant needs more K at the time of boll maturity. If sufficient K is not available to the plant, pre-mature leaf shedding may occur, with drastic effects on cotton quality. Such a situation has been noticed in some parts of Australia. The Cotton Research Unit of CSIRO at Narrabri has recently initiated work on potassium and will analyze the relation between pre-mature leaf shedding and potassium deficiency.

Cotton is not a water-loving plant, but it needs irrigation at specific intervals depending on various factors. In arid and semi-arid regions where irrigation water enables farmers to get high yields from many agricultural crops, an accumulation of salts on the soil's surface results. The cotton plant may be able to grow under saline conditions, but certainly cotton seed cannot give good germination. Fortunately, Australia does not have a salinity problem. Researchers are of the view that salinity might become a problem in irrigated cotton growing areas in about 25-30 years. Work on salinity has already been initiated.

Soil Compaction

In Australia, a standard method of seed bed preparation for planting cotton in comprised of the cultivation of soil with offset discs to a depth of 0.15 m, chisel plowing to a depth of 0.2 m and the formation of hills (1 m spaced and 0.2 m high) before the seed is planted. Most of the cotton soils are cracking clay soils which are very prone to compaction caused by cultivation operations and harvest traffic. Soil condition is changed and crop growth is reduced, ultimately affecting yield. Compaction effects are observed to carry over, reducing yield in subsequent years. Research on maintaining good soil structure and ameliorating compaction is very important for growers. One recommendation is to grow a winter crop in rotation with cotton, to dry and crack the soil, followed by chiseling.

In the last decade, there has been a shift to reduced tillage/minimum tillage in overall cropping systems, accordingly so in cotton. In Queensland, about 10% of the cotton area gets reduced or no tillage. Experiments (Constable et al 1992) have shown that the minimum tillage yield was similar to that obtained with crop rotation. The advantage of minimum tillage over conventional tillage operation is a reduction in soil preparation costs. The problem of nutgrass increases and pupae of *Heliothis* can hibernate more successfully in minimum tillage fields than tilled soil. Economic analysis has shown that minimum tillage is more economical on a long term basis. Another option is wider beds, although they are not suitable for all types of soils. Research is also underway to fix permanent tractor pathways, "controlled traffic," for cultivation, inter-culturing operations and maybe for picking.

Compaction is a severe problem due to soil types and needs a solution. It is very important to acquire knowledge of the vehicle stress on the soil. All farm machinery used on cotton need to be evaluated to know their impact on soil structure and ultimately on yield. Probably it will be necessary to set critical limits for different types of soils. This is a key area of research where collaborative work with farm machinery manufacturers can bring more practical solutions.

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Herbicide Weed Control Systems

Weeds are defined in numerous ways. Weeds are plants growing out of place or where they are not wanted. Weeds are also defined as off-type plants which grow voluntarily in a crop grown for commercial purposes. In cotton, the second definition is more applicable, where any plant other than cotton would be considered a weed. Accordingly, rice, sugarcane, corn, etc. are weeds in a cotton field unless they have been grown intentionally for commercial purposes. In this age of herbicide use, any plants voluntarily emerging from the remains of the previous crop would be considered weeds as they would be killed by presowing soil incorporated or preemergence herbicides.

Theoretically, if all resources are available perpetually in an unlimited abundant supply, weeds may not cause any damage to the commercial crop, but this is not the case. Weeds have two types of effects on the commercial crop. They interfere with the commercial crop by competing for light, water, nutrition and other inputs resulting in an uncalled for use of resources. Secondly, they leave allelopathic effects on the commercial crop.

Allelopathy results when competing plants release substances into the environment which are detrimental to other plants. Allelopathic substances are usually organic compounds released from the leaves, roots or other plant parts during the growth or decay of plant material.

Losses Due to Weeds

Knowledge in weed science is not yet so advanced that the grower can take into consideration the allelopathic effects of all plants in his field which steal the inputs directed toward cotton. Only interference of weeds with the main crop is considered important. Weeds cause quantitative as well as qualitative losses in cotton. Yield losses occur as a result of sharing inputs with the cotton plant, thus affecting plant growth, boll number and boll weight. Weeds also enhance pest pressure on the crop, thus increasing the cost of production. Quality is affected in the form of a higher amount of trash picked with cotton and lint staining.

Weeds have complex effects on a cotton plant. Losses vary with the type of weed, the time of appearance, weed density and the time of control. Some weeds cause more losses than others, depending perhaps upon their requirements for growth. Some weeds have the ability to multiply in the field at a higher rate than others, hence causing more losses. Generally, broad leaf weeds appearing before cotton seed emergence or just after seed germination cause more losses than weeds appearing at a later stage. No data are presently available, but it seems that comparative trials on weed control, fertilizer application and insecticide use, in all possible combinations, could emphasize the importance of weed control.

Herbicide Use on Cotton

The minimum level of weeds acceptable in the field without any losses in yield could be calculated by keeping one weed plant per row length and its effects on yield compared with clean cotton. A general recommendation would be to keep the field free of weeds. Weed control methods have improved from manual to mechanical and chemical methods. Labor cost and inefficiency of equipment to remove all weeds are the main reasons to look for new options. The first herbicide recommended for weed control in cotton was a postemergence spray of herbicidal oil in 1950. Later, many non-fortified oils were recommended to be used on cotton at the rate of 12.5

gallons per hectare. They proved very successful and continued to be used until arsenical herbicides became available in the 1960s.

Among the preemergence herbicides, dinoseb (called dinitro by growers and DNOSBP by scientists) was the first product used on a large area in 1952. Dinoseb killed or severely injured cotton seedlings and also vaporized quickly depending upon soil type. Chlorpropham was introduced at the same time but did not become popular. Diuron was the first most commonly used preemergence herbicide. New products continued to be introduced with the ultimate objectives of more selectivity to cotton plant and higher toxicity to weeds. Now, herbicides are commonly used on almost 100% area in Australia, Colombia, Egypt, Guatemala, Israel, Nicaragua, South Africa, Spain, and USA. They are also used on significant area in Argentina, Brazil and Turkey. In Australia where the mild climate during planting enhances germination of weed seeds, herbicides are applied 2-3 times per season. Cotton is by and large the major consumer of herbicides in the world, although herbicides are also extensively used in corn, soybeans, wheat and many other field crops.

Mode of Action of Herbicides

The mode of action of herbicides is a complicated process and, in many cases, is not yet known. The target for herbicide action may be a cell, tissue, organ (leaf, root, etc.) or even the whole plant. Herbicides are designed to inhibit a particular biochemical process or enzyme activity of the weed. Only such biochemical processes or enzyme activities can be chosen for action which are sensitive and preferably unique in the target weeds. In the case of postemergence herbicides, the product should be selective to the economic crop. The mode of action is a major consideration for chemists in designing new products. Herbicides that cause cellular collapse are expected to be more antagonistic than those which require being transported to meristemic tissues for activity. Absorption and translocation are important parts of mode of action of herbicides. A discussion of the modes of action of some major herbicide groups follows.

Arsenicals

Two commonly used arsenic compounds are MSMA (monosodium methanearsonate) and DSMA (disodium methanearsonate). They cause less contact damage and are easily translocated through plant tissues. Methanearsonate moves in the plant more like phosphate. Transport is toward growing or storage areas, thus making it more effective against perennial weeds. The mechanism of action of arsenic compounds at the molecular level is not well understood. Its effects on amino acids, respiration and chlorophyll synthesis have been reported, but none of these effects is considered primary. The primary action seems to be inhibition of carbon fixation. Inability of the plant to fix carbon in the presence of bright light causes rapid photo-oxidation damage (leaf burning).

Aryloxyphenoxy Alkanoic Acids

Commonly used members of this group, which are used in cotton to control grass weeds, are fluazifop-butyl (Fusilade) and haloxyfop-methyl (Verdict). These herbicides are quickly absorbed by leaf cuticles, probably by becoming incorporated into the waxy matrix of the cuticle, and then are diffused into adjacent cells by movement into membranes. The movement of herbicides belonging to this group is rather slow within the plant. Herbicidal injury usually follows the pattern of cessation of growth, chlorosis, meristematic necrosis and ultimately death of the weed plant. Meristemic leaf tissues are more vulnerable as herbicides accumulate more rapidly in these tissues. Lipid synthesis is also the primary target of action of these herbicides, resulting in membrane disruption and cellular collapse.

Chlorinated Aliphatic Acids

A postemergence herbicide, dalapon (Dowpon), is commonly used in cotton. The herbicide is rapidly absorbed by foliage and translocated both apoplastically (outside the cytoplasm) and symplastically (from cell to cell within the cytoplasm). The mechanism of action at the fundamental level is not known, but it is reported that dalapon acts as an inhibitor of lipid synthesis, disrupter of nitrogen metabolism and inducer of phenolic metabolism. Herbicide application results in growth inhibition, chlorosis and distortion of the growth patterns of weeds.

Chloroacetamides

The chloroacetamides are represented by alachlor (Lasso) and metachlor (Dual). Their mode of action is unknown. There is some evidence of alkylation of specific proteins. Lasso and Dual are readily absorbed and apoplastically translocated. The herbicides inhibit germination and growth.

Cineole Derivatives

Cinmethylin (Cinch) is a preemergence herbicide registered for the control of grasses in cotton. Cinch inhibits cell division and effects growth; otherwise, the fundamental activity of this herbicide is unknown.

DCPA

Dimethyl tetrachloroterepthalate (DCPA) is a preplanting herbicide. It is neither absorbed nor translocated easily by leaves. DCPA (Dacthal) stops root cell division and also acts as a growth inhibitor.

Dinitroanilines

A large number of preemergence herbicides used in cotton like dinitramine (Cobex), oryzalin (Surflan), trifluralin (Treflan), etc. belong to this group. Their action is similar to DCPA. Dinitroaniline herbicides are preplant incorporated and absorbed by roots. Translocation is almost negligible. These herbicides effect mitosis cell division at prophase stage by disrupting the spindle formation process, which enables chromosomes to align for cell division.

Glyphosate

Glyphosate (Roundup) is an ideal herbicide as it is readily absorbed by leaves, efficiently translocated within the plant and accumulated in growing tissues. It is recommended for only foliar application as it degrades in the soil very quickly. It kills root tips, rhizomes, tubers, as well as aerial parts of the plant. Glyphosate inhibits synthesis of aromatic amino acids which are required for protein synthesis, resulting in cell death. Since glyphosate is highly water soluble, it is more efficiently absorbed by plants with more hydrated cuticles.

Isoxazolidinones

This group of herbicides exhibits loss of chloroplast pigment in the leaves after treatment. The only herbicide of this group recommended in cotton, clomazone (Command), is used as a preemergence herbicide which blocks the synthesis of carotenoid and chlorophyll.

P-NitroSubstituted Diphenyl Ethers (NDPE)

NDPEs are postemergence herbicides which rapidly cause chlorosis and/or necrosis in light. Acifluorfen (Blazer or Tackle), fluorodifen (Preforan), fomesafen (Reflex or Frigate), lactofen (Cobra) and nitrofen (Tok) belong to this group. They are generally poorly absorbed and not efficiently translocated. One early symptom of damage is the breakage of plasmalemma. Light and oxygen are necessary for rapid collapse of cells.

Pyridazinone

Norflurazon (Zorial) is the only pyridazinone herbicide used in cotton as a preemergence herbicide. Cotton absorbs and translocates Zorial efficiently. Zorial inhibits two enzymatic steps in carotenoid synthesis and desaturation of phytoene and phytofluene. Accumulation of phytoene and phytofluene results in decoloration of leaves. Total loss of chlorophyll gives rise to white leaves. However, loss of chlorophyll pigments, without protection from photo-oxidation by cartenoids, soon causes the weed plant to die. Both photo-oxidation damage and a lack of production of photosynthates kill the seedling.

Sulfonylureas

No sulfonylurea herbicides are used in cotton. While cotton is sensitive to this group of herbicides, it also has the ability to metabolize the herbicides into non-phytotoxic residues.

S-Triazines

Many preemergence herbicides used in cotton contain *S*-Triazines. The mechanism of action is well known. Cotton roots can absorb quickly most herbicides and also translocate them to shoots via the transpiration stream. The primary action of these herbicides is inhibition of photosynthesis. There are some secondary effects which vary with the product.

Ureas

Urea is one of the oldest classes of herbicides used in cotton. Linuron (Loraox), diuron (Karmex) and fluometuron (Cotoran), used in many countries, belong to this group. Their mode of action is similar to *S*-Triazines. They are almost readily absorbed and translocated to leaves via xylem.

Effects of Herbicides

Herbicides are applied preplant to foliage, preplant incorporated, preemergence, directed postemergence, postemergence over the top and late postemergence (layby) stages. Herbicide application technology has not been discussed here but is a critical component in realizing the results of herbicide use and in escaping from the herbicide's effects on cotton. Herbicides are injurious organic compounds which have various types of effects on cotton plants and soil. Undesirably high doses, uneven spraying, drift of non-target herbicides and residual effects have an impact on cotton plants. Some effects on cotton are compensated for by reduced competition from weeds, while others may result in reduced growth, stunting, chlorosis or necrosis. Leaf burning in spots or malformation may appear.

As mentioned above, some herbicides are absorbed more rapidly than others. Whatsoever the absorption rate, some chemical is retained by the soil at least for some period of time and can have effects on the following crop. Treflan and Prowl have effects on sorghum and sugarbeet planted after cotton. Some products like Cotoran degrade at a slower rate and persist in the soil for a longer time. In such cases, an intensive herbicide program must be avoided. Dose and maximum number of application limits should be strictly adhered to. There may be restrictions on specific rotations to follow in the case of herbicides like Zorial which persist in the soil for more than a year. On the other hand, some herbicides do not stay in the soil for more than a few weeks and have absolutely no effects on the following crops.

Herbicides, in addition to weed control, also have beneficial effects for the control of insects. Dinoseb treated fields showed fewer attacks of plant bugs. Similarly, MSMA and DSMA may reduce the infestation of fleahopper and plant bugs.

Herbicide Injury Symptoms in Cotton (Monaco et al 1986)

Herbicides	Injury Symptoms
Trifluralin (Treflan) Pendimethalin (Prowl) Oryzalin (Surflan)	Thickened hypocotyle and tap roots having reduced lateral roots and root hairs resulting in stunted plants.
Diuron (Karmex) Linuron (Lorox)	Veinal chlorosis and stunting. Occasionally interveinal chlorosis.
MSMA and DSMA	Red stems and leaf petioles, abnormal bolls and stunting.
Alachlor (Lasso) Metolachlor (Dual)	Stunted plants with rolled leaves that do not open normally.
Paraquat (Gramoxone)	Drift can cause leaf flecking to complete destruction of leaves.
Chlorsulfuron (Glean) Chlorimuron (Classic) Metasulfuron (Ally) Imazaquin (Scepter)	Stunting, mild chlorosis of leaves and reddish-purple stem.
Atrazine (AAtrex) Simazine (Princep) Propazine (Milogard) Fluometuron (Cotoran) Prometryn (Caparol)	Interveinal chlorosis (yellow) and stunting. Occasionally veinal chlorosis.
Fomesafen (Reflex)	Stunted seedlings with yellow leaves. Dead leaves turn brown or black as if burned.
2,4-D and other phenoxy herbicides Dicamba (Benvel) Picloram (Tordan)	Stunted plant with crinkled, strapped, elongated and malformed leaves.

Herbicide Resistance

Like insects, weeds also have a tendency to become resistant to herbicides. Continuous use of products which have similar modes of action and the growing of cotton in the same field for a long time enhance the chances of developing resistance. Resistance to specific herbicides has already been confirmed in goosegrass, palmer amaranth and johnsongrass in the USA. Duke (1993) has reported three possible mechanisms of resistance development. Weeds might develop resistance at the molecular site of action. All but a few herbicides have a molecular site of binding and if the binding site is changed, herbicides lose their ability to interfere with the metabolic processes. The second reason is the increased metabolic degradation of the herbicide. The third reason could be inability of the herbicide to be absorbed properly and reach the site of its activity. Herbicide resistance is yet a minor problem, but it is growing. Chances of developing resistant biotypes could be reduced by eliminating the continuous use of herbicides with the same mode of action, restricting the spread of resistant biotypes and following proper crop rotations.

Future Trends in Herbicide Use

Herbicides are not the most desirable systems of weed control but are without a doubt an effective way of controlling weeds. Herbicides were introduced as the cost of controlling weeds by other methods increased and will stay on the market until another more effective or less expensive method becomes available. With time, more advances will be made with respect to chemicals, mode of action and application technology to prevent losses.

Genetic engineering has opened a new era of herbicide use. Glyphosate is a very effective broad spectrum, postemergence herbicide used to control broad leaf weeds and grasses in cotton. Cotton is less sensitive to this herbicide, but one cannot spray glyphosate over cotton. Research has identified a bacteria gene, which, if inserted in the commercial cultivars, can save cotton from herbicide damage. The resistant gene has been inserted in cotton through biotechnology. Transgenic cotton could be sprayed with glyphosate without any risk to the cotton plant. A gene resistant to bromoxynil herbicide has also been identified and induced in cotton. More such genes are being identified. Transgenic cotton has reached the final stage of experimentation and is expected to be available to growers for commercial cultivation in 1994 or 1995, increasing the use of herbicides.

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Physiology of the Root System in Cotton

Cotton seed has a fairly hard seed-coat which may or may not have fuzz on it. Fuzz can be removed mechanically or chemically; usually, seed is treated with acid to remove fuzz without any injury to the seed parts inside its coat. The seed-coat provides protection against adverse weather conditions and physical injuries to the cotyledons and embryo. The seed-coat, on availability of desirable conditions, absorbs moisture from its surroundings and enables the embryo to grow. Cotton seed on the plant or just after harvesting is dormant and usually gives low germination. Dormancy is due to an inhibition of activity by abscisic acid; otherwise, the seed-coat is permeable all the time. Abscisic acid increases in the seeds up to 30-40 days after anthesis and, therefor starts decreasing to below the threshold level. By the time the seed is processed from the field to a warehouse, it is ready to give good germination. If conditions are favorable, i.e., soil temperature is above 20°C and enough moisture is available, the embryo will grow and develop a root. Cotyledons will grow in size after root growth. If the radicle fails to grow and does not develop a root, the germination process will cease. Germinating roots do not necessarily require light or darkness to grow, but probably grow better in darkness. The roots taper from the very beginning and have a tendency to grow downward in the soil. The hypocotyle, formed two days after emergence of the radicle, is always bent backward. As soon as it pulls the cotyledons out of the soil, it becomes straight, bringing the stem and cotyledonary leaves to an upright position. If the seed is sown too deep (below the depth of 10 cm), the hypocotyle may not be able to push the cotyledons out of the soil or may break in hard soils, thus ceasing the germination process. In this case, the root, which has already reached a depth of 13-15 cm, may also die. A high concentration of salts in the soil is also injurious to roots at germination. In case of injury to the main root, the cotton plant does not have the ability to form adventitious roots and provide support to the hypocotyle.

Root Growth

Tender and tapering roots ultimately develop a tap root system. The size of the root greatly depends on the physical texture of the soil, fertility, soil temperature and availability of moisture in the accessible zone, In the initial stages, the root grows much faster than at later stages. The rate of growth, which is more dependent on soil temperature, is different for different types of soils. The rate of root elongation in the soil may range from 1-6 cm per day depending on the conditions available in the soil. Afzal and Ali (1983) observed that on the average in sub-tropical climates, the primary root elongates at a rate of 0.9 mm per hour at 18°C. The roots of upland cotton go up to 1.82 m deep in soil under irrigated conditions in the USA, while Egyptian cotton grows roots up to 3 m deep under irrigated conditions. The lateral spread ranges from 76-91 cm under normal conditions.

The primary root can grow without any branching for the initial few days. The first secondary roots are formed generally about 12 cm behind the primary root apex, while tertiary roots are formed about 5 cm behind the secondary root apex (McMichael, 1986). After branching has started, if the primary root is injured, there is generally an increase in the number of secondary roots, one of which might take over and act as a primary root. Total root length continues to increase with the development of the plant until a maximum height is obtained. According to Afzal and Ali (1983), downward penetration of the root was at its peak after 90 days in the case of desi cotton and 90-120 days in the case of upland cotton. Fruit formation considerably curtails the root growth rate to the extent that the root ceases to grow any further. As the plant becomes older, root length begins to decrease because some of the older tertiary roots start dying but with almost no effect on the plant.

Root Structure

By the time the cotyledons emerge from the soil, the root is well anchored at the bottom below the plow layer. The first 5-8 cm behind the root tip is the most active site of water and nutrient uptake because it is always exploring fresh soil. The older root tissues behind the root tip absorb water and nutrients by extending root hairs and lateral roots into the surrounding unexplored soil. Root hairs grow from a single cell or the root tissues. Lateral roots develop at a later stage from inside the tap root tissues. To explore more area for water and nutrients, lateral roots grow horizontally in the soil. Lateral roots formed at an early stage, being close to the warm soil surface, are critical for seedling vigor. Tap roots and lateral roots have the ability to become thicker by adding new cells from inside the root. Once the roots start thickening, their ability to absorb water decreases with age. The youngest and most active roots in absorption are called "feeder roots." From boll formation onward, the roots usually lose their ability to regrow and compensate for any physical injury from cultivation. Cotton roots have a tendency to slow down their growth rate under dry conditions. Root density under favorable conditions is 5 cm per cubic cm. Under irrigated conditions, roots need to go deep into the soil to search for water. Roots have the maximum density in the upper 30 cm of the soil.

Methods of Measuring Root Systems

It is difficult to study the cotton root system and its functions, particularly under field conditions. There are different methods to measure root growth with the ultimate objective of undertaking studies under conditions as similar as possible to the natural conditions. Perhaps the easiest way to measure root growth is to dig the soil, take out the root, wash it and study it. This method is time consuming and requires a large amount of the field plot to be disturbed and rendered unusable for a number of years.

At the Southern Plains Cotton Research Laboratory of Plant Stress and Water Conservation Research, Lubbock, Texas, USA, greenhouse studies, a polyvinyl chloride tube, 180 cm long and 20 cm in diameter, is used to grow the plants. The tube is cut into sections 15 cm long for a total length of 1 m and into 30 cm sections for the remaining length and is reassembled with the help of a strong tube. A 2 cm window is cut in each piece which is then closed with tape. One end of the tube is closed before putting it in a container. While the tube is filled with soil, the remaining space in the container is filled with coarse gravel. Seeds are planted in the tube and soil samples are drawn with a specific sampler at various stages by removing the tape from the window. Root samples are washed to determine the root length and density at a particular depth.

The field technique is a modified form of the glass wall trench. The method basically consists of drilling a hole in the soil at 30 degrees from the plant to a depth of 1.5-2.0 m. A glass wall tube about 10 cm in diameter called Minirhizotron is inserted into the hole slightly bigger than the tube. Recently, the glass wall has been replaced with plexiglas. The tube is attached to a grid which indicates the depth of the tube, root length and root density be counting the number of roots crossing the horizontal transects of the grid. The technique has been refined by employing a camera, a mirror attached to a pole equipped with a light source and a low light television camera. The technique allows the measurement of root growth and density during the entire season under relatively natural field conditions.

Water and Nutrient Uptake

While the roots anchor the plant in the soil, the major function of the roots is to absorb water form the soil. The active root zone extends downward and outward. About 40% of the water supply is estimated to be absorbed by the top quarter of the root system, 30% by the second quarter, 20% by the third quarter and only 10% by the fourth or lowest quarter (Afzal and Ali, 1983). Soluble nutrients are absorbed automatically along with the water. Cotton roots have much more area to utilize for water and nutrient absorption compared with other field crops like corn, barley, rice, sugar-cane and wheat. When water in the leaves evaporates, it tugs on the roots, pulling soil water, as well as dissolved nutrients, into the roots. A low tran-spiration rate due to low atmospheric temperature of high humidity in the air depresses the need for water uptake. Ultimately, this adversely affects the supply of nutrients from the soil. The nitrogen supply is affected more than any other nutrient because of its solubility in water. Less soluble nutri-ents like potassium and micronutrients require roots to grow nearby so than they can diffuse from soil particles to the root surface. From the root surface, the nutrients are pumped inside via the metabolic processes.

Soil composition along with fertilizer use and irrigation water increase or decrease the amount of various nutrients in the soil. The availability of nutrients in the soil affects root growth and water uptake. As the seedlings develop and nutrient deficiency becomes more severe, the root growth and degree of branching also becomes affected (Radin and Eidenbock, 1993). In the case of deficiency of nitrogen and phosphorus, a change in the hydraulic conductance (efficiency of water transport) in the roots not only changes the root morphology but also the relative amount of young and old tissues.

Radin and Matthews (1988) concluded that N and P deficiency in the soil decreases root hydraulic conductivity thereby increasing the water deficit in the top portion of the plant. The phenomenon is more pronounced during the day when the transpiration rate is at the maximum. They observed that under nutrient stress conditions, biophysical properties of the cell membranes limit water passage to the upper parts of the plant.

Oxygen Supply

Roots grow in the soil only in the presence of water, oxygen and warm temperatures. The roots respire, take in oxygen available in the pore spaces and release carbon dioxide. In general, the soil air is 20% oxygen, 79% nitrogen and less than 1% carbon dioxide at a depth of about 15 cm (McMichael, 1986). Soil air composition is changed by soil temperature and soil water contents. Elongation of the root is affected if the availability of oxygen in the soil goes below 5%. Microorganisms compete with the roots for oxygen, the competition being higher in soils rich in organic matter. Oxygen is diffused through pore spaces. The supply of oxygen to roots is limited by soil water concentration and porosity. Water logging and high compaction fail to maintain the required level of oxygen in the soil, thus causing root suffocation. If water availability in the soil exceeds the field capacity, oxygen availability also goes below minimum levels. Lack of oxygen causes wilting and ultimately the death of the plant, a condition observed under heavy rains or flooding when water stands in the cotton field for 3-4 days. However, interculturing increases the availability of oxygen under normal conditions.

Temperature Effects

Root sensitivity to temperature is highest during the first few days after germination. McMichael et al (1990) grew cotton at constant temperatures of 10, 15, 20, 25, 30, 35, and 40°C to study the thermal dependence of the root system. They found that the optimum temperature for tap root growth was 30°C. Growth was reduced at both 20°C and 40°C, with low temperatures being more harmful. They found that the optimum temperature for lateral root initiation was 35°C. If the soil temperature exceeds 40°C, there is a danger of warming the soil beyond tolerable limits of the roots. Under such conditions, roots may die because of heat stroke, resulting in seedling mortality. The most appropriate temperatures for root growth range from 28-35°C. Cotton roots also do not grow if the soil temperature is less than 15°C. Growth is half of the maximum at 21-24°C and reaches the maximum at 32°C. When the root has attained sufficient length, a high daytime temperature even for a prolonged time may not affect the sensitive roots at lower depths. Undesirably high and low soil temperatures not only adversely affect root growth but also decrease water and nutrient uptake, especially P. Roots in cool soils are also more prone to seedling diseases.

Conclusion

Undoubtedly, the requirements of the cotton plant for water and nutrients are the highest at boll formation and boll filling stages. Any stress at these stage has a direct bearing on yield in the form of lower boll weight. On the other hand, by the time the plant reaches its maximum requirement, the roots are already losing their efficiency to absorb water and nutrients from the soil, usually resulting in an imbalance between the water and nutrient supply and the requirement of the plant. At this very critical stage, the plant does not have time to compensate for any losses. Research efforts are needed to increase understanding of and provide solutions for the balance of plant requirements and supplies from the root at later stages of boll development.

The root is a vital part of the plant, responsible for providing all nourishment from the soil. Unfortunately, very little work has been done on roots compared with the upper parts of the plant. What work has been done has been to understand the mechanism of the root’s functions or its behavior under various conditions. Additional studies are needed to improve the functioning of the root and better its abilities to avoid stress on the plant under both low and high soil moisture conditions.

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Short Notes

- Trap cropping is an old device used to minimize the populations of different cotton pests. The philosophy of trap cropping is to grow a small block of an early crop in order to attract the pest at a time when no other preferred host is available in the field. Once the adult insects have moved to that field, it is sprayed to kill the insects. The University of Arizona is trying trap cropping as a component of integrated pest management in Marana, Arizona. Pink bollworm larvae, *Pectinophora gossypiella*, look for older plants with buds, flowers and bolls to feed on and, more importantly, on which to lay eggs. In this effort, they are automatically attracted to the early grown crop. Spraying the trap crop before a specific date is not advised, thus allowing the population to build up. Before the insects move to a commercial crop, the trap crop is sprayed to kill the pink bollworm moth and plowed to destroy the infested parts of cotton plant. During 1992/93, growers spaced the trap crop at one-half mile intervals and planted 19 trap crop plots. This year there are 32 plots of trap crop scattered throughout the growing area of over 5500 hectares in the county. Uniformity of planting dates and in maturity fo varieties is an integral part of such a program. (Source: *The Cotton Gin and Oil Mill Press*, July 10, 1993)

- The International Textile Manufacturers Federation (ITMF) undertakes a survey on cotton contamination every other year. The survey, conducted regularly since 1982, provides information on the status of contamination and foreign matter in cotton produced in different countries. 235 mills from 30 countries participated in the 1993 survey. The number of samples evaluated varied from 1-180 for each country for a total of 1,575 samples. The survey questionnaire was designed to collect information on whether a mill noted fabrics and strings made of woven plastic, plastic film, jute/hessian and cotton, organic matter (sand/dust, rust, metal/wire) and other substances/chemicals (grease/oil, rubber, stamp color, tar) in a particular type of cotton used in their mill. In total, 16 sources of contamination were studied. The respondents were asked if the contamination was non-existent/insignificant, moderate or serious. The survey also included questions regarding stickiness and contamination from seed-coat fragments.

  The most contaminated cotton (all 16 sources included), where 30% or more of the samples had moderate or serious contamination, originated from Turkey (Cukurova and Izmir), India (H 4), Tanzania (Coastal) and Pakistan (MNH 93). Cotton coming from Zimbabwe, Mexico (Juarez), Israel (Acala), USA (El Paso) and Australia was the least contaminated. Contaminated samples from these countries were less than 5% of the total analyzed samples. Cotton from Spain, Togo, Chad, Israel (Pima), Burkina Faso, Côte d'Ivoire, Malawi, Paraguay, USA (Arizona, California, Pima) and Syria had 5-10% contaminated samples.

The most sticky cotton originated from Sudan. Shambat and Acala varieties were 100% sticky. More than 50% of the cotton surveyed from Nicaragua, Cameroon, Colombia (Coastal), China (Xinjiang) and USA (Arizona) had stickiness. Cotton from Pakistan (varieties/types other than Afzal, 1505 and MNH 93), Israel (Acala), Malawi and USA (El Paso) and Mexico (Juarez) was free of stickiness. Less than 10% of the samples showed stickiness in cotton coming from Argentina, Greece, Spain, Zimbabwe, Australia, Turkey (Antalya) and Uganda.

Seed-coat fragments were recorded in 40% or more of the samples of cotton originating from India (DCH, Shankar-4/6), Brazil (South Brazil), Sudan (Acala), Pakistan (MNH 93 and all others except Afzal and 1505), Turkey (Cukurova/Southeast) and Sudan (all except Shambat). Cotton from Mexico (Juarez and Mexicali) was free of seed-coat fragments. Only 8-9% of cotton samples from Greece, Nicaragua and Australia had seed-coat fragments.

On an overall basis, 85% of cotton is free of any contamination or has insignificant contamination. 11% of the sampled cotton had a moderate level of contamination of all the 16 sources of contamination. Only 5% of the cotton was found to be seriously contaminated. Organic matter and jute/hessian fabric and strings were found more frequently to be a source of contamination compared with others. Of the 1,575 samples, 26% of the cotton had some level of stickiness, while 36% had seed-coat fragments. Compared with the last survey undertaken in 1991, there is no improvement in the cleanliness of cotton. The stickiness problem is almost constant; if not improved significantly, at least it has not gotten worse. Seed-coat fragments increased from 34% in 1991 to 36% in the 1993 survey (Source: *ITMF Cotton Contamination Survey*, 1993)

- Plastic mulching is done in Spain and Greece with the objective of preserving moisture and improving soil temperature. Trials conducted in Côte d’Ivoire to compare mulching with conventional practices showed that mulching, on the average, increased soil temperature by 2.5°C. The results also revealed that on the 50th day of the crop, mulched plants were physiologically 5 days ahead of plants in the control plots. The mulched plants entered the fruiting phase earlier but terminated at the same time, thus giving an extended fruiting period. Weed control cost was lower in mulched plots as preemergence herbicide was required only on the uncovered area. The mulched plots gave a 20% higher seed cotton yield over non-mulched plots. The yield margin increased with the delay in the sowing date: 13% for early sowing (mid-June) and 23% for intermediate sowing (end of June) and 30% for late sowing (early July). The yield increase was due to a higher number of bolls and a higher seed index without any effects on lint percentage (Source: *Coton et fibres tropicales*, Vol. 48, No. 1, 1993)