Breeding and Cultivar Development of Cotton for specific Cropping Systems

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ABSTRACT

A cropping system integrates all practices to manage and produce a crop. In particular, there are usually constraints with soil, climate and pests that may limit productivity. The cotton plant has been very successfully adapted by breeding for our requirements. From originally selecting better plants from among very diverse wild populations, we have progressed through intensive conventional breeding programs to genetic engineering. The traditional genotype x environment analysis actually embodies system-specific breeding. This paper reviews where plant breeders have made an impact in adapting cotton for a wide range of systems and in particular in addressing problems such as climate (water or heat), diseases and pests. As a consequence, yields continue to rise. The development of earlier maturity in cotton cultivars has been important, allowing production in short or dry seasons. Likewise, tolerance to diseases such as Verticillium wilt has allowed cotton production to continue where those diseases occur. Significant improvements have been made in achieving tolerance to insect pests with morphological characters and especially with the development of transgenic Bt cotton. Production systems can be more successful or resume under circumstances where insect pests are a problem. The development of transgenic tolerance to herbicides will influence some cropping systems, allowing changes in weed control strategies, row space and mechanical harvesting methods. There will be a continuing need to raise yields by removing limits imposed by climate and pests. Even though breeding progress will continue, the best cropping systems should combine appropriate cultivar with good, responsible management.

Introduction

Over the centuries, man has made great progress in adapting the cotton plant. From what were tropical perennial shrubs, Gossypium hirsutum and G. barbadense now cover large areas of many different climates and soil types worldwide. Asian species G. arboreum and G. herbaceum also cover significant areas. Although all these species have a significant role in their own region, this review concentrates on G. hirsutum. Since selecting better plants among diverse wild populations (Niles and Feaster, 1984; Van Esbroeck et al., 1999), we have progressed through pioneering and intensive conventional breeding programs to the recent introduction of genetic engineering. Each step has progressed commercial performance: conventional breeding has increased yield by about 1% per year (Meredith, 1991; Culp and Green, 1992). Genetic engineering will assist with maintaining that improvement.

Whether the system is large scale and mechanized with high inputs, or a small-scale manual labour system, the grower is aiming to produce high and improving yields for their system. Brummer (1998) in questioning the sustainability of modern agricultural systems has highlighted the need to consider economic and environmental aspects in producing the best cultivars for diverse, stable integrated systems. This complicated subject highlights the role plant breeding can play in a farming system. Given the diverse cropping systems in existence for cotton, the breeder's role will vary accordingly.

Figure 1 depicts many of the more common issues and impacts of an overall cropping system for each soil type and climate. There are considerable interactions between these factors: crop rotation and tillage practices may have direct and indirect effect on soil issues such as erosion, compaction and fertility. Those effects may flow through to soil biology: there are impacts of crop rotation on insects, weeds and disease. Tillage to control insect pupae for example (Fitt and Forrester, 1987) or to incorporate stubble for disease management may have a negative impact on soil structure or weed management. These are not tenuous links with breeding and cultivar development because genetic tolerance to disease for example may make a production system both economically and ecologically more sustainable.

The common analysis of genotype x environment interaction (GxE) means one cultivar does relatively better in one location – system (environment) while another cultivar does relatively better at another system. The reasons for a GxE vary according to the scheme presented in Figure 1: it might arise from disease tolerance, earliness or some other factor under genetic control. The following sections illustrate the...
contribution made by plant breeding of cotton on components of the cropping system.

Mechanization and plant architecture

Cotton plant morphology is strongly genetically controlled and hence is relatively easily modified by breeding. Fruiting branch habit is determined by at least three genes that will determine branch length, cluster fruiting and even normal fruiting branches replaced by adventitious branches (Butany and Singh, 1963; Coffey and Davis, 1985). Plant architecture in terms of plant size, growth habit, earliness, fruiting branch length, boll size, boll shape, boll stormproof character, etc, can be important for the type of production system, particularly method of harvest. An example of purpose breeding for plant habit is Tadjik G. barbadense. These cultivars have been selected for 75-cm rows and mechanical harvesting and results in dramatic contrast in plant architecture (cluster fruiting) compared with conventional types.

Hand harvesting is still done on approximately 65% of cotton by area throughout the world. The best plant type for ease of hand harvesting is relatively tall with long fruiting branches and large bolls with locks that 'tag' out to some degree. These plants are usually widely spaced (<5/m²; (Lee, 1968; Matthews et al., 1972; Srisko et al., 1973).

The development of mechanical harvesting in cotton took more than 40 years and the current spindle picking concept has only been available since 1941 (Wendel, 1993). Modifications to stripper harvesting are still being made to develop a cheaper harvesting method than spindle pickers (Taylor et al., 1971).

For (brush or finger) stripper harvested cotton, the plant type is usually more determinate, earlier maturing, with shorter fruiting habit and some degree of stormproof of open bolls (Namken and Heilman 1973). Stripper cotton will be in more dense spacing (>15/m²; Parish et al., 1973), with ultra narrow rows being re-evaluated in recent studies (Brown et al., 1998; Gwathmey, 1998) with the incentive to gain early maturity and cheaper harvesting operations.

Spindle pickers require an intermediate type of plant habit and density, most likely because this harvest method is used in production systems with high input and high yield; some characters such as cluster fruiting and earliness maybe associated with lower yield potential.

It is interesting to note that published research results rarely demonstrate a strong, consistent and statistically significant interaction between plant morphology and yield under different plant spacing systems. Some interaction can be demonstrated in experiments with early determinate cultivars performing relatively better at high density (Marani et al., 1974; Low et al., 1975; Kerby et al., 1990; Heitholt, 1994), but others show no difference (Andries et al., 1971a; Rao and Weaver, 1976; Constable, 1977; Heitholt et al., 1996), so the interaction varies with each system. Overall my conclusion is that the best cultivar at a location for normal densities will usually be the best for high densities. There is a need for carefully designed research to address plant type requirements for different plant densities. The assumption that earliness or okra leaf shape or cluster fruiting confers a benefit under high density is not well proven. Plant breeders may well be advised to simply select for yield under high density and not constrain yield potential by starting with characters that prove to be unnecessary or detrimental.

Growth regulators are now commonly used to correct what might be an unacceptable growth habit in cotton (Cothren, 1994). Products such as mepiquat chloride can reduce cell expansion and so prevent excessive vegetative growth if applied at the correct time. If shorter, more determinate growth habits are desirable, then plant breeders can select for that either directly on a morphological basis, or preferably by aggressive selection for yield under the appropriate conditions. Some okra leaf types and a new normal leaf cultivar (Sicola 40) in Australia have little or no yield response to growth regulators (Constable, 1994). It seems incongruous to apply high rates of fertilizer and irrigation to a cotton crop, which then requires the use of a growth regulator on the subsequent excessive vegetative growth.

Many other aspects of agronomy and farming systems are affected by genotype. Differences between cultivars have been reported for water use efficiency (Ray et al., 1974; Quisenberry and McMichael, 1991; Stiller and Constable, 1999). Some cultivars are more tolerant to salt (Gossett et al., 1994). Other physiological measurements such as radiation use efficiency (Gerik and Rosenthal, 1990) and photosynthesis (El-Sharkawy et al., 1965; Pettigrew and Meredith 1994; Pettigrew and Turley 1998) have shown cultivar differences. Nutritional disorders can be modified by cultivar (manganese - Foy et al., 1969; Foy et al., 1981; potassium - Cassman et al., 1989), although Pettigrew et al. (1996) found no cultivar interactions with potassium and nitrogen requirement. All of these factors together will show differences between cultivars in different cropping systems. Gwathmey and Michaud (1998) found a significant cultivar-tillage interaction for earliness in a short season production system. It is important to recognise the reason why particular cultivars perform best in a system; whether the key factor was morphological, nutritional, pathological, etc needs to be known so that benefit can be exploited further.

Earliness

Earliness is one of the most powerful tools in a cropping system and cotton breeders have made very
significant progress in breeding types enabling successful production at high latitudes. Cotton is now grown successfully from the tropics to latitudes more than 40° north. Such a contrast in extremes and pattern of season length, rainfall and temperature create a challenge for cotton breeders. Higher latitudes have longer days in summer and some continental locations may have extremely high temperatures, so cultivar characteristics of vastly different combinations of maturity and heat tolerance are required for each climate. It is possible that earliness in some locations might limit yield potential (Quisenberry and Roark, 1976) and early maturing cultivars may have lower fiber properties (Murray and Verhalen, 1969). Earliness for each cropping system therefore becomes a careful calculation to optimise yield, quality, maturity and costs (Watson, 1980).

There are many incentives for earliness: of particular interest is to avoid cool temperatures at sowing or during fiber development; to match crop growth better with rainfall (Ngigi, 1994); to avoid rain near harvest; and to avoid late season insect damage such as boll weevil (Helms, 1980; Luttrel et al., 1994). In tropical Australia cotton is being researched as a winter crop to avoid the high level of Helicoverpa in summer (Strickland et al., 1998). This system does not necessarily require an early cultivar, but one which tolerates the short days of winter and finishes boll development under hot conditions.

Breeding procedures for earliness can involve selection for a low node of first fruit (Ray and Richmond, 1966) as well as careful evaluation of breeding material under the conditions expected. May and Bridges (1995) utilized a selection site with late sowing to identify genotypes best adapted to that particular short season condition.

**Disease**

Integrated Disease Management involves crop rotation, genetic resistance, biological control and chemicals. There are many examples of very successful resistance being exploited to cotton diseases such as bacterial blight (Knight, 1946), Verticillium wilt (Bell, 1994), Fusarium wilt (Ibrahim and Fadl Alla, 1994), Alternaria (Hillocks, 1991), nematodes (Noor M. and Jones, 1990; Creech et al., 1995; McPherson et al., 1995). There are many excellent reviews on this subject (Bird, 1975; Bird, 1982; Innes, 1983; El-Zik, 1985; Hillocks, 1992; Hillocks, 1998). Different disease tolerance between cultivars is often a major cause of large GxE effects in multisite experiments.

Disease nurseries and artificial infection are used for screening for diseases. In many cases of disease the uniformity of infection can limit accuracy in nurseries. Bassett (1974) and Marani and Yaacobi (1976) found that when screening for *Verticillium* infection, it was better to assess foliar symptoms at peak flower, rather than stem cuts at maturity. Markers for the presence of disease resistance genes would be very helpful in a breeding program, but none of these have reached the application stage yet.

**Insects**

Integrated Pest Management will involve genetic resistance, biological control, cultural manipulation and chemicals in association with accurate scouting using appropriate pest damage thresholds that take account of natural plant compensation for damage.

Reviews of Host Plant Resistance characters used in cotton show there are real benefits to be exploited in breeding (Thomson, 1987; El-Zik et al., 1991; Jenkins, 1994). Commercial applications for these characters are less than desired for some breeders, but successful examples are gossypol gland density (Parrott et al., 1989; Calhoun 1997), nectariless (Meredith, 1991), okra leaf shape (Thomson 1994) and leaf hair (Mursal, 1994). Transgenic cotton expressing the Bt gene (Perlak et al., 1990) has been commercial for up to five years in the USA. This technology has enabled a 50% decrease in pesticide application to cotton in Australia (Long et al., 1997). We need management systems to protect this technology from insects developing resistance to the Bt protein (Roush, 1994). That will need a contribution from breeders in possibly stacking different insect-active genes.

Breeding procedures to select for insect resistance range from unsprayed plots to artificial infection (Jenkins and McCarty, 1994; Jenkins et al., 1998). It is important to recognise that yield potential is a HPR trait (Thomson, 1987; McCarty and Jenkins, 1995): a high yielding genotype with damage may still yield more than a genotype with a trait associated with a yield penalty.

**Weeds**

Integrated Weed Management involves cultural, chemical and biological methods. In practice that will involve crop rotation and cultivation combined with herbicides and Andries et al. (1971b) demonstrated cultivar and row space differences on weeds, with wide rows and okra leaf permitting greater weed incidence.

A very significant genetic component of IWM is now possible with the development of transgenic herbicide tolerance to Bromoxynil (Panter, 1997), Glyphosate (Hearing et al., 1998) and Glufosinate (Dotray et al., 1998) by a number of different chemical and seed companies. That new technology will allow some changes to the herbicide spectrum being applied (reduction in some residuals, Charles et al., 1995) and also allow for other changes to the cropping system such as reducing the row spacing (Kerby, 1998).
Conclusions

Plant breeders have made a significant contribution to improving productivity and sustainability of cotton cropping systems throughout the world. Yield and fiber quality have been improved through disease tolerance, earliness, etc. We are benefiting from a tradition of excellent research and development in many disciplines that has followed cotton from early times. The lesson is that we should continue a high standard of science in addressing and solving production or environmental problems.

Cultivar is only one component of a cropping system, so there is little use in having all the management refined if the wrong cultivar is grown. Likewise having a cultivar with high yield potential is wasted in a system which lacks some essential management factor such as fertilizer or weed control.

References


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Figure 1. Interrelationships between management issues and impacts in a cotton cropping system for each soil type and climate. Plant breeding and cultivar developments have a role to play in many of these factors to produce a sustainable and productive system.