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 dries 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

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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 $<5/m^2$ (Lee, 1968; Matthews *et al.*, 1972; Srisook *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 ($> 15/m^2$; 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 (Sicala 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 40o 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; Luttrell *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 V*erticillium* 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 (Heering *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

Andries, J.A., A.G. Douglas and R.C. Albritton. (1971a): Performance of normal, okra and super okra leaf types in three row widths. In: Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Council, Memphis. TN. Pp 59.

Andries, J.A., A.G. Douglas and R.C. Albritton. (1971b): Effectiveness of weed control treatments in cotton of three leaf types grown in three row widths In: Proc. Beltwide Cotton Prod. Res. Conf. J.M. Brown (Ed). Natl. Cotton Council, Memphis. TN. Pp 65.

Bassett, D.M. (1974): Resistance of cotton cultivars to Verticillium wilt and its relationship to yield. Crop Sci. 14, 864-867.

Bell, A.A. (1994): Mechanisms of disease resistance in Gossypium species and variation in *Verticillium dahliae*. In: Challenging the Future: Proc. World Cotton Research Conf.e-1. G.A. Constable and N.W. Forrester (Eds), CSIRO, Melbourne. Pp 225-235.

Bird, L.S. (1975): Genetic improvement of cotton for multi-adversity resistance. In: Proc. Beltwide Cotton Conf. J.M. Brown (Ed). Natl. Cotton Council, Memphis.TN. Pp 150-152.

Bird, L.S. (1982): The MAR (Multi-Adversity Resistance) system for genetic improvement of cotton. Plant Dis. 66:172-176.

Brown, A.B., T.L. Cole and J. Alpha. (1998): Ultra narrow row cotton: economic evaluation of 1996 BASF field plots. In: Proc. Beltwide Cotton Conf. P. Dugger and D.A Richter (Eds). Natl. Cotton Council, Memphis. TN. Pp 88-91.

Brummer, E. C. (1998): Diversity, stability and sustainable American agriculture. Agron. J. 90:1-2.

Butany, W.T. and M. Singh. (1963): Inheritance of uni-nodal sympodium and flower cluster habit in an intra *Gossypium hirsutum* cross. Indian J. Genet. Plant Breed. 23:300-305.

Calhoun, D.S. (1997): Inheritance of high glanding, and insect resistance trait in cotton. Crop Sci. 37:1181-1186.

Cassman, K.G., T.A. Kerby, B.A. Roberts, D.C. Bryant and S.M. Brouder. (1989): Differential response of two cotton cultivars to fertilizer and soil potassium. Agron. J. 81:870-876.

Charles, G.W., G.A. Constable and I.R. Kennedy. (1995): Current and future weed control practices in cotton: the potential use of transgenic herbicide resistance. In: Herbicide Resistant Crops and Pastures in Australian Farming Systems. G.C McLean and G. Evans (Eds). DPIE, Canberra. Pp 89-100.

Coffey, B.N. and D.D. Davis. (1985): Short-branch and cluster-fruiting habit inheritance in crosses of eight cotton lines. Crop Sci. 25:729-731.

Constable, G.A. (1977): Narrow row cotton in the Namoi Valley. I. Growth, yield and quality of four cultivars. Aust J. Exp. Agric. Anim. Husb. 17:135-142.

Constable, G.A. (1994): Predicting yield responses of cotton to growth regulators. In: Challenging the Future: Proc. World Cotton Res. Conf.-1. G.A. Constable and N.W. Forrester (Eds). CSIRO, Melbourne. Pp 3-5.

Cothren, J.T. (1994): Use of growth regulators in cotton production. In: Challenging the Future: Proc. World Cotton Res. Conf.-1. G.A. Constable and N.W. Forrester (Eds), CSIRO, Melbourne. Pp 6-24.

Creech, R.G., J.N. Jenkins, B. Tang, G.W. Lawrence and J.C. McCarty. (1995): Cotton resistance to root-knot nematode. 1. Penetration and reproduction. Crop Sci. 35:365-368.

Culp, T.W. and C.C. Green. (1992): Performance of obsolete and current cultivars and Pee Dee germplasm lines of cotton. Crop Sci. 32:35-41.

Dotray, P.A., J.W. Keeling, J.R. Gannaway, I.K. Blair, J.E. Quisenberry and M.J. Oliver. (1998): Performance of Liberty-tolerant cotton. In: Proc. Beltwide Cotton Conf. P Dugger and D.A Richter (Eds). Natl. Cotton Council, Memphis, TN. Pp 860.

El-Sharkawy, M.A., J.D. Hesketh and H. Muramoto. (1965): Leaf photosynthetic rates and other growth characteristics among 26 species of *Gossypium*. Crop Sci. 5:173-175.

El-Zik, K.M. (1985): Integrated control of Verticillium wilt of cotton. Plant Disease. 69:1025-1032.

El-Zik, K.M., P.M. Thaxton and R.A. Sequeira (1991): Genetic gains in resistance to pests in the MAR germplasm. II. Insects. In: Proc. Beltwide Cotton Conf. D.J. Herber and D.A Richter (Eds). Natl. Cotton Council, Memphis, TN. Pp 545-549.

Fitt, G.P. and N.W. Forrester. (1987): Overwintering of *Heliothis*: the importance of stubble cultivation. The Australian Cottongrower 8(4):7-8.

Foy, C.D., A.L. Fleming and W.H. Armiger. (1969): Differential tolerance of cotton varieties to excess manganese. Agron. J. 61:690-694.

Foy, C.D., H.W. Webb and J.E. Jones. (1981): Adaptation of cotton genotypes to an acid, manganese toxic soil. Agron. J. 73:107-111.

Gerik, T.J. and W.D.Rosenthal. (1990): Varietal differences in radiation-use efficiency. In: Proc. Beltwide Cotton Conf. J.M. Brown and D.A Richter (Eds). Natl. Cotton Council, Memphis, TN. Pp. 52.

Gossett, D.R., E.P. Millhollow and M.C. Lucas. (1994): Antioxidant response to NaCl stress in salt-tolerant and salt-sensitive cultivars of cotton. Crop Sci. 34:706-714.

Gwathmey, C.O. (1998): Reaching the objectives of ultra-narrow row cotton. In: Proc. Beltwide Cotton Conf. P Dugger and D.A Richter (Eds). Natl. Cotton Council, Memphis, TN. Pp 91-92.

Gwathmey, C.O. and C.E. Michaud. (1997): Conventional and no-tillage effects on earliness of contrasting cotton varieties. In: Proc. Beltwide Cotton Conf. P Dugger and D.A Richter (Eds). Natl. Cotton Council, Memphis, TN. Pp1457.

Heering, D.C., R.D. Voth, K. Ferreira and J.A. Mills. (1998): Commercial experience with Roundup Ready cotton in 1997. In: Proc. Beltwide Cotton Conf. P Dugger and D.A Richter (Eds). Natl. Cotton Council, Memphis, TN. Pp 851.

Heitholt, J.J. (1994): Canopy characteristics associated with deficient and excessive plant population densities. Crop Sci. 34:1291-1297.

Heitholt, J.J., W.R. Meredith and J.R. Williford. (1996): Comparison of cotton genotypes varying in canopy characteristics in 76 cm vs 102 cm rows. Crop Sci. 36: 955-960.

Helms, D. (1980): Revision and reversion: changing cultural control practices for the cotton boll weevil. Agric. History 54:108-125.

Hillocks, R.J. (1991): *Alternaria* leaf spot of cotton with special reference to Zimbabwe. Trop. Pest Management 37:124-128.

Hillocks, R.J. (1992): (Ed.) Cotton Diseases. CAB International, 403 pp.

Hillocks, R.J. (1998): Cotton disease control: contrasting approaches. In: New Frontiers in Cotton Research: Proc. World Cotton Res. Conf.-2 F. Gillham (Ed); Publishers: WCRC-2 Organizing and Scientific Committees, Athens, Greece. In press.

Ibrahim, G. and A.S. Fadl Alla (1994): Loss in seed cotton yield due to *Fusarium* wilt in Sudan Gezira. In: Challenging the Future: Proc. World Cotton Res. Conf.-1. G.A. Constable and N.W. Forrester (Eds). CSIRO, Melbourne. Pp. 242-243.

Innes, N.L. (1983): Bacterial blight of cotton. Biol. Rev. 58:157-176.

Jenkins, J.N. (1994): Host plant resistance to insects in cotton. In: Challenging the Future: Proc. World Cotton Res. Conf.-1. G.A. Constable and N.W. Forrester (Eds). CSIRO, Melbourne. Pp. 359-372.

Jenkins, J.N. and J.C. McCarty. (1994): Comparison of four cotton genotypes for resistance to *Heliothis virescens*. Crop Sci. 34:1231-1233.

Jenkins, J.N., J.C. McCarty, R.E. Buehler, J. Kiser, C. Williams and T. Wofford. (1998): Resistance of cotton with d-endotoxin genes from *Bacillus thuringiensis* var. *kurstaki* on selected Lepidopteran insects. Agron. J. 89:768-780.

Kerby, T.A. (1998): UNR cotton production system trial in the mid-south. In: Proc. Beltwide Cotton Conf. P Dugger and D.A Richter (Eds). Natl. Cotton Council, Memphis. Pp 87-88.

Kerby, T.A., K.G. Cassman and M. Keeley, (1990): Genotypes and plant densities for narrow-row cotton systems. 1. Height, nodes, earliness and location of yield. Crop Sci. 30: 644-649.

Knight, R.L. (1946): Breeding cotton resistant to black arm disease (*Bact. malvacearum*). Empire J. Exp. Agric. 14:153-174.

Lee, B.J.S. (1968): Agronomic trials on cotton in Western Nigeria 1962 to 1967. Cotton Grow. Rev. 45: 81-90.

Long, A., B, Pyke and P. Slack-Smith. (1997): The performance of Ingard cotton in Australia, 1996/97 season. Occasional Paper, Cotton R and D Corporation, Narrabri, N.S.W. 23 pp.

Low, A., J.P. McMahon and G. Pistillo. (1975): Varietal responses to high plant densities in three climatic regimes in Australia. Cotton Grow. Rev. 52:112-125.

Luttrell, R.G., G.P. Fitt, F.S. Ramalho and E.S. Sugonyaeu. (1994): Cotton Pest Management Part 1: A World Wide Perspective. In: Cotton Pest Management. R.G. Luttrell, G.P. Fitt, F.S. Ramalho and E.S. Sugonyaeu. (Eds) Annual Review of Entomology. Entomological Society of America. Pp 517-536.

Marani, A. and Y.Z. Yaacobi. (1976): Evaluation of Verticillium wilt tolerance in upland cotton relative to lint yield reduction. Crop Sci. 16:392-395.

Marani, A., E. Ephrat and Z. Dor. (1974): Effect of wide plant spacing on six cultivars of upland cotton. Crop Sci. 14:271-275.

Matthews, G.A., J.G. Rowell and P. Beeden. (1972): Yield and plant development of reduced cotton stands in Malawi. Exptl. Agric. 8:33-48.

May, O.L. and B.C. Bridges. (1995): Breeding cottons for conventional and late-planted production systems. Crop Sci. 35:132-136.

McCarty, J.C. and J.N. Jenkins. (1995): Performance of commercial cotton cultivars under elevated densities of tobacco budworm. Agron. J. 87:804-807.

McPherson, G.R., J.N. Jenkins, J.C. McCarty and C.E. Watson. (1995): Combining ability analysis of root-knot nematode resistance in cotton. Crop Sci. 35:373-375.

Meredith, W.R. (1991): Contributions of introductions to cotton improvement. In Use of Plant Introductions in Cultivar Development, Part 1, CSSA Special Publication No 17, Madison WI, Crop Sci. Soc. of America, 1991. Pp 127-146.

Murray, J.C. and L.M. Verhalen. (1969): Genetic studies of earliness, yield and fiber properties in cotton (*Gossypium hirsutum* L). Crop Sci. 9:752-755.

Mursal, I.E.J (1994): New cotton varieties for cotton pest management. In: Challenging the Future: Proc. World Cotton Res. Conf.-1. G.A. Constable and N.W. Forrester (Eds). CSIRO, Melbourne. Pp. 373-375.

Namken, L.N. and M.D. Heilman. (1973): Determinate cotton cultivars for more efficient cotton production on medium textured soils in the Lower Rio Grande Valley of Texas. Agron. J. 65:953-956.

Ngigi, R.G. (1994): Performance of early and late maturing varieties of cotton (Gossypium hirsutum L) in the marginal rainfall areas of central and eastern Kenya. In: Challenging the Future: Proc. World Cotton Res. Conf.-1. G.A. Constable and N.W. Forrester (Eds). CSIRO, Melbourne. Pp. 389-392.

Niles, G.A. and Feaster, C.V. (1984): Breeding. In Cotton, R.J. Kohel and C.F. Lewis (Eds). American Society of Agronomy, Madison, WI, pp 201-231.

Noor Muhammad and J.E. Jones. (1990): Genetics of resistance to reniform nematode in upland cotton. Crop Sci. 30:13-16.

Panter, D., R. Ward, M. Barfield, J. Kiser and C. Houck. (1997): BXN47: a new Buctril resistant cotton variety from Stoneville Pedigreed Seed company. In: Proc. Beltwide Cotton Conf. P Dugger and D.A Richter (Eds). Natl. Cotton Council, Memphis, TN. Pp. 43.

Parish, R.L., S.M. Brister and D.E. Mermoud. (1973): Wide bed, narrow row cotton: preliminary research results. Ark. Farm Res. March-April 1973.

Parrott, W.L., J.N. Jenkins, J.C. Mulrooney, J.C. McCarty and R.L. Shepherd. (1989): Relationship between gossypol gland density on cotton squares and resistance to tobacco budworm larvae. J. Econ. Entomol. 82:589-592.

Perlak, F.J., W.R. Deaton, R.L. Armstrong, R.L. Fuchs, S.R. Sims, J.T. Greenplate and D.A. Fishoff. (1990): Insect resistant cotton plants. Bio/Technology 8:939-942.

Pettigrew, W.T. and R. Meredith. (1994): Leaf gas exchange parameters vary among cotton genotypes. Crop Sci. 34:700-705.

Pettigrew, W.T. and B.B. Turley. (1998): Variation in photosynthetic components among photosynthetically diverse cotton genotypes. Photosynthesis Res. 56:15-25.

Pettigrew, W.T., J.J. Heitholt. and W.R. Meredith. (1996): Genotype interactions with potassium and nitrogen in cotton of varied maturity. Agron. J. 88:89-93.

Quisenberry, J.E. and B. Roark. (1976): Influence of indeterminate growth habit on yield and irrigation water-use efficiency in upland cotton. Crop Sci. 16:762-765.

Quisenberry, J.E. and B.L. McMichael. (1991): Genetic variation among cotton germplasm for water use efficiency. Envir. Exp. Bot. 31:453-460.

Rao, M.J. and J.B. Weaver. (1976): Effect of leaf shape on response of cotton to plant population, nitrogen rate, and irrigation. Agron. J. 68:599-601.

Ray, L.L and T.R. Richmond. (1966): Morphology measures of earliness of crop maturity in cotton. Crop Sci. 6:527-531.

Ray, L.L., C.W. Wendt, B. Roark and J.E. Quisenberry. (1974): Genetic modification of cotton plants for more efficient water use. Agric. Meteorol. 14:31-38.

Roush, R.T. (1994): Managing pests and their resistance to *Bacillus thuringiensis*: Can transgenic crops be better than sprays ? Biocontrol Science and Technology 4:501-516.

Srisook, D., R. Ferraris and P. Mathpon. (1973): Effect of time of sowing, spacing and nitrogen on cotton in the central plain of Thailand. Cotton Grow. Rev. 50:63-71.

Stiller, W.N. and G.A. Constable, G.A. (1998): Identification of characters for selecting increased water use efficiency in cotton. In: New Frontiers in Cotton Research: Proc. World Cotton Res. Conf.-2. F. Gillham (Ed). Publishers: WCRC-2 Organizing and Scientific Committees, Athens, Greece. In press.

Strickland, G.R., S.J. Yeates, G.P. Fitt and G.A. Constable. (1998): Prospects for a sustainable cotton industry in tropical Australia using novel crop and pest management. In: New Frontiers in Cotton Research: Proc. World Cotton Res. Conf.-2. F. Gillham (Ed). Publishers: WCRC-2 Organizing and Scientific Committees, Athens, Greece, In press.

Taylor, P.A., J. Czech and W.R. Read. (1971): CSIRO development in narrow row cotton harvesting. Power Farming and Better Farming Digest, January 1971.

Thomson, N.J. (1987): Host plant resistance in cotton. J. Aust. Inst. Agric. Sci. 53:262-270.

Thomson, N.J. (1994): Commercial utilization of the okra leaf mutant of cotton – the Australian experience. In: Challenging the Future: Proc. World Cotton Res. Conf.-1. G.A. Constable and N.W. Forrester (Eds). CSIRO, Melbourne. Pp. 393-401.

Van Esbroeck, G.A., D.T. Bowman, O.L. May and D.S. Calhoun. (1999): Genetic similarity indices for ancestral cotton cultivars and their impact on genetic diversity estimates of modern cultivars. Crop Sci. 39:323-328.

Watson, T.F. (1980): Short-season cotton in the west. The Cotton Gin and Oilmill Press, Jan 26, 1980. Pp 29-30.

Wendel, C.H. (1993): 150 Years of International Harvester. Motorbooks International: Osceola WI. 416 pp.

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.