The Agronomy of Complex Farming Systems

Grant Roberts
Australian Cotton Cooperative Research Centre and CSIRO Plant Industry, Narrabri, NSW 2390

Abstract

Responsible cotton production – this is the future. Increasingly the growing of cotton will need to be conducted in a way that minimises its perceived impact on the environment and greater community. This will need to involve a greater understanding of the interactions that occur within our cotton production system such that we start to maximise the synergies that can be achieved by optimsing the components that interact. A top down approach of looking at important driving influences such as economics and linking this to rotation and agronomy planning can provide some important clues as to the direction cotton growers can take their production systems in the future. The farming systems approach aims to link some or all of the various components (soil, insects, weeds, disease, water, economics) into a single framework. Many components of a sustainable system have been researched and are ready to be applied to a package.

Why are we researching complex farming systems?

The simple answer to this question is that the easy questions have already been dealt with in a vast array of excellent discipline related research over the past 30 years. We have good knowledge on nutrition, water management, soils, varieties, insect ecology and the general agronomy of cotton which is evidenced by some of the highest average yields/ha in the world. However, as we move into the next 30 years of cotton production in Australia the consummation of this previous knowledge into a fully integrated production system will be essential not only to increase yield but maintain the economic advantage cotton has as a broadacre field crop. Cotton growers will be increasingly challenged to reduce the level of synthetic inputs in an attempt to reduce the negative impacts (real or perceived) on the environment and communities in which they farm. As such this will require more sophisticated farming systems that utilise all of the knowledge we have to grow cotton in a way that is still economically viable.

In essence many growers, consultants and agronomists have come to a point where the decision on which way to direct their cotton production is not as simple as when the knowledge base was more limited. Often there appears to be a conflict in selecting certain options (e.g. cereals versus legume rotation crops, direct drill versus pupae busting, retaining crop residues versus burning for disease control), however, in many cases these are not conflicting strategies, just different approaches. Our aim therefore in conducting farming systems research is to examine the 'sum of the effects' in a package which will help deliver answers to the more complex questions now being asked.

What are the questions now being asked?

The key question is 'How do we manipulate our farming system to deliver high yields sustainably'.

Economics

If we consider that economics are the most important consideration for the cotton grower and a suitable return on capital invested is a major goal then the Australian Cotton CRC rotation sites can provide an interesting starting point for some comparisons. Table 1 provides yields and gross margin estimates for six rotations at Merah North, NSW. The two points that are clear from this medium term experiment are that even though continuous cotton yields decline over time, the cumulative gross margin is superior to any other rotation. Clearly the high price received for cotton lint relative to the other commodities is driving the economic profitability of this rotation. Nevertheless the yields have not declined to a point where the gross margin is compromised, the obvious question is how long can this continue? A similar trend was found at the Australian Cotton CRC Warren site (Hickman *et al.* 1998).

Table 1. Number of cotton crops for each rotation, average annual yield (bales/ha) and cumulative gross margin for each rotation at the Australian Cotton CRC Merah north rotation site from June 1993 to May 1999. (source Hulugalle *et al.* 2000)

Treatment	Number of cotton crops	Average yield (bales/ha)	Cumulative Gross margin ($/ha)
Continuous-cotton	6	6.4	$9,534
Long fallow-cotton	3	7.8	$5,935
Fababean-cotton	4	6.1	$4,413
Lablab/fababean/wheat-cotton[1]	3	7.7	$5,943
Lablab-cotton	3	7.6	$5,437
Lablab (P+K)-cotton[2]	3	7.9	$5,323

[1] Lablab and fababean green manured in the first year followed by a wheat-cotton rotation.
[2] Phosphorous and Potassium equivalent to that removed in seed cotton added as fertiliser.

Insects

Insect management ranks only second to economics as a major driving force behind the methods of growing cotton in Australian. The questions now being asked are how do we manage populations of *Helicoverpa* and other insects that are highly resistant to a large percentage of our conventional insecticides? What do winter rotation crops do to the local populations of both problem and beneficial insects? Can we utilise these crops to our advantage? These questions are most relevant to the intensive mixed cropping locations such as the Darling Downs but have significant implications to Area Wide Management and Integrated Pest Management concepts in all valleys. The deployment of *Bt* technology adds additional constraints to crop rotations and soil management due to mandatory pupae busting. Growers who wish to practice direct drilling, particularly in dryland cropping situations, desperately require accurate methods of soil pupae detection to estimate reliably the risks in each field. The use of insect models to simulate diapause induction relative to when the dryland crops finish will be a useful tool in the future. It is possible that if regrowth elimination was guaranteed, some of these crops would have no pupae below them. In the end the desire to find new methods of *Helicoverpa* management may be the key driver of reduced till permanent bed systems. There is some evidence that *Helicoverpa* numbers are reduced where cotton is planted into standing stubble (Waters *et al.* 1998). There are also measurable differences in secondary pest and beneficial insect populations (Robert Mensah pers comm) which may be important in the overall management of insects. The concept is gaining momentum in all cotton valleys and reconfirms the need to assess this system thoroughly.

Soils

Ranking equal to water, soil is the most important asset the cotton grower owns but this is often where the greatest number of conflicts appear to occur (real or perceived).

Cultivation

There is clear evidence that suggests excessive cultivation causes structural decline and compaction (Freebairn *et al.* 1998) of soils yet several cultivation passes per field are still widely practiced. Growers often suggest the crop looks greener after cultivation and at least in 1m bed formations there is some requirement to reform the hills and furrows. Recent work by Skjemstad *et al.* (1998) also suggests that some cultivation to mix the different layers of non-living soil organic matter may be beneficial. There are however several growers who have had 2m permanent beds in place for 10 years or more. Why is it that the industry has not adopted these as standard practice? The new Beeline guidance system recently introduced to Australia will also make the permanent bed system much easier to implement. Some growers have sited problem weeds such as nutgrass as a reason for not accepting this technology, however, there is no clear evidence that permanent beds alone are responsible for this weeds increase in fields already infested.

Insect management

Cereals verse Legumes

There is sometimes a debate as to the type of rotation crop that should be used, legume or cereal. The decision can be easily clarified by determining the requirements of the rotation crop. The simplest and easiest to manage of the rotation crops are the cereals wheat and barley. These two crops are easy to establish, have an excellent range of herbicide control options, grow rapidly, are easily marketed and profitable. Hulugalle *et al* (1999) has also shown that wheat is excellent in maintaining and or repairing soil structure, nutrient recycling and does not contribute to disease build up. The obvious advantages of legumes are the ability to contribute nitrogen to the soil reducing the need for additional fertilizer N. Rochester *et al.* (1998) has demonstrated this ability with a range of summer and winter legumes. There are questions about disease carryover and buildup and phytotoxic affects that still need addressing with legumes. The herbicide options for controlling weeds in legume rotations is significantly reduced along with the ability to kill the legume when required. It is also known that legumes such as chickpeas can be excellent early hosts for *Helicoverpa*, which is often not desirable. The agronomic management of legumes is also significantly higher than cereals with most legumes sensitive to depth of sowing, residual herbicides, phosphorous and zinc levels and a range of leaf diseases. One of the most promising legumes is vetch. It is inexpensive and has few disease problems. It grows well in our soils and provided it is sown early and achieves a large biomass by spring can provide in excess of 170 kg/ha of nitrogen if green manured (Rochester and Peoples 1998). Combinations of vetch and cereals in an inter-row configuration (e.g. furrow-vetch, hill-cereal) could prove useful in possibly providing benefits equal to growing a cereal and legume to the same field. Winter weed control may however be a problem

Weed management

The majority of herbicides registered in cotton are applied as soil applied residuals. Most of these do an excellent job in controlling weeds. The main problem is lack of flexibility with other management strategies. Products such Trifluralin and Pendimethalin require incorporation and as such can be in direct conflict with direct drilling and minimum tillage. Slashed or standing stubble also reduces soil-herbicide contact and increases organic matter that can tie up herbicides, effectively deactivating them. The use of inter-row cultivation can be very effective in controlling furrow weeds and is a recommended integrated weed management tool but each pass compacts the soil, damages roots and kills some cotton plants. In cover crop and mulch systems, cultivation is lost as a tool and weed management within the cover/mulch crop and the cotton crop is completely reliant on herbicides. The use of post emergent herbicides in herbicide tolerant varieties will.

Diseases

Disease management has almost been exclusively managed with seed dressings and resistant or tolerant varieties. Until the advent of Fusarium wilt and the increase in black root rot levels in 1992/93 this approach was effective with levels of diseases such as Verticillium wilt actually decreasing (Allen and Lonergan 1998). Both black root rot and Fusarium seem to increase independently of crop rotation and Black Root Rot severity is mostly a function of the number of the years cotton is grown within a field. There is a strong need for the farming systems approach to tackle this problem, to minimise the impact of Fusarium until varietal resistance/tolerance can be found. The concept of growing the least susceptible variety × most effective biocontrol agent × appropriate agronomic management package needs to be examined.

Summary

In summary, of the above components it is clear that the number of cotton crops in a rotation drives the profitability but what is less clear are the long term effects of continuous cotton on soil, disease, weeds and localised insect population properties. We don't have long term data on when yield declining attributes (disease, structural decline, etc) level off, but we know from medium to long term cropping experiments in other systems that measurable differences can take up to ten years or more to materialise. Are our soils different or does it even matter that we degrade them to a lower but more stable plateau that still supports economic cotton production? There are some fields in the Namoi valley that have had continuous cotton for at least 15 years or more, and are still profitable. The question of a need to have a rotation is probably valid but the long term field experiments to answer this question are only in their infancy. The ability to reverse any adverse effects particularly to soil structure will be essential if soil properties were degraded to the point of severely limiting yield. All rotation crops repair the soil structure to some degree and legumes have the additional benefit of providing nitrogen. Given most growers have more land than water allocation, rotation crops are probably here to stay.

Building flexibility and adaptability into the system

It is important that we remain flexible in our farming systems to allow for changing circumstances. Change on a yearly basis may occur in many areas including climate, insect, weed and disease pressure, water allocations, economics of inputs and outputs, environmental requirements and lifestyle. The ability to manage this change by having access to a range of options will ensure that each cotton operation returns an adequate result (i.e. profit, spray reduction) in each year cotton is grown.

To understand how important flexibility can be in adapting to this change the hypothetical example of optimizing a rotation to cotton price variability will be used. A typical 3 year irrigated cotton rotation is Cotton-Cotton-Wheat. Two scenarios are then put forward-: Scenario A the cotton price remains constant for the three years with the result there is no advantage to gross income if the rotation is changed. In scenario B the cotton price drops by $100/bale in year 2 and increases by $100/bale in year 3. The average cotton price for the three years is the same for both Scenario A and B but by dropping out cotton and growing wheat in year 2 because the price was lower and then growing the cotton in year 3 when the price went up the grower is financially better off over the rotation. Importantly the number of cotton crops has not changed just the sequence they were grown. This is an over simplification of the system because in practice the use of cotton futures and currency hedging can reduce the effects of price fluctuations, but the principles remain intact for a range of variables including agronomics. It can be quickly surmised from the simple example above that the most profitable time to grow cotton is when the price is at its highest. However, to further improve the gross income it would be even better if the yield increased in the same year that the price did. Table 1 suggests that rotations involving legumes or wheat can optimise cotton yield. In addition it would be better again if the area devoted to cotton was also maximised on the farm at the same time. This of course depends on water allocation, machinery and labour supply and the ability to manage the larger cotton areas. The main point is that the ability to switch in and out of cotton production to optimise an outcome (in this case profitability) is important. There are numerous other examples were an outcome can be optimised by having flexibility built into the system.

In the future the use of a number of models that integrate climate, crop yield, insect pressure and economic scenarios will enable us to explore options in the farming system as required on a strategic (i.e. yearly) and tactical (i.e. daily) basis. These models will not replace on-farm field experimentation but will allow a greater number of scenarios to be tested via simulation than could otherwise occur. The introduction of these models has already been successful in small farm groups associated with the FARMSCAPE program as outlined by Carberry and Bange (1998).

Conclusions

The most important consideration in solving complex problems is the ability to think laterally when required. This often means looking at options beyond the cotton crop itself. Examples of this include controlling weeds in other phases of the rotation. Roberts and Gibb (1998) outlined a strategy in which mintweed would be easier to control in the rotation phase rather than trying to target it in cotton. Increasingly entomologists are also looking away from the cotton crop directly to provide answers to control *Helicoverpa* and other pests in novel ways such as interplanting lucerne strips (Mensah and Kahan 1997), trap crops (Sequeria 1998) and area wide management.

The farming system must also remain dynamic to allow it to respond to change as required. This will allow the astute cotton growers to capitalise on opportunities as they arise and to sustain a higher level of profitability while reducing risk. As these opportunities and/or risks rarely operate independently it is useful to use an approach that integrates more than one facet of the system together – farming systems research. It is important to understand that farming systems research can not solve all problems and there is still an essential requirement to have conventional basic and applied research on which farming systems research is often based. In addition it is not up to the research fraternity involved in farming systems research to direct cotton growers in how to manage their farms but rather to highlight the risks and opportunities of selecting the various options available to them. Farming systems research simply endeavors to integrate components of the system to provide answers to problems that often involve complex interactions. Finally new tools such as biotechnology and precision agriculture are advancing rapidly and promise to provide some solutions to our problems. Integrating this new technology will be essential to progress but also offers new challenges.

References

Allen, S.J. and Lonergan, P.A. (1998). Trends in diseases in Australian cotton. *Proc. 9th Aust. Cotton Conf.* August 12th-14th, Broadbeach, QLD, 541-547.

Carberry, P. and Bange, M. (1998). Using systems models in farm management. *Proc. 9th Aust. Cotton Conf.* August 12th-14th, Broadbeach, QLD, 153-160.

Freebairn, D.M., Hulugalle, N., Tullberg, J.N. and Connelly, R.D. (1998). Greenhouse gas emission from cropping- The role of the alternative tillage systems on clay soils. *Proc. Symposium Cons. Till. – can it assist in mitigating the greenhouse gas problem*? Uni. Queensland.

Hickman, M., Rochestor, I., Tennakoon, S., Hare, C., Hulugalle, N., Charles, G., Allen, S., Nehl, D., Scott, F., Cooper, J. and Conteh, A. (1998). Rotation crops: What is the impact on a irrigated farming system. *Proc. 9th Aust. Cotton Conf.* August 12th-14th, Broadbeach, QLD, 49-59.

Hulugalle, N.R., Entwistle, P.C., Weaver, T., Scott, F. and Finlay, L.A. (2000). Cotton rotation systems in a grey clay: effects on soil quality and profitability. *Aust. J. Exp. Agric.* **40**, (In press).

Hulugalle, N.R., Entwistle, P.C., Cooper, J.L., Scott, F., Nehl, D.B., Allen, S.J. and Finlay, L.A. (1999). Sowing wheat or field pea as rotation crops after irrigated cotton in a grey Vertosol. *Aust. J. Soil Res.*, **37**, 867-889.

Mensah, R.K. and Khan, M.. (1997). Use of *Medicago sativa* (L.) interplantings/trap crops in the management of the green mirid, *Creontiades dilutus* (Stal) in commercial cotton in Australia. *Int. J. Pest Manag.*, **43**(3) 197-202.

Roberts, G.N. and Gibb, D. (1988). Herbicide control of mintweed (*Salvia reflexa*) in cotton production systems. *Proc. 9th Aust. Agron. Conf.* July 20th-23rd, Wagga Wagga, NSW, 597-598.

Rochester, I., Peoples, M., Constable, G.A. and Gault, R.R. (1998) Faba beans and other legumes add nitrogen to irrigated cotton cropping systems. *Aust. J. Exp. Agric.* **38**, 253-260.

Rochester, I. and Peoples, M. (1998). Optimising cotton nutrition. *Proc. 9th Aust. Cotton Conf.* August 12th-14th, Broadbeach, QLD, 139-144.

Sequeria, R. (1998). Trap cropping – a way of managing Heliothis. *Proc. 9th Aust. Cotton Conf.* August 12th-14th, Broadbeach, QLD, 263-269.

Skjemstad, J.O., Janik, L.J. and Talyor, J.A. (1998). Non-living soil organic matter: what do we know about it? *Aust. J. Exp. Agric.* **38**, 667-680.

Waters, D., Black, S., Yule, D. Drysdale, R. (1998). Wheat/double cropping. A farming system to reduce soil erosion and pesticide use. *Proc. 9th Aust. Cotton Conf.* August 12th-14th, Broadbeach, QLD, 87-92.