Sustainable Cropping Systems for Irrigated Cotton: Sowing Wheat or Grain Legumes as Rotation Crops

Nilantha Hulugalle[1], Peter Entwistle[1], Fiona Scott[2] and James Kahl[3]
1. CRC for Sustainable Cotton Production, Australian Cotton Research Institute, NSW Agriculture, Narrabri, NSW
2. Tamworth Centre for Crop Improvement, NSW Agriculture, Tamworth, NSW
3. Merced Farming Pty Ltd., Wee Waa, NSW

Introduction

Sustainability in any farming system is dependent upon a number of interacting factors which include climate, soil quality, plant nutrition, management, weed and disease incidence, and economic factors (Greenland and Szabolcs, 1994). Measures of soil quality in agricultural land include soil tilth (described by porosity, aggregation and other structural measures) as an index of soil physical quality, and pH, N, exchangeable cations, salinity, toxic chemicals and soil organic carbon as indicators of soil chemical quality (Karlen *et al.*, 1992; Walker and Reuter, 1996). Among these, soil organic carbon has been proposed as a primary indicator of soil quality (Lal, 1997; Reeves, 1997). The frequency and amounts of carbon and N inputs needed to replenish soil carbon and N reserves have been suggested as good indicators of long-term sustainability of many cropping systems, and has been incorporated into predictive models of sustainability (Fig. 1) (Lal, 1997; Reeves, 1997; Freebairn *et al.*, 1998). Predictive models derived for dryland clay soils suggest that the first indicators of a system run-down under commercial cropping are increased requirements of fertilizer N (and other nutrients such as P and S) and water to maintain yields. In the longer-term yield and profitability losses also occur (Freebairn *et al.*, 1998).

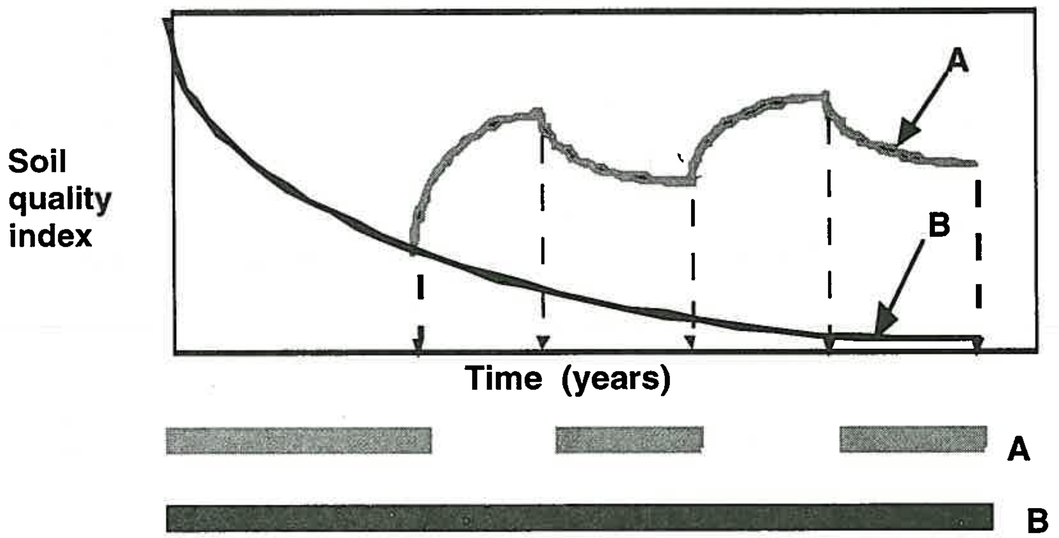

Fig. 1. Schematic representation how soil quality indices such as organic C, tilth and N might behave under 2 contrasting cropping systems (from Freebairn *et al.*, 1998). System A includes a regular ameliorative phase (shown as blank spaces in the bar graph) and system B depicts a continuous cropping situation which allows continual run-down to some new equilibrium. An example of system A is a zero tilled wheat-pasture ley system where the pasture is dominated by grass but also includes a legume component, whereas stubble-burned, intensively tilled wheat monoculture is an example of system B (Freebairn *et al.*, 1998).

In cotton-based farming systems it has been assumed that system A (in Fig. 1) is represented by a cotton-rotation crop system, whereas system B has been assumed to be represented by continuous cotton (McKenzie *et al.*, 1995; Constable *et al.*, 1992). As a consequence many cotton growers sow rotation crops in irrigated cotton-based farming systems with the assumption they will improve soil quality and maintain profitability of cotton (Cooper, 1993).

The most commonly used crop which is sown in rotation with cotton is wheat (*Triticum aestivum* L.), although more recently leguminous crops such as dolichos (*Lablab purpureus* L.), faba bean (*Vicia Faba* L.) and chickpea (*Cicer arietinum* L.) have also been used (Cooper 1993). Although past research has addressed issues such as soil structure, nitrogen and water use (Constable *et al.*, 1992), the comparative advantages and disadvantages of a range of rotation crops, and the sustainability of such rotation systems over extended periods has been addressed in only a few studies (Hulugalle and Entwistle, 1997; Hulugalle *et al.*, 1997). As a consequence, a number of long-term on-farm trials were established during 1993 in New South Wales and Queensland to evaluate the sustainability of selected rotation crop-cotton sequences (based on cotton growers' recommendations) with issues such as soil quality and biodiversity, cotton agronomy and economic benefits receiving a high priority (CRDC, 1994; CRC for Sustainable Cotton Production, 1994). This paper will focus on a trial established during 1993 at "Glenarvon", near Wee Waa, north-western NSW. The soil (55% clay, 18% silt and 27% sand in the surface 0.6 m) is a grey clay. The cropping systems used in the trial were cotton followed by N fertilised wheat (urea at 140 kg N/ha in 1993; 120 kg N/ha thereafter), unfertilised wheat, unfertilized grain legumes (chickpea in 1993; faba bean thereafter) which were either harvested or the grain incorporated during land preparation.

Soil Quality (Nilantha Hulugalle, Peter Entwistle)

Organic Carbon

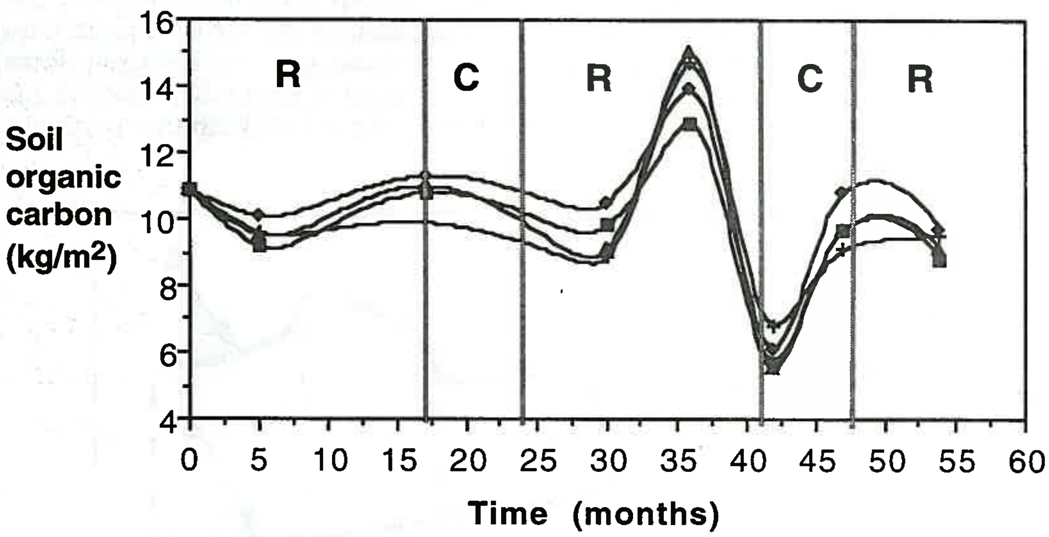

Fig. 2. Variation of soil organic C in 0-0.6 m depth with time (June 1993-September 1997). ■ - fertilized wheat; ▲ - unfertilized wheat; ◆ - grain legume/seed harvested; + - grain legume/seed incorporated. R - rotation crop/summer fallow phase; C - cotton phase. Overall, significant differences did not occur between rotation crops, but did so between times of sampling.

Soil organic C in the 0-0.6 m depth was not affected by rotation crop, although variations between times of sampling did occur. A sharp peak was observed in 1996 before sowing the 1996-1997 cotton crops and after the rotation crops of 1995. Overall, however, regression analysis indicates that there has been no net gain or loss of organic C between June 1993 and September 1997 at this site (Fig. 3). This is not the situation in all Cotton CRC Farming System experimental sites, as net losses of organic C appear to have occurred, with the intensity of the decreases being modified by the rotation crop and its management. At "Auscott-Warren" for example, where N was added to the rotation crop either as a fertilizer or fixed from the atmosphere the rate of organic C loss was reduced. In general, net losses of soil organic C were negligible in sites such as ACRI (Australian Cotton Research Institute, Narrabri) and "Glenarvon" which had higher values of organic C at the start of the trial, applied less N fertilizer to the cotton and had longer irrigation cycles. Note that the lower values and greater rate of organic carbon decrease at "Auscott-Warren" are due partly to differences in soil mineralogy between the soil at that site and the soils in the other sites reported in Figure 3. In addition the occurrence of black root rot disease at "Auscott-Warren" may also have played a part.

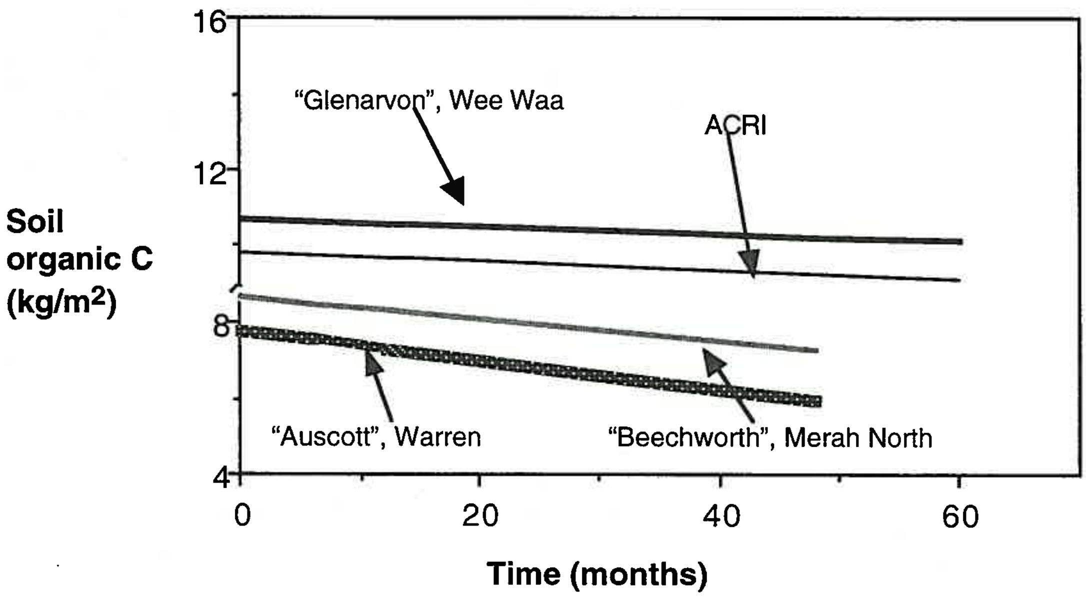

Fig. 3. Net changes in soil organic C at experimental sites in the Namoi and Macquarie valleys.

Nitrate-Nitrogen

Sowing leguminous rotation crops resulted in substantial increases in nitrate-N values (Fig. 4). Unfortunately significant losses of nitrate-N occur at this site (probably due to denitrification and leaching) and the following cotton crop cannot depend entirely on the N fixed by the legumes. Fertilizer inputs of 100-120 kg N/ha were, therefore, needed to maintain cotton yields. Further statistical analysis also indicated that with time (from June 1993 to September 1997) a net increase in soil nitrate-N reserves occurred with all rotation crops, although there were no significant differences between rotation crops.

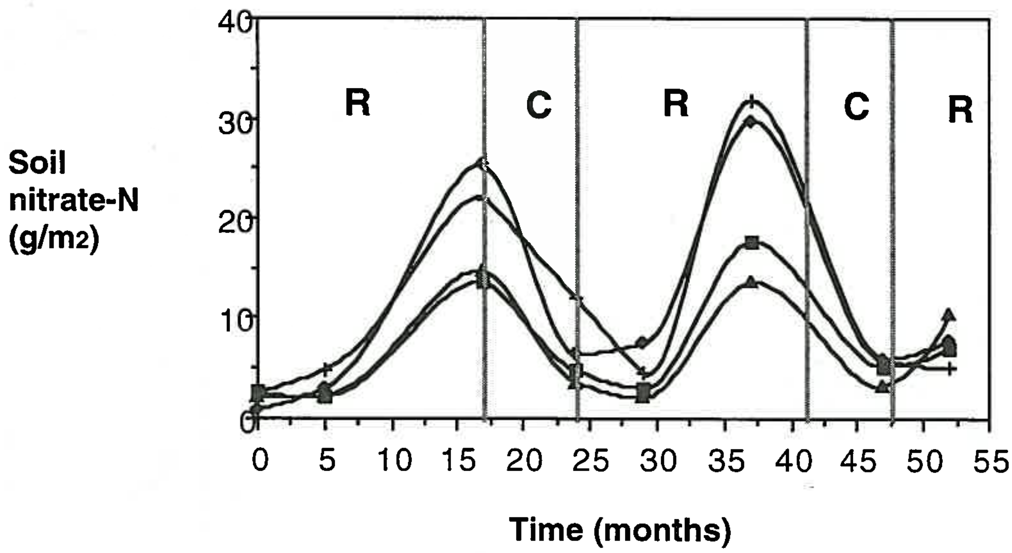

Fig. 4. Variation of soil nitrate-N in 0-0.6 m depth with time (June 1993-September 1997). ■ - fertilized wheat; ▲ - unfertilized wheat; ◆ - grain legume/seed harvested; + - grain legume/seed incorporated. R - rotation crop/summer fallow phase; C - cotton phase. Overall, significant differences occurrd between rotation crops and between times of sampling.

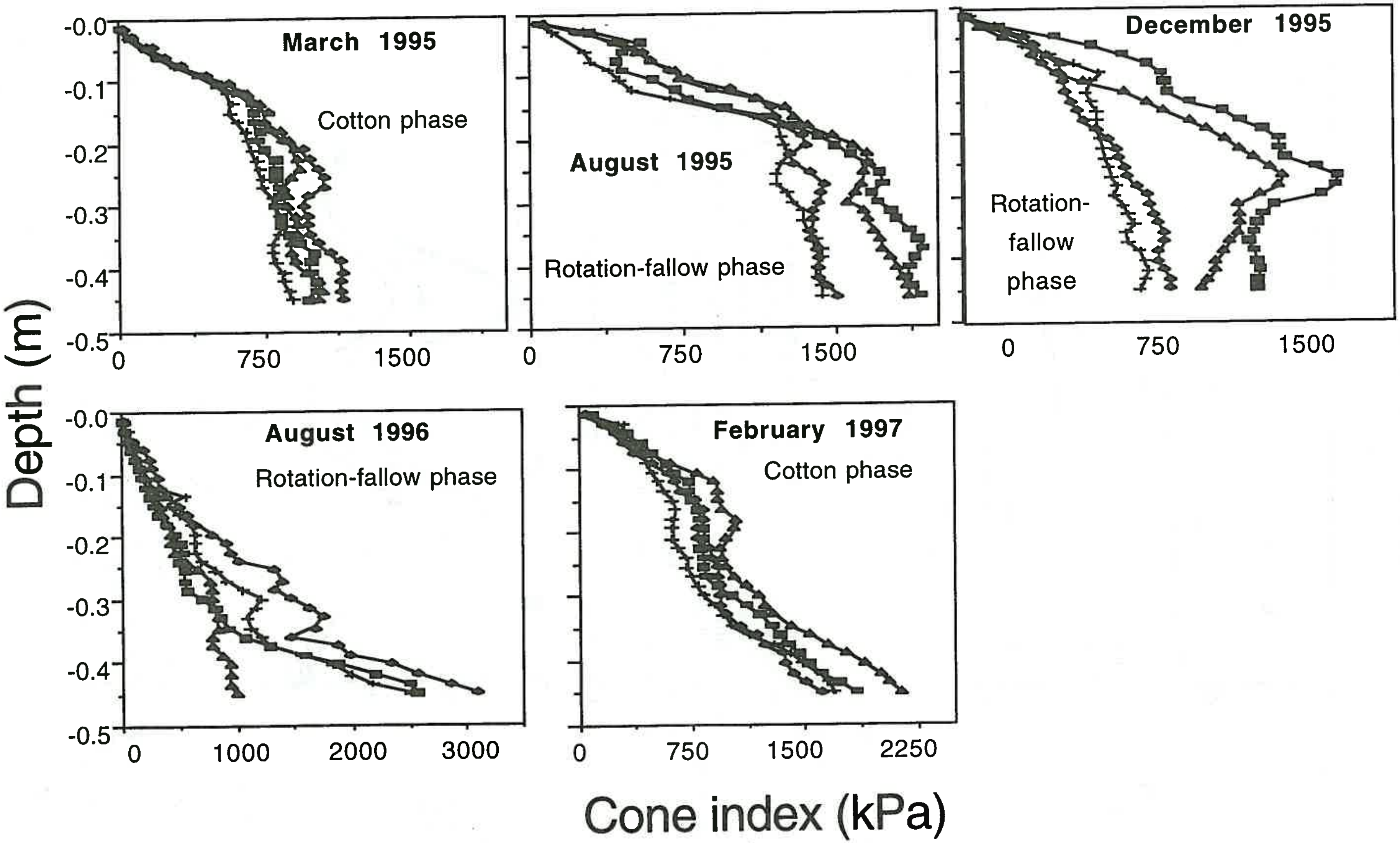

Fig. 5. Effect of rotation crop on of soil strength shown as cone index at various times. ■ - fertilized wheat; ▲ - unfertilized wheat; ◆ - grain legume/seed harvested; + - grain legume/seed incorporated.

Soil Strength

Soil strength was affected by rotation crops only during the rotation crop-summer fallow phase of the rotation cycle (Fig. 5). This was such that soil strength was lower with leguminous rotation crops only during the life of the crop and shortly after (until stubble decomposition was completed). Thereafter a "slumping" of the soil appears to take place with consequent increases in soil strength. During the cotton phase there was little difference between cropping systems (see for example the cone index values for March 1995 and February 1997). Overall an increase in soil strength has also occurred in all cropping systems, and is supported by measures of clod density taken between 1993 and 1997.

Cotton Lint Yield, Fibre Quality and Economic Returns (Nilantha Hulugalle, Fiona Scott, Peter Entwistle)

Cotton lint yield, quality and gross margin were always higher where wheat was the rotation crop (Tables 1 and 2). Addition of N fertilizer to wheat did not significantly increase cotton lint yield and fibre quality. Lint yield and fibre quality at this site were decreased by sowing leguminous rotation crops due to allelopathic effects of the legume stubble and seed material which remained in the field at the time of sowing cotton (Hulugalle *et al.*, 1998). Nutrient uptake by cotton was better after wheat during the 1994-1995 cotton season (Hulugalle *et al.*, 1996) but did not differ significantly between rotation crops during the 1996-1997 cotton season.

Gross margin results were used to show the profitability of each treatment. A gross margin is the gross income from an enterprise less the variable costs (costs directly attributable to the enterprise). Fixed costs such as depreciation, permanent labour and overhead costs are not included. Gross margins were calculated using the input operations and yield results for each treatment. Some input prices (such as for harvesting and irrigation) were drawn from Scott (1997). The commodity and individual input prices used were the same for each season (eg $495/tonne for cotton lint). This was to prevent fluctuations in commodity prices and input prices concealing rotation effects on the gross margins. The fertilized wheat treatment returned the highest gross margin from 1993 to 1997 (Table 2). The gross margin of the fertilized wheat treatment was higher than that for unfertilized wheat due to relatively higher yield and protein percentage.

Management Constraints (James Kahl)

In the experiment described in this paper and in the commercial cotton fields at "Glenarvon" rotation crops have been sown (on a 1:1 basis) for more than 6 years. Our experience in managing rotations is not, therefore, only limited to field experiments. However, we continue to search for the most **cost-effective** management system for our rotations which can produce better returns, now and in the future, from both the rotation crops and the cotton. Our commercial results and the management constraints which we have had to confront mirror those of the experiment described in this paper. The management constraints which we have experienced are as follows:

- Legumes will not tolerate as wide a range of seedbed preparation methods and sowing conditions as much as the cereals. However, cereals need to be sown into moist soil as watering up tends to burst the seed, far more so than with legumes.

- Legumes are more difficult to manage during their growth phase due to a limited choice of effective herbicides and a high probability of insect pressure. Cereal rotation crops do not have these problems.

- High levels of applied fertilizer are necessary for best results from cereals (this is a cost consideration only).

Table 1. Effect of cropping system on cotton[1] lint yield, quality and value, 1994-95 and 1996-97 seasons. (*, ** and *** indicate that the treatments differed significantly at the 95%, 99% and 99.9% levels of probability. NS = did not differ significantly).

Rotation crop	Lint yield (bales/ha)		Micronaire (µg/in")		Fineness (millitex)		% mature fibres	
	'94-'95	'96-'97	'94-'95	'96-'97	'94-'95	'96-'97	'94-'95	'96-'97
Fertilized wheat	8.8	7.6	3.5	3.6	152	154	82.1	78.5
Unfertilized wheat	9.0	7.9	3.5	3.7	154	155	80.7	79.5
Grain legume/grain harvested	8.0	7.1	3.3	3.4	145	145	80.3	73.5
Grain legume/grain incorporated	8.2	7.1	3.3	3.3	149	148	79.9	76.6
P <	*	**	*	***	*	*	NS	**

1. The cotton varieties used were CS-50 in 1994-1995, and CS 8-S in 1996-1997.

Table 2. Effect of cropping system on cumulative gross margins and yield from June 1993 to December 1997.

Rotation crop	Cumulative cotton lint yield (bales/ha)	Cumulative cotton seed yield (t/ha)	Cumulative grain yield (t/ha)	Average wheat protein (%)	Cumulative gross margin ($/ha)
Fertilized wheat	16.4	5.5	12.9	12.2	5,812
Unfertilized wheat	16.9	5.6	9.0	10.3	5,701
Grain legume/grain harvested	15.1	5.3	1.2	-	3,737
Grain legume/grain incorporated	15.3	5.3	-	-	3,643

- Harvesting of legumes is slower, harder to achieve a satisfactory result (eg. harvesting losses) and more expensive.
- Managing legume stubble is far easier than incorporating high yielding cereal stubble into the soil.
- Legume regrowth is much more expensive to deal with than cereal regrowth.
- Achieving best returns from legumes is difficult as there is no established futures market and the numbers of alternative buyers present in the marketplace are few. Consequently growers are forced to become price takers.

In concluding, we are pleased to see the trends in the different field experiments conducted by NSW Agriculture because from a management point of view we would much rather use cereals in rotations to achieve better cotton crops and higher overall economic return.

Conclusions

Soil quality indices such as soil organic carbon, nitrate-N and soil strength were not affected over the long term by the individual rotation crops and their management. However, soil organic carbon levels were stabilized and did not change with time. In comparison with the other rotation crop experimental sites monitored, soil organic C values observed in this site are between 25-80% higher. Soil nitrate-N did show some increase with time in all rotation systems, with very sharp increases occurring after the legumes. Unfortunately these increases were not maintained. Some increase in soil strength was also observed under all rotation crops. The single most significant determinant of cotton yields and gross margins at this site was the allelopathic effect of the legume stubble and seed material. This was such that cotton lint yield, fibre quality and gross margins were lower in cotton-legume rotation systems. Higher yield, better fibre quality and higher gross margins occurred in the cotton-wheat rotation systems. However, compared with unfertilized wheat, applying N fertilizer to wheat rotation crops resulted in higher grain yield, protein content and gross margins. Management constraints were greater with leguminous rotation crops than with wheat.

References

Constable, G.A., Rochester, I.J., and Daniells, I.G., 1992. Cotton yield and nitrogen requirement is modified by crop rotation and tillage method. ***Soil and Tillage Research,*** 23: 41-59.

Cooper, J., 1993. Rotopak - Developing Rotations to Overcome Soil Degradation for Irrigated Cotton Systems. ***Final Report on Project No. DAN 76C of Cotton Research and Development Corporation of Australia.*** (NSW Agriculture, Orange, NSW).

Freebairn, D.M., Hulugalle, N.R., Tullberg, J., and Connolly, R.D., 1998. Greenhouse gas emission from cropping - the role of alternative tillage systems on clay soils. Paper presented at symposium on ***"Conservation Tillage: Can it Assist in Mitigating the Greenhouse Gas Problem?"***, 30 April 1998, University of Queensland, St. Lucia, Qld.

Greenland, D.J., and Szabolcs, I., (eds.) 1994. ***Soil Resilience and Sustainable Land Use.*** (CAB International, Wallingford, UK).

Hulugalle, N.R., Cooper, J.L., Entwistle, P., Eveleigh, R., Kay, A., and Patrick, I., 1996. Managing wheat rotation crops: Effects of N fertilizer on soil properties, nutrient uptake by cotton and cotton lint yield. ***Proceedings 8th Australian Cotton Conference, 14-16 August 1996, Broadbeach, Qld., Australia,*** pp. 479-484. (Australian Cotton Grower's Research Association, Wee Waa, NSW, Australia).

Hulugalle, N.R., and Entwistle, P., 1997. Soil properties, nutrient uptake and crop growth in an irrigated Vertisol after nine years of minimum tillage. ***Soil and Tillage Research***, 42: 15-32.

Hulugalle, N.R., Lobry de Bruyn, L.A., and Entwistle, P., 1997. Residual effects of tillage and crop rotation on soil properties, soil invertebrate numbers and nutrient uptake in an irrigated Vertisol sown to cotton. ***Applied Soil Ecology,*** 7: 11-30.

Hulugalle, N.R., Entwistle, P.C., Roberts, G., and Finlay, L.A., 1998. Allelopathic behaviour of grain legumes in cotton-based farming systems. ***Proceedings of 9th Australian Agronomy Conference, 20-24 July 1998, Wagga Wagga, NSW,*** In Press.

Karlen, D.L., Eash, N.S., and Unger, P.W., 1992. Soil and crop management effects on soil quality indicators. ***American Journal of Alternative Agriculture,*** 7: 48-55.

Lal, R., 1997. Degradation and resilience of soils. ***Philosophical Transactions of the Royal Society of London Series B - Biological Sciences,*** 352: 997-1008.

McKenzie, D.C., Hall, D.J.M., Daniells, I.G., Abbott, T.S., Kay, A.M., and Sykes, J.D., 1995. Soil management for irrigated cotton. ***Afgact P5.3.6***. (NSW Agriculture, Orange, NSW).

Reeves, D.W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. ***Soil and Tillage Research***, 43: 131-167.

Scott, F. 1997. ***Farm Budget Handbook 1997: Northern NSW - Summer Crops.*** (NSW Agriculture, Orange, Australia).

Walker, J., and Reuter, D.J., 1996. ***Indicators of Catchment Health: A Technical Perspective***. (CSIRO, Collingwood, Australia).