Sustainable Land Management Systems for Cotton

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ABSTRACT

Two projects in central Queensland, Australia, aim to minimize the impacts of irrigated and dryland cotton production on the environment. The projects are developing sustainable land management systems that will reduce soil structural degradation, runoff and soil erosion, and pesticide movement from cotton farms. The irrigated project focuses on reducing off-farm movement of pollutants through fallow management, since the highest off-farm risk occurs in a four month period near cotton planting. Winter wheat rotation is tested at a farm scale to provide high cover levels in annual cotton. In the dryland project, downslope Controlled Traffic Farming (CTF) (1% slope, 550m long) is tested to control runoff and erosion, to increase fallow water storage, and to reduce environmental impacts. Wheat in irrigated cotton systems has reduced erosion by 70%. Previous research also found a similar reduction in pesticide movement off-farm. Production benefits have been great, with early season insecticide sprays reduced by three, while maintaining yield. The dryland experiment has been constrained by drought, but the bed and furrow CTF system has controlled erosion to <7 t ha^{-1} yr^{-1} by maintaining high ground cover and reduced off-farm transport. Soil structure in the root bed has improved. This research has provided a sound basis for CTF adoption. These management systems provide for a sustainable cotton industry by improving on-farm and off-farm natural resources while optimizing cotton production.

Introduction

Sustainable land management systems are complex, but must involve cropping systems, farming systems, erosion control, soil degradation control, soil fertility, and environmental management systems. In Australia, these systems are highly mechanized. Multiple tillage operations destroy soil structure, reduce ground cover, cause compaction, and reduce organic matter. Runoff and soil erosion will be increased, and the off-farm environmental impacts can be unacceptable due to high sediment, pesticide and nutrient loads.

Seasonal soil erosion from Australian cotton fields is variable - 4-8 t ha^{-1} in central Queensland to 10-12 t ha^{-1} in New South Wales (Silburn *et al.*, 1997). As soil erosion is directly related to runoff (Freebairn and Wockner, 1986), it can be minimized by reducing the concentration of sediment in the runoff (maintaining high ground cover) and managing the amount of runoff by maintaining a high soil water deficit or increasing irrigation efficiency. Pesticides are transported in runoff either attached to sediment or dissolved in the water (Leonard, 1990, quoted by Finlayson and Silburn, 1996). Pesticide losses in runoff from rainfall are reduced significantly by retaining surface cover, especially when combined with reduced soil compaction using controlled traffic (Silburn, 1994).

Pesticides that are potential environmental threats, such as endosulfan, have been the focus of many research studies in Australia. Examination of runoff water from both irrigation and rainfall reveals that significant amounts of these pesticides are carried off-farm (Simpson *et al.*, 1996). Periods at highest risk are early in the growing season when ground cover levels are low and following the application of pesticides when in-field levels are high. Inappropriate soil management can cause greater damage off the farm than on it (Ball *et al.*, 1997). Examples are eutrophication of surface water, impairment of water quality and destruction of aquatic habitats.

Soil compaction is known to provide conditions unsuitable for root growth and may limit cotton growth and yield (McGarry, 1989). The infiltration rate of the soil is decreased (Soane and van Ouwerkerk, 1995), and runoff and soil erosion will increase. Compaction can not be eliminated, but it can be managed by controlling where machinery traffic operates.

Controlled Traffic Farming is a system in which the crop zone and traffic lanes are permanently and distinctly separated. Combined with minimum tillage and crop rotations, this system has the potential to optimize soil structure, reduce runoff and soil erosion, and increase water availability. Consequently, crop production will increase and environmental impacts decrease.

Two studies are being undertaken to address these issues. The irrigated cotton study aims to reduce the off-farm movement of sediment and pesticides using wheat-cotton rotations. The dryland study aims to assess the effects of downslope Controlled Traffic Farming and crop rotations on soil structure, runoff

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and soil erosion, and environmental impacts in dryland cotton production systems.

Material and Methods

Location

The studies are conducted on commercial cotton farms near Emerald in central Queensland, Australia. The region has a semi-arid tropical environment, with summer-dominant rainfall. Mean annual rainfall and evaporation are 639 mm and 2265 mm, respectively. The soil at both sites is a black cracking clay (Vertisol, Typic Torrert, fine montmorillonitic hyperthermic). Particle size distribution in the 0-10 cm depth was 21% sand, 17% silt and 63% clay.

Irrigated study

A conventional continuous cotton rotation (C-C) is compared with a double cropped wheat/cotton rotation (W-C) treatment. Rainfall volume and intensity, runoff, soil erosion, and pesticide movement are measured at the tail drain outlet of each 30 ha treatment for all irrigation and rainfall runoff events (Figure 1). Insect pressure, pesticide applications and management practices are recorded.

Dryland study

Nine plots, 550 m long and 8 m wide, are oriented down a 1.0% slope. Each plot consists of permanent 2 m wide beds. Traffic is restricted to the furrows between these beds. Cotton is grown in the permanent beds in rotation with sorghum and wheat. This produces a range of ground cover at all times.

Runoff, soil erosion and pesticide movement is measured from bed and furrow units (Figure 2). Soil erosion is measured in two components: the coarse bedload material is collected in a trough, and the finer suspended material is collected by a flow based integrated sample. Rainfall volume is measured on a daily basis at two locations within the study area. Rainfall intensity is recorded by a pluviometer. Ground cover levels in each plot are assessed at two locations following runoff.

Soil compaction control is assessed in a 2 m transect across a permanent wheel track (“WT”) and root bed (“bed”). Penetration resistance is measured by a recording cone penetrometer in 1.5 cm increments to 45 cm depth, and at 10 cm intervals across the transect. Changes in water content at 20 cm intervals across the transect is measured over five weeks using 5 cm diameter cores, with increments of 10 to 100 cm depth.

Results and Discussion

Irrigated study

During the 1997/8 irrigated cotton season, W-C had 2.1 t ha^{-1} soil erosion compared with 6.4 t ha^{-1} from C-C from six irrigations. For all irrigations, W-C reduced soil erosion (Figure 3) and resulted in a 70% reduction over the six irrigations. The higher soil erosion in irrigations 4-6 in the W-C is due to inter-row cultivation commencing after irrigation 3. The high ground cover levels provided by the anchored wheat stubble prevented soil detachment. Due to below average rainfall during 1997/8 (336 mm), there was insignificant rainfall runoff. Since rainfall runoff typically produces 80% of the seasonal soil erosion (Carroll *et al.*, 1995), larger reductions in soil erosion may be expected from the W-C treatment in wetter years.

Simpson *et al.* (1996) found a high correlation between sediment concentration and endosulfan concentration in runoff water from small plots (less than 1 ha). Endosulfan export was subsequently reduced by 73% by wheat stubble during the first irrigation.

Early season insect pressure in the W-C was less than the C-C. The cumulative mean bollworm (H*elicoverpa spp.)* numbers for the season reduced from 49 m^{-1} in the C-C to 12 m^{-1} in the W-C. W-C had three less sprays than C-C to control bollworm. Predator numbers in the W-C were 20% higher than in the C-C. As the cotton emerged above the standing wheat stubble, there was no difference in pesticide application between treatments. This indicates that the standing wheat stubble may have acted as a physical barrier, preventing bollworm moths locating the cotton plants.

The W-C cotton yield was 6.25 bales ha^{-1}compared to 7.5 bales ha^{-1} in the C-C. However, when the wheat yield and less sprays are considered, the W-C had a higher gross margin than the C-C. Cotton yield in the previous year (1996/7) found no difference (7.5 bales ha^{-1}) between the W-C and C-C.

Dryland study

Nine rainfall events, ranging in amount and intensity, since 1994 have produced runoff. At the time of runoff, the plots provided a range of ground cover levels. Each plot has been grouped into similar cover ranges. Total runoff and soil erosion from each cover range are shown in Figure 4. Since 1994, total rainfall has been 1646 mm. Of this rainfall, 104 mm has run off plots with less than 10% ground cover. Subsequent soil erosion was 11.4 t ha^{-1}. At 20-30% cover, runoff was reduced to 61 mm and soil erosion to 5.9 t ha^{-1}. When ground cover levels were greater than 40%, both runoff and soil erosion were reduced dramatically. Individual events are reported in Rohde and Yule (1995) and Yule and Rohde (1996). A growing sorghum crop produced 60-70% cover, with 50-60% cover provided by a growing cotton crop. Wheat stubble at the end of the fallow provided 40-50% cover. Stubble from cotton crops generally produced less than 10% cover at the end of the fallow. Carroll *et al.* (1997) also found that 30% cover was required to control erosion. These results clearly show that rotation crops and minimum tillage practices, which produce and maintain high cover levels throughout the fallow, are essential in minimizing runoff and soil erosion, and hence off-farm environmental impacts.

The last tractor wheeling in the WT was three months prior to the soil structure sampling. The bed had not been trafficked since 1993. Penetration resistance below the WT was higher than the bed (Figure 5). Values over 2 MPa occurred within 5-10 cm of the soil surface directly below the WT, and are considered to restrict the taproot penetration of cotton by 40% compared with that where root penetration was not impeded (Taylor and Gardner, 1963). Values over 3 MPa have stopped the development of cotton roots (McGarry, 1994). These high values are not evident within the bed. At 10-20 cm below the soil surface, the average penetration resistance was 1.69 MPa below the WT, decreasing to 1.48 MPa in the bed. Penetration resistance greater than 2 MPa occurred again 20-40 cm below the soil surface of the WT. This narrow band of high resistance is only 20 cm wide, and not evident in the bed.

These results show no evidence of soil compaction in the bed, and no evidence of sideways movement of the WT. Any soil structural damage is restricted to a zone 40-60 cm wide directly below the WT. Soil structural damage in the WT did not affect the change in soil water content measured over a five-week period. The change in water content in the WT is similar to that in the bed (0.045 Mg Mg_{-1}).

Conclusions

High ground cover levels need to be consistently retained to control soil erosion in both irrigated and dryland cotton systems. Insufficient ground cover to control soil erosion occurs when cotton is grown as a monoculture crop.

Double cropped wheat-cotton rotations in irrigated cotton systems provide high ground cover levels and significantly reduce soil erosion with a similar decrease in the off-farm movement of pesticides. A significant reduction in the number of pesticide applications needed to control bollworm was an unexpected benefit. Cotton yields were maintained.

Controlled traffic in dryland farming has controlled runoff and soil erosion, with crop rotations further reducing these losses. Penetration resistance is greater in the wheel track than the root bed. Restricting all traffic to permanent wheel tracks has maintained the remaining soil in a non-compacted condition so that plant root development and crop production are optimized.

These sustainable land management systems provide a sustainable future for the Australian cotton industry by improving the on-farm and off-farm natural resources while optimizing cotton production.

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Figure 1. Instrumentation used to measure runoff, soil erosion and pesticide movement in the irrigated study.

Figure 2. Instrumentation used to measure runoff, erosion and pesticide movement in the dryland study.

Figure 3. Soil erosion resulting from irrigation in continuous conventional cotton (C-C) and wheat-cotton (W-C) rotations.

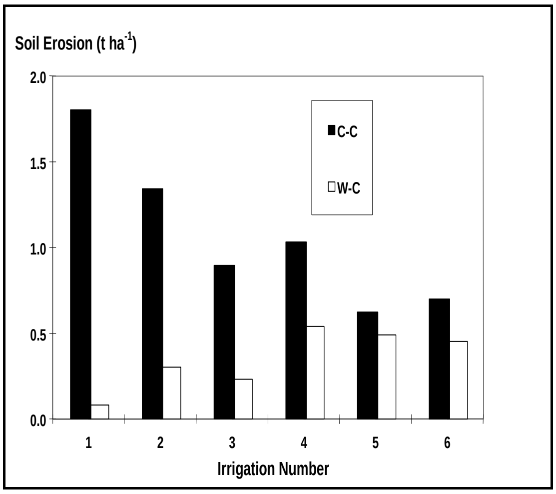

Figure 4. Total runoff and soil erosion since 1994 from each ground cover range in the dryland study.

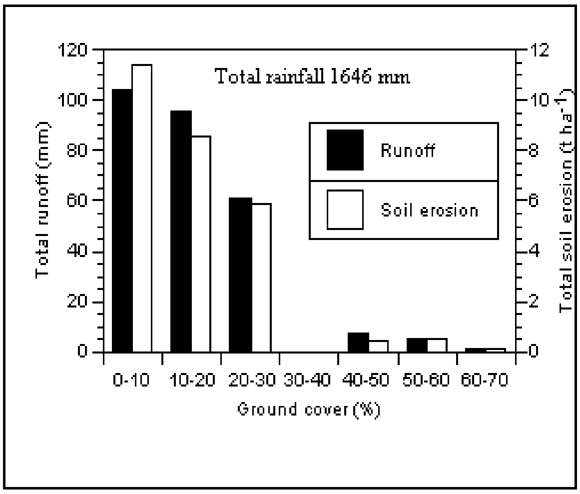

Figure 5. Penetration resistance (MPa) across a 2 m transect of a permanent wheel track and bed. The soil surface profile, wheel track and plant rows are also shown.