Soil structure affects water balance of Ferrosol cropping systems

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ABSTRACT

Pasture leys and tillage practices (reduced/zero tillage, deep ripping and controlled traffic) were evaluated as a way of overcoming declining soil physical fertility on cropped Ferrosols of the inland Burnett. Treatments were able to substantially improve rainfall infiltration and reduce runoff, but experimental crops were unable to capitalise on this extra soil moisture due to relatively low available moisture capacity. Productivity of soils with different soil structure was investigated using APSIM simulations, with results also suggesting a similar lack of crop response to improved soil structure, with the increased infiltration being lost to deep drainage. The greater drainage losses were confirmed experimentally under real and artificial rainfall events, and highlight the potential salinity risks of widespread adoption of conservation tillage in the region. Selective use of farm forestry in key parts of the catchment is being investigated as a potential solution to the developing hydrologic imbalance.

KEY WORDS

Farming system, leys, minimum tillage, deep drainage, soil fertility.

Introduction

The Red Ferrosols of the inland Burnett region of southeast Queensland support predominantly rainfed cropping systems producing summer grain legume and cereal crops. The traditional land management practices include regular tillage, crop residue removal as hay and low levels of fertiliser inputs, and combined with low levels of crop residue production in dry years, have led to a decline in the physical and chemical fertility of these soils (3, 6). This decline, combined with the dry seasonal conditions experienced in recent years, has seriously threatened the continued viability of these farming systems and led to economic hardship.

One of the most common characteristics of these soils after long term cropping is a loss of the originally high rainfall infiltration capacity – a key factor in successful rainfed cropping (3). This has been due to two factors – a decline in labile organic C resulting in surface crusting, and subsoil compaction reducing hydraulic conductivity down the profile (1, 2). To try and overcome these soil problems and increase the efficiency of use of incident rainfall, pasture leys, deep ripping and reduced or zero till farming systems were evaluated in a number of on-farm situations and in a core experiment over more than five years.

Bell *et al.* (1) reported that Kikuyu (*Pennisetum clandestinum*) and Rhodes grass (*Chloris gayana*) pasture leys were able to dramatically improve soil organic matter contents in the upper 30cm and infiltration rates into the soil profile. This paper reports the impact of tillage systems on the persistence of these ley effects, the change in infiltration rates with long term zero tillage and the effect of these changes on crop performance and the water balance of the cropping system.

Materials and Methods

In the core experiment at Goodger, kikuyu pasture was established on a degraded cropping site in the spring of 1990. The pasture was not cut or grazed during the next four years, while four management regimes were imposed. These were (a) low input pasture, where no fertiliser or other inputs were supplied; (b) fertilised pasture, where annual applications of N, P and K fertiliser were made; (c) fertilised, ripped pasture, where the sward was ripped to a depth of 35-40 cm during year 2 of the ley; and (d)

fertilised pasture with earthworms, where locally adapted earthworms (*Fletcherodrilus unicus, Aporrectodea trapezoides* and *Potoscolex corethrurus*) were introduced during pasture establishment.

At the end of the ley phase, the kikuyu was sprayed out with Roundup CT (1800 g ha^{-1} glyphosate) and plots were returned to cropping using either (i) direct-drill, controlled traffic or (ii) conventional cultivation, random traffic practices in a split plot design. An additional area of continuously cropped, degraded soil in an adjoining contour bay was prepared as an unregenerated reference. Treatments in this bay represented factorial combinations of + or - deep ripping in a background of direct drill, controlled traffic or conventional cultivation, random traffic. Plots were sown to a sequence of crops over the next five summer seasons (soybean, maize, peanut, maize and peanut from 1994/95 to 1998/99), with winter wheat double cropped into the zero till plots in 1995, 1997 and 1998. Soil water was monitored using a neutron moisture metre or an Enviroscan soil moisture monitoring system using capacitance sensors.

Infiltration parameters were measured at Goodger using either a portable rainfall simulator that delivered high-energy rain ($29 \text{ J/m}^2/\text{mm}$), or a drip infiltrometer delivering low energy rain ($3 \text{ J/m}^2/\text{mm}$). Details of each system are described in (1) and (3), respectively. Rainfall simulator runs were used to determine time to commencement of runoff, cumulative infiltration over one hour and the final steady state infiltration rate using rainfall intensities of 150 - 175 mm/h depending on sampling occasion. Drip infiltrometer rates were varied during runs to ensure runoff did not occur, with the steady state infiltration rate used as a measure of subsurface hydraulic conductivity. Some rainfall simulator runs were conducted on plots with embedded access tubes containing capacitance sensors (Sentek[R]) to monitor rates of water infiltration and drainage during controlled rainfall events. Similarly, tensiometers were embedded at regular intervals down the profile to 45cm in plots during drip infiltrometer runs so that moisture potential of different parts of the profile could be determined during controlled rainfall events.

Soil physical and chemical properties were also determined on a number of commercial properties using contrasting management practices (eg. pasture leys, and either direct drill or conventional tillage cropping). This was undertaken to capture longer term changes with tillage systems that were not possible to generate from the shorter duration Goodger site. The rainfall simulator and disc permeameters were used to determine hydraulic properties, using similar methods as at Goodger.

Finally, soil properties were used to parameterise the APSIM model (5), which contains functions to represent infiltration in detail. We used the SWIM (7) with SURFACE modules in APSIM to represent processes of infiltration. SWIM and SURFACE represent the development of a surface seal associated with variable rainfall intensity, cover and roughness and seal disturbance associated with tillage. Infiltration and runoff are functions of the permeability of the surface seal and sub-surface soil layers. We estimated the impact of measured changes in soil properties on crop yield, rainfall infiltration and the water balance of various cropping systems.

Results and Discussion

Tillage and ley treatments were able to greatly increase the soil capacity to infiltrate rainfall (Fig. 1), due to a combination of reduced surface crusting (due to cover and increased labile C) and increased macroporosity and hydraulic conductivity in the subsoil. The most successful treatments (ley pastures with introduced earthworms or long-term zero till/controlled traffic with deep ripping), when fully protected by stubble cover, produced infiltration rates approaching those of virgin soil (120 mm/h).
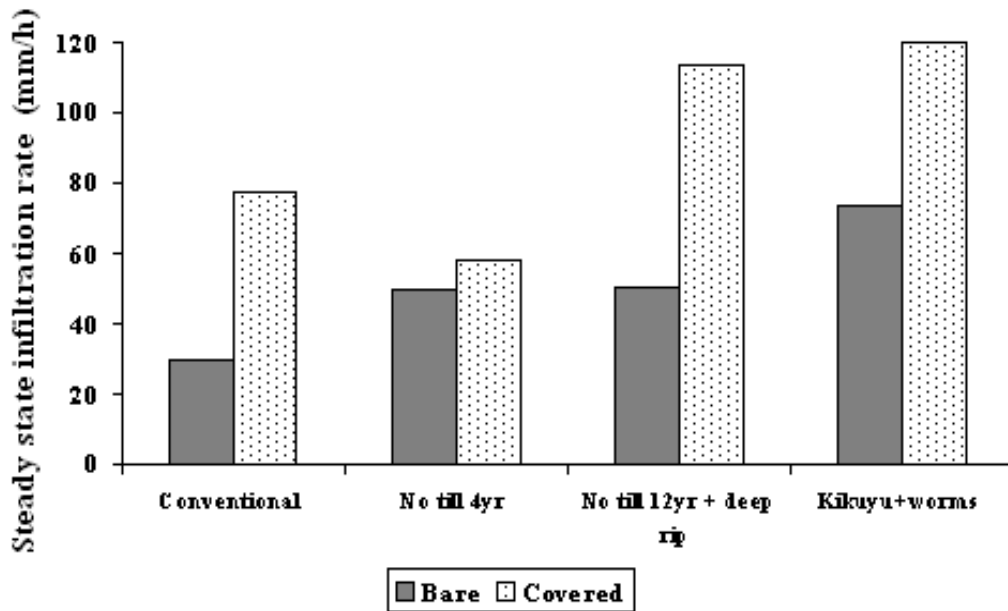
Figure 1. Effect of tillage and ley pastures on steady state infiltration rate (mm/h) of high intensity rainfall on cropped Ferrosols in the inland Burnett. The kikuyu pasture had been sprayed out after 4 years growth and cropped using direct drill techniques.

Despite these major improvements in ability to capture seasonal rainfall, which were confirmed by seasonal monitoring of soil water status during the Goodger experiment, there was no significant improvement in crop biomass production, yields (Fig. 2) or water use efficiency resulting from these improvements. In fact, there was even a slight negative impact on yield overall due to an increased occurrence of N deficiency in the grain crops during the cycle – either due to greater N immobilisation or leaching. This lack of crop response was puzzling, suggesting that crops were not accessing the increased rainfall that infiltrated.

We used the APSIM model to explore this issue, examining various cropping options (eg. conventional tillage with winter fallows, versus zero tillage with opportunity double cropping) on soils with hydraulic properties that matched the degraded condition, the most improved treatments and those of virgin soils. In the absence of other limitations (eg. N), simulations duplicated our findings at Goodger, with no yield advantage from improved infiltration capacity (data not shown). The reasons for this appeared to lie in the water balance components of the simulated system (Fig. 3). The current degraded system 'loses' an average of 20% of annual rainfall (approx. 150 mm/year) to runoff and deep drainage, with the majority of that loss (110 mm) occurring as runoff. The rehabilitated profile, on the other hand, also loses 20% of the annual rainfall, but this is entirely due to deep drainage (ie. there is no runoff). Opportunity double cropping had minimal impact on these losses, with the water used by the winter crop otherwise accounted for by soil evaporation (data not shown). In other words, the improved infiltration capacity was countered to a large extent by an inability to hold that water for subsequent crop use. The major factor causing this result is the relatively low available water storage in these degraded Ferrosols, which is only 0.1 cm^3/cm^3 compared with 0.3 - 0.4 cm^3/cm^3 for Vertosols (ie. 100 - 110mm in a 140cm root zone; (2)).
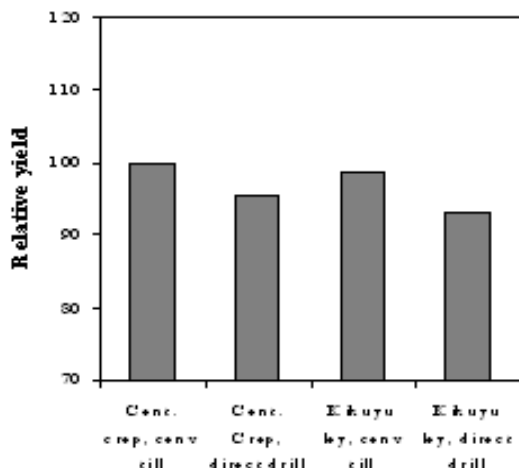
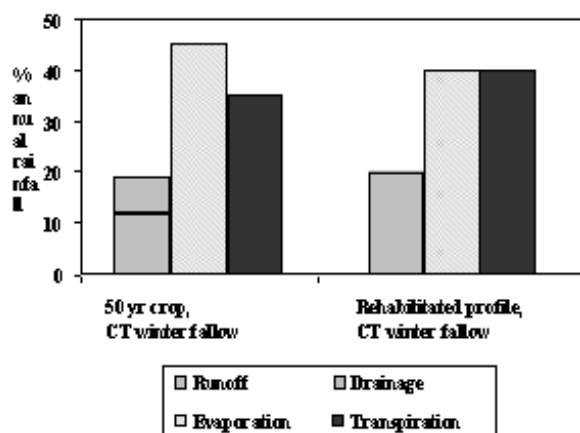**Figure 2. Effects of tillage and prior grass leys on relative crop yield over 5 years at Goodger.**

Figure 3. Simulated impact of improved rainfall infiltration and hydraulic conductivity on water balance components in a conventionally tilled (CT) summer crop/winter fallow system on a Ferrosol.

This result was both surprising and alarming. We have checked the crop data and have found the model is well calibrated against measured yields of soybean, maize and peanut. Examination of independent data from the Enviroscan sensors at the Goodger site confirm that after a significant rainfall event, infiltrated soil water moved to a depth of 90cm much more quickly in the ley/zero till treatment, compared with conventional till. Profile moisture had returned to before-rain levels within two days, during which total water 'use' from the profile was 14 mm/day, while evapo-transpiration was only 4 mm/day.

These data gave us some confidence in the model's deep drainage estimates, but to confirm the projections, rates of wetting front penetration and drainage were determined using a drip infiltrometer on profiles pre-wet to field capacity. A degraded soil profile (continuous crop, conventional till) was compared to 'rehabilitated' ley pasture/direct drill profiles (deep ripped or with added earthworms) at Goodger. Results confirmed the very rapid rates of infiltration (Fig. 4) and drainage down the rehabilitated profiles. Clearly defined wetting fronts reached 90cm in 35-40min in the rehabilitated profiles, while only reaching 70cm after 3h in the degraded profile. Similarly, the complete 90cm profile had returned to the pre-dripper water contents (field capacity) within 24h in the rehabilitated treatments, but required more than 83h to do

the same in the degraded profiles. Clearly there would be little opportunity for crops to use excess water in rehabilitated profiles before it was lost to deep drainage below the effective root zone.

These results have major implications for long term sustainability. If growers change to a zero-till farming system to reduce run-off and erosion and improve soil structure, there will be significantly increased accessions to ground water in the inland Burnett. This will result in increased waterlogging in lower slope positions and the expansion of salt affected areas if recharge rates exceed local groundwater discharge rates. At the present time, salting is only a minor problem in the district (although present in every drainage line), but the problem will only increase. A farming system that will utilise the increased accession to groundwater is needed. Active transpiration throughout the year (eg. from pasture leys) will help, but pastures are also too shallow-rooted to utilise quickly draining soil water. In addition, most farm sizes are too small to run beef cattle enterprises and obtain a return from pastures. One attractive possibility is an integrated agro-forestry farming system, and this is currently being explored in terms of the likely impact on catchment water balance and farm viability.

Figure 4. Rate of wetting front penetration into pre-wet soil profiles with differing degrees of soil structural rehabilitation at Goodger.
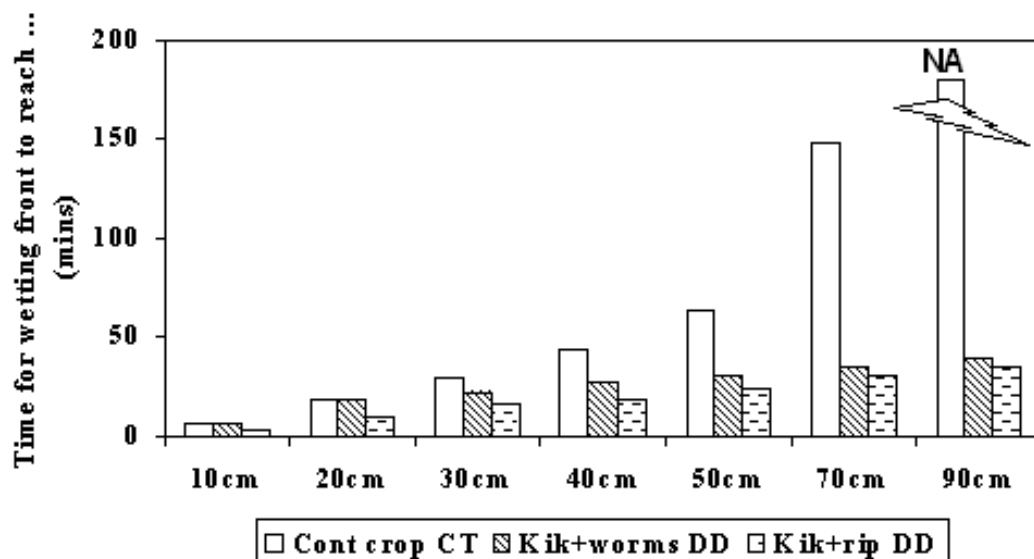
Conclusions

Results have shown that management strategies can overcome soil structural degradation resulting from tillage and soil compaction in cropped Ferrosols. However, while such improvements reduce runoff and the risk of soil erosion they are likely to have little impact on crop production and system financial viability due to a concurrent increase in deep drainage. Unless this deep drainage is countered, the resultant groundwater accessions will raise water tables and increase the incidence of dryland salinity. A mixed farming system (utilising crops, pastures and deep-rooted farm forestry species) holds promise in addressing this imbalance at a sub-catchment scale, and is currently under investigation.

Acknowledgments:

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