EFFECT OF TILLAGE PRACTICES ON CHLORIDE MOVEMENT AND DEEP DRAINAGE AT BILOELA, CENTRAL QUEENSLAND

P.E. Tolmie[A] and B.J. Radford[B]
[A] Agricultural Production Systems Research Unit, Department of Natural Resources, Mines & Energy, Toowoomba, Australia.
[B] Department of Natural Resources, Mines & Energy, Biloela, Australia.

Abstract
Leaching of accumulated salts from the crop root zone and associated deep drainage is a cause for concern from a salinity perspective. Soil chloride data and the transient chloride mass balance are useful approaches for investigating deep drainage under a range of land uses. We compared management practices in terms of their chloride profiles and inferred drainage rates from a long-term tillage trial at Biloela in the Fitzroy Basin, central Queensland. The tillage trial was established on a clay soil at Biloela in 1983, to investigate the effect of tillage practices on dryland production. A range of summer and winter crops were grown. Soil samples taken from the experimental treatments in 1984, 1993 and 2003 and from an adjacent uncleared area in 2003, were analysed for chloride, and mass balance calculations performed. Chloride levels across treatments a year after the trial began were still similar to each other. By 1993 differences between treatments were apparent. The zero tillage treatment had leached the most chloride, with the peak occurring at a depth of 3.1 m. The traditional tillage treatment had leached little chloride compared with 1984, with the peak occurring at a depth of 2.4 m. Chloride measured in 2003 showed no further leaching across treatments. This can be attributed to the episodic nature of drainage events and increased frequency of summer cropping over the last 10 years.

Additional Keywords: Australia, deep drainage, salinity, soil, zero tillage

Introduction
Deep drainage has the potential to cause both on-site and off-site effects, through processes such as mobilisation of stored regolith salts by leaching or groundwater rise. Even when salts are not present in the regolith, and salinity is not a significant hazard, deep drainage results in lost productivity due to water moving below the reach of crop roots (Tolmie and Silburn 2001).

Farming systems alter the pattern of soil water storage (Freebairn *et al.* 1996) compared with native vegetation and therefore change the frequency and magnitude of drainage episodes. Fallowing to accumulate soil water and reduce the riskiness of cropping can create conditions suitable for drainage (Tolmie and Silburn 2001). Soil surface condition and management also affects drainage. Evidence of greater solute movement, and implied greater drainage, under zero tillage than under conventional till has been noted in a number of studies (Dalal 1989; Turpin *et al*. 1999; McGarry *et al*. 2000). However with little previous research on deep drainage, the real extent of the change in drainage is uncertain. Modelling studies (Walker *et al*. 1999; Paydar *et al*. 1999; Keating *et al*. 2001; Yee Yet and Silburn 2002) have compared farming systems in terms of their susceptibility to drainage. They generally find for example: drainage under annual wheat > annual sorghum > opportunity crop > perennial pasture > native vegetation.

One of the challenges facing land managers is that changes in deep drainage rate may not affect the aquifer recharge rate for a period of time (Cook *et al*. 2002). Determination of deep drainage is necessary for quantitative hydrology modelling, particularly with regard to determining the likely impacts of changing land use on salinity risk and water quality.

The aim of this study was to obtain estimates of deep drainage occurring under different tillage treatments for a dryland agricultural system in the Fitzroy Basin, central Queensland. It follows on from a similar study conducted in the Queensland Murray-Darling Basin, reported in Tolmie *et al.* (2003a).

Materials and Methods
Field Site
The site is a long-term tillage trial, located at the Biloela Research Station (24°22’S, 150°31’E; altitude 173 m). Native vegetation was cleared in 1924 and the site used for pasture and crop production until 1983 when the trial was begun (Radford *et al*. 1995). Four tillage treatments were applied, varying in frequency and/or soil

disturbance, in the order traditional tillage (TT) > stubble mulch tillage (SM) > reduced tillage (RT) > zero tillage (ZT) (Radford *et al*. 1995). Results for TT and ZT treatments are reported here.

The soil comprises black cracking and non-cracking clays developed on alluvium (Radford *et al*. 1995). Average annual rainfall is 665 mm, with 73% falling in summer (October-March).

Sampling
Soil chloride samples were taken in 1984 (one year after the trial began), 1993 and 2003. Samples were taken to a depth of 1.6 m in 1984 and 4.5 m in 1993 and 2003. Native vegetation was also sampled in 2003 on an area adjacent to the trial plot and was used as the benchmark against which chloride from the experimental plots was compared. Site history, rainfall, bulk density and soil moisture data were collated.

Analysis
The transient chloride mass balance approach was chosen for this study as it is a cost effective way of examining a large number of sites with standard soil sampling equipment and makes use of existing data and archived samples.

Chloride mass balance is based on conservation of mass, in this case the conservation of chloride mass within the root zone. Transient chloride mass balance copes with non-equilibrium situations i.e. where there has been a change in land use. Rose *et al*. (1979) developed a model of solute dynamics in slowly permeable soils, which allowed calculation of the deep drainage rate between two times from soil solute data. Thorburn *et al*. (1987) developed a simple computer program (SODICS), with which to perform these calculations. It is run in an Excel spreadsheet via Visual Basic code to iteratively solve the equation using a Solver function. The main input parameters are rainfall (mm/yr), time between sampling (yrs), solute concentration of rainfall (mg/L) and for each depth increment in the soil profile: chloride concentration (mg/kg); air dried soil moisture content (% g/g); bulk density (g/cm^3); and drained upper limit moisture content (DUL, g/g).

Assumptions made when using SODICS analysis are: flow is in the vertical direction; chloride is not transformed or sorbed in the profile and any uptake by plants is returned to the soil; leaching occurs at drained upper limit water content; complete mixing occurs without bypass flow; and solute concentration in drainage is a constant proportion of the profile average concentration.

The mass of chloride (kg/ha) in rain, in the soil to various depths, and lost from the soil was calculated. Spreadsheet calculations were used to determine the amount of chloride lost under the different management systems as a percentage of the initial chloride present at T_0 (native vegetation), and as cumulative mass lost (t/ha) relative to T_0. SODICS was then used to interpret the same data in terms of drainage (mm/yr).

Results and Discussion
Chloride profiles for the traditional tillage (TT) and zero tillage (ZT) treatments are shown in Figure 1 and Figure 2, respectively. Chloride levels for TT and ZT treatments were very similar a year after the trial began. This is reflected in the average drainage calculations for this period (Table 1). By 1993 however, chloride profiles indicate large differences between treatments. Average drainage over the 9 year period was 6.0 mm/yr for TT, compared with 43.9 mm/yr for ZT, an increase of over 7-times. This is consistent with known greater water storage of ZT at this site (Radford *et al*. 1995; McGarry *et al.* 2000).

McGarry *et al*. (2000) conducted a detailed study at this site to investigate reasons for increased water storage under ZT treatment as reported by Radford *et al*. (1995). They found evidence of increased earthworm and termite activity under ZT and related this to increases in sorptivity and hydraulic conductivity in the ZT plots. McGarry *et al*. (2000) considered peak values of chloride 10 years after trial establishment for the TT and ZT treatments and inferred higher drainage under ZT compared with TT but did not quantify this result. They attributed increased deep drainage under ZT to inadequate cropping frequency, despite 11 crops in 10 years (5 summer and 6 winter).

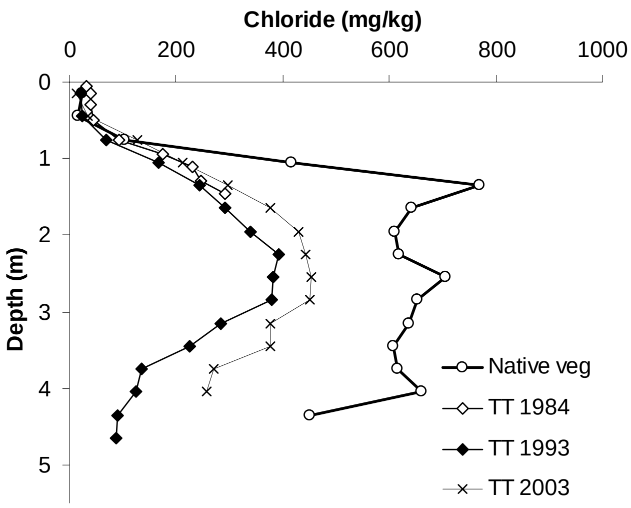

Figure 1. Chloride profiles for traditional tillage (TT)

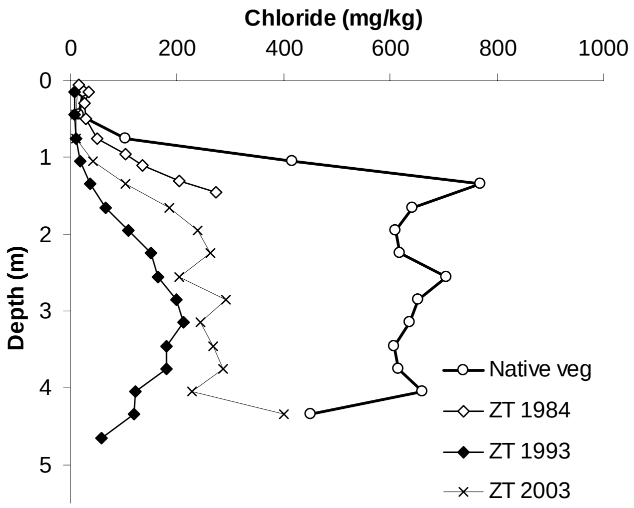

Figure 2. Chloride profiles for zero tillage (ZT)

Table 1. Summary of chloride lost and drainage at Biloela tillage trial. Average rainfall 665 mm.

Period	Land use history since clearing	Chloride lost at 1.5 m (t/ha)		Average drainage at 1.5 m (mm/yr)	
		TT	ZT	TT	ZT
1924-1984	59 yrs pasture and crop production; 1 yr tillage trial	3.13 (52%)	3.85 (66%)	3.2	3.4
1984-1993	9 yrs tillage trial	0.52 (18%)	1.63 (82%)	6.0	43.9
1993-2003	10 yrs tillage trial	- #	- #	-*	-*
1924-2003	59 yrs pasture and crop production; 20 yrs tillage trial	2.8 (61%)	5.0 (94%)	2.5	3.4

No net chloride lost for this period. * Unable to be determined (and implies zero drainage for this period).

In the ten years since their study, another 11 crops were grown in 10 years but summer cropping predominated (7 summer and 4 winter). Chloride profiles for the 2003 sampling showed upward movement of chloride for both treatments, suggesting no drainage during the 1993-2003 period. We attribute this to the increased frequency of summer cropping, resulting in a drier soil profile. Rainfall in the 1993-2003 period was not much less than that in the 1983-1993 period, 633 mm 1983-1993, compared with 596 mm 1993-2003. Rainfall distribution was also similar, as 70.7% of the rainfall fell during fallows in the first 10 years and 68.9% in the second.

Over the entire cultivation period of 79 years, ZT lost 33% more chloride than the TT treatment. Average drainage over this period was 2.5 mm/yr under TT and 3.4 mm/yr under ZT. This was an order of magnitude higher than that for native vegetation at 0.29 mm/yr (determined using steady state mass balance).

It is important to note that while deep drainage is reported here as an average annual rate (mm/yr), water balance modelling shows that drainage is highly episodic (Yee Yet and Silburn 2003). For example, from Table 1, drainage of 43.9 mm/yr for ZT does *not* mean that 43.9 mm/yr drainage occurs every year. Indeed, detailed water balance modelling currently underway for this site suggests 6 drainage events occurred during the 9 year period (1984-1993), ranging in size from <2 mm/yr to 109 mm/yr (J. Owens pers. comm.).

Conclusions

Soil chloride loss and drainage were greater where ZT had been practised since 1983 compared with TT. The change in soil chloride since clearing indicates a large mass of salt has been added to the groundwater. Drainage in the Queensland environment is episodic and depends on rainfall sequence. This is reflected in the above results in that drainage determined from time sequence data is specific for the given time and rainfall period.

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