Nitrate-N losses in drainage water under irrigated vertosols of north-western NSW.

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Abstract
A comparison on the effects of soil and crop management practices in irrigated farming systems on the quality of drainage water in Vertosols has not been reported in the literature. The objective of this study was to quantify nitrate-N in drainage water in the subsoil (0.6, 0.9, 1.2 m) of sodic and non-sodic Vertosols under selected crop rotations, viz. continuous cotton (*Gossypium hirsutum* L.), cotton–dolichos (*Lablab purpureus* L.) and cotton–wheat (*Triticum aestivum* L.). A cotton–wheat rotation was sown at Wee Waa and Myall Vale; wheat stubble was incorporated in the former and retained as *in situ* mulch in the latter. At Merah North, there were three cropping sequences; viz. continuous cotton, cotton–wheat, and cotton–dolichos sown between 1993 and 2000 in adjacent plots with identical land management histories. The three treatments were sown with cotton during the 2000–2001 and 2002–2003 growing seasons, wheat during the 2001 winter and sorghum during the 2001–2002 growing season with stubble being incorporated. Drainage water was sampled with 50-mm diameter ceramic-cup samplers from depths of 0.6, 0.9 and 1.2m in six sites in each plot and irrigation water from the head ditch after irrigation between mid-October and late February during the cotton-growing seasons of 2000-2001 and 2002–2003. Soil water extracted from the ceramic-cup samplers was analysed for nitrate-N. The nitrate-N concentrations in drainage water varied among sites, and reflected variations in soil properties, fallow length since the preceding crop, fallow rainfall and irrigation water quality.

Key Words
Drainage, Nutrient, Irrigation, Vertosol, Sodic

Introduction
Leaching of nitrate-N has been observed in swelling clay soils by a number of researchers (Zischke and Gordon, 2000; Phillips, 2002; Silburn et al., 2009; Gunawardena et al., 2011; Tolmie et al., 2011). Zischke and Gordon (2000), for example, reported that amounts of nitrate-N leached ranged from 174 to 212 kg/ha/yr under furrow irrigation and from 560 to 691 kg/ha/yr under subsurface drip irrigation in Vertosols. It is widely believed that the primary pathway of drainage and leaching in clay soils is preferential flow through soil cracks, slickenside and biopores (Ringrose-Voase and Nadelko, 2010), although Tolmie et al. (2011) suggested that matrix flow was the major pathway. In summary, the chemistry of drainage water in clayey soils such as Vertosols is such that it is greatly enriched with nutrients like nitrate-N and leached from the soil during the drainage process, which in most instances is via preferential flow systems. Comparative research on the effects of soil and crop management practices in cotton farming systems on the quality of drainage water in irrigated Vertosols has not been reported in the literature. The objective of this study was to quantify nitrate-N in drainage water in the subsoil (0.6, 0.9, 1.2m) of sodic and non-sodic Vertosols under some typical irrigated crop rotations, viz. continuous cotton (*Gossypium hirsutum* L.), cotton–dolichos (*Lablab purpureus* L.) and cotton–wheat (*Triticum aestivum* L.).

Methods
Experimental sites
The experimental sites were located at the Australian Cotton Research Institute (ACRI) near Myall Vale (149^o 36’ E, 30^o 12’ S), and on two commercial cotton farms near Wee Waa (149^o 27’ E, 30o 13’ S) and Merah North (149^o 18’ E, 30^o 12’ S), in northern New South Wales, Australia. These sites have a semi-arid climate (Kottek et al., 2006) with four distinct climatic seasons with a mild winter and a hot summer. The hottest month is January (mean daily maxima and minima of 34^{o}C and 19 ^{o}C, respectively), whereas July is the coldest (mean daily maxima and minima 18^{o}C and 3^{o}C, respectively). The soils were alkaline, self-mulching grey Vertosols and classified as fine, thermic, smectitic, Typic Haplusterts (Soil Survey Staff, 2010). The Myall Vale site (average clay content in the 0–1.2m depth was 62g/100g) was sown with a cotton–wheat rotation on permanent beds where wheat stubble was retained as *in-situ* mulch. The Wee Waa site (average clay content in the 0–

1.2m depth was 61 g/100g) was sown with a cotton–wheat rotation where stubble was incorporated. At the Merah North site (average clay content in the 0–1.2m depth was 67g/100g), there were three cropping sequences; viz. continuous cotton, cotton–wheat, and cotton–dolichos sown between 1993 and 2000 in adjacent plots with identical land management histories. The three treatments were sown with cotton during the 2000–01 and 2002–03 growing seasons, wheat during the 2001 winter and sorghum during the 2001–02 growing season with stubble being incorporated. Further details of the experimental sites and their management have been reported by Weaver et al. (2005), and water and N fertiliser inputs are briefly summarised in Table 1. Soil properties in these sites are shown in Table 2.

Table 1. Water and nitrogen inputs during irrigated seasons of 2000-01 and 2002-03 at the Narrabri, Wee Waa and Merah North sites.

Site	Season	N (kg N/ha)[a]	Number of Irrigations	Irrigations (mm)	Rainfall (mm)	Total water input (mm)
Narrabri	2000-01	140	2	200	517	717
	2002-03	150	5	500	279	579
Merah North	2000-01	130	7	700	300	1000
	2002-03	220	10	1000	265	1265
Wee Waa	2000-01	151	4	400	579	979
	2002-03	160	7	700	300	1000

[a]N was applied as anhydrous ammonia at the Narrabri and Merah North.

Table 2. Soil properties in the 0-1.2m depth in the experimental sites at Myall Vale, Wee Waa and Merah North, September 2000.

Site	Depth (m)	pH	EC1:5 (dS/m)	Cl (mg/kg)	Organic carbon (g/100g)	Exchangeable cations (cmolc/kg) Ca	Mg	Na	K	ESP	ESI
Myall vale	0-0.3	7.4	0.24	9	0.71	21	9	0.6	1.2	2	0.1
	0.3-0.6	7.5	0.21	17	0.54	19	11	1.3	0.9	5	0.05
	0.6-0.9	7.6	0.24	23	0.48	18	13	1.9	1	7	0.04
	0.9-1.2	7.6	0.24	21	0.4	18	13	2.1	1	7	0.03
Merah North	0-0.3	7.2	0.37	14	0.62	21	15	3.1	0.9	9	0.05
	0.3-0.6	7.4	0.38	29	0.48	19	15	5.4	0.7	14	0.03
	0.6-0.9	7.4	0.46	67	0.43	18	15	6.7	0.7	18	0.03
	0.9-1.2	7.4	0.57	526	0.41	17	14	6.5	0.7	18	0.03
Wee Waa	0-0.3	7.2	0.26	16	0.72	19	11	0.9	0.8	3	0.08
	0.3-0.6	7.3	0.26	18	0.62	18	11	1.1	0.7	4	0.06
	0.6-0.9	7.4	0.3	15	0.51	17	12	1.5	0.8	6	0.05
	0.9-1.2	7.3	0.26	14	0.46	16	12	1.5	0.9	5	0.05

ESP, exchangeable sodium percentage; $EC_{1:5}$, electrical conductivity of a 1:5 soil:water suspension; ESI, electrochemical stability index (=$EC_{1:5}$/ESP). pH was measured in 1:5 soil:0.01 M $CaCl_2$ suspension.

Drainage water (leachate) was sampled with 50-mm diameter 200 kPa high-flow ceramic-cup samplers (Soil Moisture Equipment Corporation, type 653X01-B02M21) from depths of 0.6, 0.9 and 1.2m in six sites located in a diagonal transect in each plot and irrigation water from the head ditch after irrigation between mid-October and late February during the cotton-growing seasons of 2000–2001 and 2002–2003. Samples were extracted from the ceramic-cup samplers with a hand pump. Water extracted at 7–10 day intervals was taken back to the laboratory, filtered and analysed for nitrate-N using a nitrate ion selective electrode calibrated with the Kjeldahl method, after extraction with 2M K_2SO_4.

Results

Irrigation water quality

Chemical characteristics of irrigation water (sampled from the head ditch) during the experiment are given in Table 3. These values indicate that the irrigation water was alkaline, salinity relatively low and sodium adsorption ratio, SAR, generally low to moderate. SAR values were such that structural deterioration was unlikely. Nitrate-N concentrations were moderate but comparable with other recirculated irrigation water.

Table 3. Average concentration of irrigation water nitrate-N, 2000-2001 and 2002-03.

Site	Season	NO_3^--N (mg/l)	SAR	pH_w	EC_w (dS/m)
Myall Vale	2000-01	13 (39)	1.4	8.2	0.5
	2002-03	22 (109)	0.9	8.1	0.3
Merah North	2000-01	24 (214)	3.0	8.2	0.4
	2002-03	23 (210)	2.3	8.4	0.3
Wee Waa	2000-01	24 (119)	1.4	8.1	0.4
	2002-03	21 (144)	0.9	8.1	0.2

ECw, electrical conductivity; SAR, sodium adsorption ratio. Values in parentheses are the seasonal amounts (kg/ha) that entered the fields in irrigation water.

Changes in nitrate-N concentrations between years in cotton–wheat rotation in all sites
Nitrate-N concentration either decreased (0.6, 0.9 m) or did not change significantly (1.2 m) at Merah North, whereas in the other two sites it increased between two and four times, although N fertiliser application rates to cotton during 2002–2003 were similar for all three sites (160 kgN/ha at Merah North and Wee Waa and 150 kgN/ha at Myall Vale). The differences in NO_3^--N concentrations may be due to Merah North being sown with wheat during the 2001 winter and sorghum during the 2001–2002 summer, whereas wheat was sown only during winter 2001 at the other two sites. This resulted in a short fallow of ~5months at Merah North during winter 2002 (fallow rainfall of 78mm) but an 11-month fallow (summer 2001–2002 and winter 2002, fallow rainfall of 224mm) at the other two sites. Organic matter mineralisation may, thus, have been less and N uptake more at Merah North. Long fallows when combined with frequent rainfall can result in saturated or near-saturated soil and drainage enhancement in Vertosols (Paydar et al., 2005). This in turn, may have increased rates of NO_3^--N leaching at Myall Vale and Wee Waa (Figure 1 a). In comparison with Myall Vale and Wee Waa, therefore, NO_3^--N was lower at Merah North (Figure 1 a).

Variation in nitrate-N concentrations among sites in the cotton–wheat rotation.
Nitrate-N was significantly higher at Wee Waa and Myall Vale when compared to Merah North (Figure 1 a). Differing fallow length was suggested as a possible reason for this in the previous section. The values of nitrate-N are comparable to those reported by Zischke and Gordon (2000) for a Vertosol in southern Queensland.

Variation in nitrate-N concentrations among rotations at Merah North
Nitrate-N concentration was higher under continuous cotton at the 0.9m depth during the 2000–2001 season, presumably due to accumulation of nitrate-N over time (Figure 1 b). Similar differences were absent during the 2002–2003 season. Greatest salinity and SAR of drainage water occurred with the cotton–dolichos rotation. During the 2000–2001 season, relative to irrigation water, average ECw at 0.9 and 1.2m was 8 times higher with continuous cotton, 9 times higher with cotton–wheat and 16 times higher with cotton–dolichos. Similarly, SAR of drainage water in the same depths was of the order of 20.0 with continuous cotton, 14.6 with cotton–wheat and 20.1 with cotton–doliochos but was 3.0 in irrigation water. The higher concentrations of salts in drainage water under cotton–dolichos is probably a consequence of salt accumulation in the root zone due to low deep drainage under this rotation, and suggests that deterioration of soil quality in this rotation is likely to be more rapid than with either continuous cotton or cotton–wheat. Deep drainage under cotton–dolichos accounted for a very small proportion (i.e. 2%) of total water inputs (Weaver et al., 2005). This was probably caused by the poorer subsoil structure under dolichos when compared with either wheat or cotton (Hulugalle et al., 2002), which in turn was thought to be due to the inability of dolichos to tolerate wet, sodic soils. Dolichos roots were, thus, unable to penetrate deep into the subsoil in this site. The absence of roots meant that the subsoil was not subjected to sequences of structure-improving wetting–drying cycles and populations of biopores remained low (Pillai and McGarry, 1999). As subsoil porosity was low, deep drainage under cotton–dolichos rotations was also low, which in turn resulted in salt accumulation within the crops' root zone. Inclusion of a legume in cotton-based rotations is of limited value in sodic soils, therefore, as most leguminous crops are poorly adapted to sodicity. Including crops tolerant of sodic conditions such as barley (*Hordeum vulgare* L.) and wheat in the rotation, or applying high rates of gypsum, are alternative strategies that have proven to be effective.

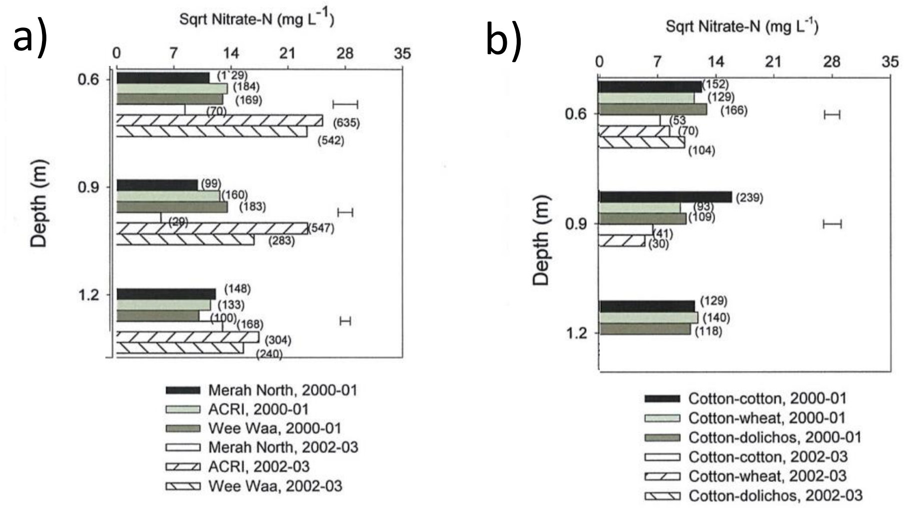

Figure 1. Nitrate-N concentrations in a) drainage water at 0.6, 0.9 and 1.2 m during the cotton-growing seasons of 2000-01 and 2002-03 at Myall Vale (ACRI), Wee Waa and Merah North and b) under continuous cotton, cotton-wheat and cotton-dolichos at Merah North. Horizontal bars are standard errors of the differences among means (a) site x season and (b) rotation history x season. Values in parentheses are back-transformed values.

Conclusions

Nitrate-N in drainage water varied among the study sites, and reflected variations in soil properties, fallow length since the preceding crop, fallow rainfall and irrigation water quality. Salinity and SAR of drainage water were many times higher than those of irrigation water. Salinisation and sodification of shallow groundwater reserves under irrigated cotton in Vertosols are, therefore, a distinct possibility. Salinisation and sodification of the root zone may occur in cotton-based rotations that result in poor subsoil structure and, thus, limited drainage even when irrigated with water of a quality that is generally accepted as being ‘reasonable’.

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