Impact of nitrogen management and subsoil properties on deep nitrate accumulations in soils of the Darling Downs: case studies

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Abstract

Nitrogenous (N) fertilisers have been used extensively since the 1960s in a range of crop rotations practised on the cracking clay soils of the Central Darling Downs of Queensland. In recent years, soil tests have detected significant levels (up to 500 kg/ha) of nitrate-N accumulating in the 0.9-1.5 m soil layer. This paper describes a participatory action learning study involving 10 farms in the area, to investigate whether crop management practices and/or inherent soil properties are responsible for nitrate accumulation in the sub-soil. Pre-plant and post-harvest soil nitrate levels were measured over two successive years in rotations representative of each farm. Cropping and fertiliser management history was obtained for each rotation. Excessive applications of N fertiliser associated with the combination of a simplified budget approach to N management and unfavourable soil properties such as salinity, high pH and chlorides, appear to be exacerbating the accumulation of soil nitrates.

KEY WORDS

Participatory, nitrate, accumulation, cotton, nitrogen management.

INTRODUCTION

Nitrogen management has been a focal point of agricultural research and extension over the past few decades (1). The annual usage of N and phosphorus fertilisers continues to increase throughout the northern Australian grain region (2). Despite this increase, the natural fertility of much of the northern Australian grain producing area has been seriously depleted through a sustained program of intensive opportunity cropping predominantly with cereals. However, farmers are becoming increasingly aware of the need to fine-tune their management practices to minimise fertility depletion. This awareness is further endorsed by the call from the Murray Darling Basin Ministerial Council for a redirection of current research efforts into fine-tuning farming systems so that less rainfall is allowed to move to ground water, resulting in a greater long-term potential for sustainable salinity management (3). The detrimental effect of salinity on a range of crops is well documented. For example, a glasshouse study found that the growth of normally salt tolerant barley was decreased by 29% when exposed to 100 mM concentrations of NaCl (4).

Deep soil sampling to monitor available soil water and nitrate-N on the Darling Downs during the last decade has revealed high concentrations of nitrate-N in the 0.6-0.9 m layer (5, 6). Research has suggested that leaching of nitrate-N from the plant root zone was enhanced through the application of higher rates of N fertiliser, the burning of stubble, and by zero–tillage which promoted greater water infiltration (6). Nitrogen management has been described as the array of field activities that inadvertently or by design, interact to control the supply of available N to the crop (7). Many factors affect the optimum rate of N including seasonal conditions, soil fertility and texture, cultivar, insect population, and crop rotation. Studies have shown also that cotton grown on high pH soils may have a higher N requirement than when grown on neutral to acid soils and that N should not be applied too far ahead of planting (8).

Over the past decade, cotton production has increased significantly on the Darling Downs of Queensland. In an attempt to maximise yields and optimise their profit margins, some growers appear to have been more liberal in the use of N fertiliser on cotton crops. However, due to the unreliable rainfall, these crops have not always been able to utilise the whole of applied N. Hence, it is suspected that the unused N has been leached into the deeper layers of the soil profile where, in some cases, there has been considerable accumulation of nitrate-N. Furthermore, the budget approach to N management, a tool that has been widely used in recent years (1), is reliant upon the accurate estimation of N required for a target yield. This method is based on a sound knowledge of pre-plant soil N, as well as an accurate estimate of target yield and proportion of available N converted into grain or produce. Inaccurate estimation of any of these inputs may lead to excess N being present in the system, which then may be leached deeper into the profile.

The main purpose of this participatory learning study was to determine whether crop management practices and in particular, the inclusion of cotton in the rotations, was impacting on the accumulation of N in the soil profile. Furthermore, knowledge of the presence of N in the subsoil may save on fertiliser costs and influence crop choice (9). It is envisaged that the results of this study may provide insights for the development of strategies for farmers to fine-tune N management practices.

METHODS

The Formartin group of 11 farmers from the Central Darling Downs, with irrigated and dryland farming operations, participated in this research activity, which was conducted as part of the GRDC, DPI, DNR and CSIRO sponsored Eastern Farming Systems Project. Predominant crops grown were cotton, sorghum, maize, barley, wheat, chickpeas, mungbeans and sunflowers. Ten sites were selected on the properties that were located across an area of approximately 600 kms$^{2.}$ The annual average rainfall for the area is about 675 mm. The soils were mostly variants of the cracking clays, with some sites comprising the Mywybilla and Norillee series (10). The area of each site ranged from 2.5 ha to 25 ha.

Pre-plant and post-harvest plant available water and soil nitrate-N were measured over two successive years at each site, commencing in September 1998. Soil samples were taken from 50 mm cores to a depth of 1.2 m in year 1, or 1.5 m in year 2. Cores were divided into 0.3 m sections. The number of cores for each site varied from 10 to 16, increasing with area. Cores were taken in a rectangular grid pattern and their positions recorded using a Global Positioning System. Composite samples from the cores for each soil layer were analysed for electrical conductivity, pH and chloride. Salinity levels were measured using the $EC_{1:5}$ method. Soil samples for chemical analysis were dried at 40^{0}C and ground to <2 mm diameter. Gravimetric water measurements were taken to measure plant available soil water. Bulk Density values were derived for each site by reference to data obtained from previous research work in the district. Crop rotation, rainfall/irrigation, fertiliser, yield and protein history for the preceding five years was obtained where possible for each site.

RESULTS AND DISCUSSION

The post-harvest residual soil nitrate-N levels ranged from 2 kg/ha to 588 kg/ha in year 1 and from 18 kg/ha to 409 kg/ha in year 2. The level was >80 kg/ha for 5 sites in at least one season, and for 4 sites in the 2 seasons. The autumn 2000 nitrate-N levels, which includes some pre-plant sites (5, 8 and 9), the chloride and $EC_{1:5}$ data for the 10 sites are shown in Figures 1, 2 and 3 respectively.

The crop management and subsoil properties of 4 sites (1, 2, 3, and 5) containing high nitrate-N levels are considered in more detail. Site 1 is zero-tilled and dryland, showing the highest salinity levels (EC) in the subsoil (Fig.3). Site 2 is also zero-tilled and dryland, showing the highest accumulation of residual nitrate-N (Fig.1). Site 3 is minimum-tilled and irrigated and had high pre-plant soil nitrate-N in year 1 (377 kg/ha to 1.2 m), which included an application of 190 kg/ha of fertiliser N in preparation for cotton planting. Site 5 is conventional-tilled and irrigated, with little subsoil accumulation of N, but had the most N fertiliser (585 kg/ha) applied in its recent cropping history. Sites 2 and 5 have chloride levels>1000 mg/kg (Fig. 2) below 0.9 m while sites 1 and 3 have levels >850 mg/kg. The $EC_{1:5}$ levels (Fig.3) below 0.9 m are similar for sites 3 and 5, somewhat higher for site 2, and very high for site 1. Mean soil pH's below 0.9 m range from are 8.3 (site 1) to 9.3 (site 2).

Recent N management was examined for these 4 sites. For site 1, estimated N removal (225 kg/ha) for cotton and forage maize during the past 18 months exceeded the quantity applied (190 kg/ha) by 35kg/ha.

For site 2, estimated N removal (130 kg/ha) by successive crops of cotton, wheat and maize crops over 18 months, was about 20 kg/ha less than the quantity (150 kg/ha) applied. Soil sampling in autumn 2000 identified 175 kg/ha nitrate-N in the top 0.9 m, and 220 kg/ha between 0.9 m and 1.50 m (Fig. 1). However, an examination of the water data showed that only 20 mm of water appeared to have been extracted (Fig. 4) by the preceding maize crop from below 0.3m during a period devoid of any effective rainfall (12 mm) in the 3 months prior to harvest. This crop was planted in mid December. While adequate rainfall (220 mm) was received during the first third of the growing season, it appeared that the apparent unfavourable subsoil properties (high salinity, pH and/or chlorides) may have restricted the crops' ability to uptake significant quantities of both water and nutrients in the dry latter stage of the season.

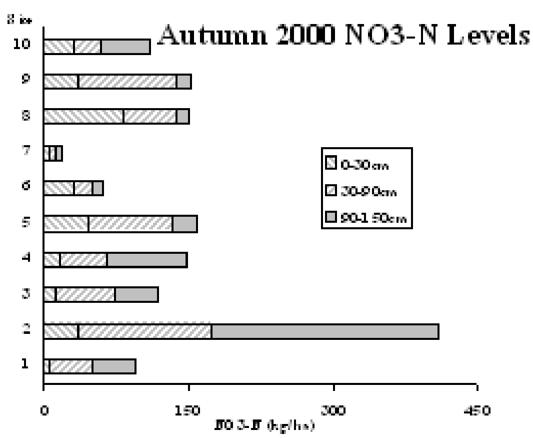

Figure 1.

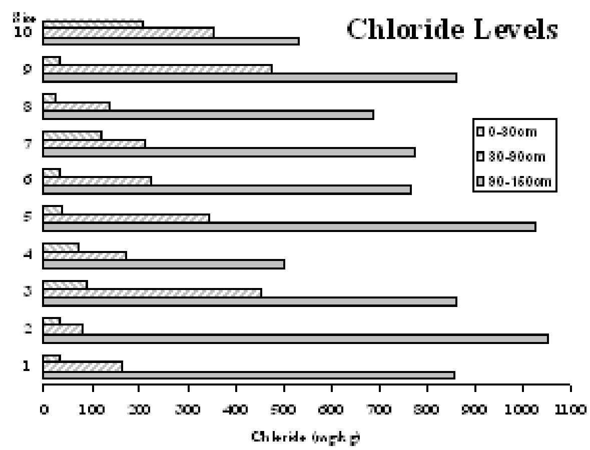

Figure 2.

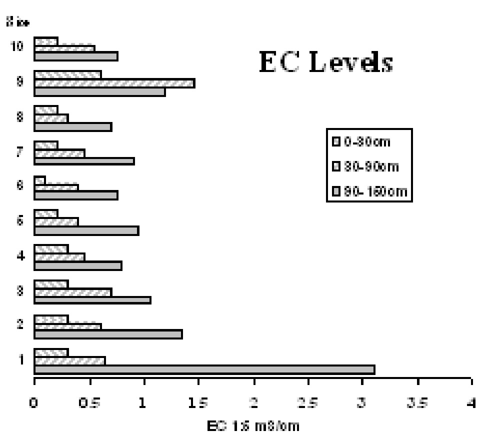

Figure 3.

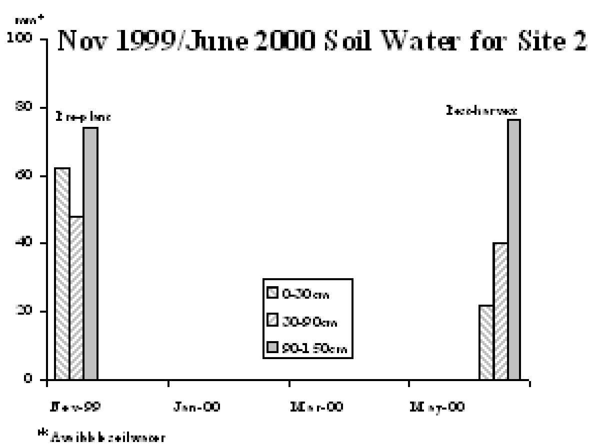

Figure 4.

For site 3, the large quantity of soil nitrate-N (377 kg/ha) present in the spring of 1998 was reduced substantially by autumn 2000, after successive cotton, wheat and sunflower crops removed about 250 kg/ha, leaving 120 kg/ha to 1.5m. The wheat and sunflowers received a combined total of 110 kg/ha of applied N. For site 5, three irrigated crops grown since 1994 removed about 285 kg N/ha compared to 565 kg N/ha being applied to these crops. Soil sampling in September 1998 revealed that only a small amount (15 kg/ha) of the 300 kg/ha of nitrate-N to 1.2 m had accumulated below 0.9 m. Soil sampling in autumn 2000 after the 98/99 cotton crop followed by a fallow, revealed that only 25 kg/ha the total nitrate-N (150 kg/ha) to 1.5 m had in fact accumulated below 0.9 m.

The above consideration of N management neglects the amount of soil N mineralised during cropping. Although there has been a limited opportunity to conduct measurements on the rate of mineralisation, soil tests on site 1 showed that approximately 95 kg/ha was mineralised in a zero-tilled fallow from April 1999 to November 1999. Furthermore, a similar amount was mineralised on site 5 during a longer fallow from April 1999 to February 2000. Results suggest that any over-fertilisation with N could be partly due to an under-estimation of the rate at which these soils mineralise N.

CONCLUSIONS

On some sites there is evidence to support the perception that over-fertilisation with N in association with cotton production has contributed significantly to subsoil nitrate accumulation in this area. It is also likely that nitrate accumulation in subsoils may be associated with soils exhibiting potentially unfavourable properties for water and nutrient uptake such as high salinity, pH and/or chloride. Over-fertilisation with N may also be accentuated by the use of the budget approach to N management for successive crops when the quantities of residual soil N as well as the rate of N mineralisation are ignored. Soil testing to a depth of 0.9 m as practiced commercially may not reveal subsoil accumulations, which appear to lie below 0.9 m. Furthermore, nitrate-N below 0.9 m in the soil profile appears to be inefficiently used by most crops in rotations. It represents, therefore, an unnecessary production cost as well as being a source for future contamination of ground water. Results gathered in this study have been used by farmers in the group to estimate the efficiency of the recovery of N fertiliser by specific crops in rotations, and to adjust their N management and cropping programs to match the residual levels of nitrate-N. Finally, the results have highlighted the unfavourable nature of the deeper layers of some soils of the district. An action learning activity is being developed based on these findings to fine-tune N management strategies and improve the sustainability of cropping practices in this and other districts.

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