Effect of early season leaching on the amount and distribution of soil mineral nitrogen under a maize grain crop in Waikato

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Abstract

There is little information on potential nitrate leaching from maize paddocks during the growing season. In 2003-04, a project was designed to determine the potential extent of in-season N leaching from maize crops and identify fertiliser management strategies to reduce losses. A split plot experiment was established on a Horotiu sandy loam just south of Hamilton, and run as two irrigation main plots (to induce leaching) over five fertiliser N subplots, a control and 325 kg N ha^{-1}, applied at different stages of crop growth. Soil mineral N and moisture content was measured down to 180 cm at crop establishment, after each irrigation and at crop harvest. The negative effects of our worst-case scenario, observed early in the season were nullified by harvest. Regardless of fertiliser treatment, N movement down the soil profile was restricted to the maize rooting zone, even in this free draining soil. However, as maize grain paddocks are often left fallow over winter, the movement of N down the soil profile may continue in the absence of crop uptake, demonstrating the importance of growers using appropriate fertiliser N inputs.

Additional key words: *Zea mays*, soil nitrogen distribution, nitrogen leaching, urea, irrigation.

Introduction

The key drivers of N leaching losses are drainage, driven by rainfall and irrigation, and soil N status, driven soil type and management practices. Waikato maize crops are unirrigated. Decision support tools help maize growers to maximise crop uptake of soil N so soil N at the start of winter is low and leaching risk is minimised (Li *et. al*., 2006).

If growers are managing their crops to minimise leaching losses over winter, the greatest risk of N loss then becomes spring when fertiliser N is applied and the crop is still small so there is little crop N uptake although heavy rainfall events in spring are uncommon in the Waikato. On average, a rainfall event exceeding 100 mm can be expected every three years while a 200 mm rainfall event during spring has not occurred in the past 35 years (Reid *et al*., 2005).

An experiment was run in 2003-04 to identify the potential extent of early season leaching that could occur during a maize crop and investigate fertiliser management strategies to reduce N losses.

Materials and Methods

The trial was conducted at Waikato Research Orchard, Rukuhia, Hamilton in a long term cropping paddock (soil type Horotiu sandy loam, field capacity 348 mm to 100 cm depth). The crop (Pioneer hybrid 36H36) was sown on 7 November 2003 at 94,000 plants

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ha^{-1} (76 cm row spacing). Base fertiliser of 50 kg P ha^{-1} and 50 kg K ha^{-1} was broadcast and incorporated prior to sowing to ensure these nutrients were not limiting.

The four replicate split plot experiment compared two irrigation regimes (main plot 35 m x 6 rows wide) and five N fertiliser treatments (sub-plot 7 m x 6 rows). The irrigation treatments were 0 and irrigation to simulate heavy rainfall events on 1 December 2003 (97 mm) and 12 January 2004 (133 mm). Irrigation was applied by mini-sprinklers at 5-6 mm hour^{-1}.

All N fertilisers were applied at 325 kg N ha^{-1}, a rate, which exceeds crop requirements. The high N rate was used so movement of N, via leaching from irrigation, would be easier to detect and to help us approximate a near worst-case scenario for N leaching. Five N fertiliser treatments were used. Side-dressed fertiliser was 'knifed in' 5 cm beside and 5 cm below the soil surface.

N_1. Control (no N fertiliser)
N_2. Standard urea at planting: ⅔ broadcast pre-plant and incorporated; ⅓ banded at planting
N_3. Slow release urea at planting: ⅔ broadcast pre-plant and incorporated; ⅓ banded at planting. This was a polymer-coated urea
N_4. Standard urea, standard practice: ⅓ banded at planting; ⅔ side-dressed 4 weeks after planting
N_5. Standard urea in three applications: ⅓ banded at planting; ⅓ side-dressed 4 weeks after planting; ⅓ broadcast 10 weeks after planting.

Soil mineral N ($NO3^-$ and $NH4^+$) and gravimetric water content was measured in 30 cm increments to a depth of 180 cm at four sampling times. Mineral N (nitrate $NO3^-$ and ammonium $NH4^+$) was extracted by shaking soil in KCl solution (2 mol l^{-1}) and measured colorimetrically (Blakemore *et al.*, 1987). Soil bulk density was measured to convert mineral N in ppm to kg ha^{-1}. The four sampling times were before sowing (6 November 2003), after the first irrigation (2 December 2004), after the second irrigation (13 January 2004) and after grain harvest (25 May 2004).

A neutron probe access tube was installed in each irrigated main plot. Soil volumetric water content was measured by neutron probe to 180 cm before, during and after each irrigation. This process enabled the calculation of soil field capacity (547 mm to 180 cm depth) and the tracking of irrigation water movement. Drainage was calculated for each soil layer assuming piston flow and measured values for soil field capacity, pre-irrigation soil moisture content and the amount of irrigation water applied.

Data was analysed by split-plot analysis of variance (main plot = irrigation, sub-plot = fertiliser) using Genstat 6.1. Each depth was analysed separately for soil mineral N and gravimetric moisture content. All soil mineral N results were log transformed as the data was not normally distributed.

Results

First irrigation, 1 December, 97 mm

The crop was at the three-leaf growth stage and approximately 20 cm tall. The soil was moist (317 mm to 100 cm) because of recent rain (78 mm in the previous week). Treatments N_2 and N_3 had received the same amount of fertiliser N (325 kg N ha^{-1}) but as different forms of urea. Treatments N_4 and N_5 received the same amount of fertiliser N as urea (108 kg N ha^{-1}) so were combined for statistical analysis.

Our drainage calculations showed movement of water from all monitored soil depths. Drainage would have moved N from 0-30 cm to a depth of 53 cm.

Both irrigation and N fertiliser treatments affected soil N levels down to 60 cm (Table 1). There were no treatment effects below this depth, which agrees with our drainage calculations. Over all N treatments, irrigation reduced soil N at 0-30 cm and increased soil N at 30-60 cm. Among individual fertiliser treatments, irrigation reduced soil N (0-30 cm) in N_4 and N_5 only (108 kg N ha^{-1}), and increased soil N (30-60 cm) where standard urea had been used (N, N_4 and N_5). Soil N (0-30 cm and 30-60 cm) was higher for standard urea (N_2) than slow release urea (N_3) at the same N rate.

Second irrigation, 12 January, 133 mm

The full amount of fertiliser N had been applied to treatments N_2, N_3 and N_4, and, after this second irrigation, the final N application was made to N_5. The soil was dryer when irrigation commenced (282 mm to 1 mm) so even though more water was applied in the second irrigation, there was less drainage. We calculated no drainage below 140 cm. Fertiliser N that was moved to 53 cm by the first irrigation would have been moved to around 80 cm by the second irrigation, still well within the rooting zone of a maize crop. Fertiliser N (0-20 cm) applied after the first irrigation was calculated to have moved to a depth of around 41 cm.

Soil mineral N was significantly affected by both irrigation and fertiliser treatments (Table 2). Over all N treatments, there was no effect of irrigation on soil N to 90 cm. The only individual fertiliser treatment that was reduced by irrigation at 0-30 cm was N_5, which was unusually low. At 60-90 cm, irrigation increased soil N only for N_3. Over all fertiliser treatments, there was a significant increase in soil N with irrigation below 90 cm but the increases were very small except in N_2, the worst-case scenario. Compared to N_2, the slow release urea (N_3) had less soil N at 90-150 cm under irrigated conditions.

Drainage calculations estimated that N fertiliser, applied at planting, could have moved from 53 to 80 cm in this second irrigation event. Increases below this depth could be due to either preferential water flow down through soil structural cracks to a greater depth (unlikely in a sandy soil) or leaching in addition to that caused by irrigation from earlier rainfall. This is more likely as 78 mm of rain was recorded in the fortnight following the first leaching event when the soil was at field capacity.

Grain harvest, 25 May

At this final sampling, all fertilised treatments had received the same amount of N and no irrigation had been applied since January. Over all N fertiliser treatments, there was no effect of irrigation on soil N at 0-30 cm or 30-60 cm (Table 3). This could be due to a number of factors including the length of time since irrigation occurred and plant uptake of N from the topsoil. Irrigation decreased soil N (0-30 cm) in N_4 and N_5, probably due to movement of N to depth.

Irrigation significantly increased soil N below 60 cm. At 60-90 cm, irrigation increased soil N in N_2. At 90-120, irrigation increased soil N in N_2 and N_3. At 120-150 cm, irrigation only increased soil N in N_3 only. Irrigation very slightly (1 kg N ha^{-1}) increased soil N at 150-180 cm in all fertilised treatments (N_2-N_5).

Among irrigated treatments, N_3 (slow release urea) consistently had the highest soil N level at all depths and total soil N (0-180 cm). This treatment received the same rate of fertiliser N as the other fertilised treatments but, because it was slower to dissolve, it retained more soil N. These slow release fertilisers may be useful for reducing N leaching in high rainfall environments. Irrigation did not affect total N (0-180 cm) in treatments N_1, N_2 and N_5 although N distribution was altered in the soil profile.

Table 1. Soil mineral nitrogen (N) per depth (kg N ha^{-1}) as measured after the first irrigation with. N treatments (N_1 Control; N_2 standard urea at planting (325 kg N ha^{-1} N_3 Slow release urea at planting (325 kg N ha^{-1}); N_4 Standard urea, standard practice; N_5. Standard urea in 3 applications).

	Irrigation Treatment								
	Unirrigated				Irrigated				LSR $_{0.05}$*
N Fertiliser	N_1	N_2	N_3	N_4 and N_5	N_1	N_2	N_3	N_4 and N_5	
0 –30	16	213	91	36	22	162	61	20	1.54
30-60	26	28	13	12	14	79	23	22	1.78
60-90	7	6	6	5	7	6	5	4	1.73
90-120	5	5	3	4	6	4	4	4	1.68
120-150	4	4	3	4	4	4	4	4	1.36
150-180	3	4	5	5	4	4	5	3	1.37
Total**	69	250	124	63	55	261	106	58	1.32

*LSR = Least significant ratio. **Totals may not add due to rounding and logarithmic transformation.

Table 2. Soil mineral nitrogen with depth (kg N ha^{-1}) as measured after the second irrigation (**A**) and at grain harvest (**B**) (N treatments as in Table 1)

A	Irrigation Treatment										
	Unirrigated					Irrigated					
N Fertiliser	N_1	N_2	N_3	N_4	N_5	N_1	N_2	N_3	N_4	N_5	$LSR_{0.05}$*
0-30	11	25	46	36	58	11	25	23	48	17	3.31
30-60	9	27	23	30	17	5	24	31	27	11	2.03
60-90	6	10	7	7	10	5	11	15	8	12	2.13
90-120	3	4	4	4	3	5	10	4	6	6	1.75
120-150	3	4	4	3	4	3	9	4	5	5	1.53
150-180	3	4	4	3	3	3	4	4	4	6	1.40
Total**	33	54	88	84	96	32	86	82	108	56	1.68
B											
0-30	9	19	27	42	31	14	18	38	20	19	1.51
30-60	10	21	26	28	30	10	21	33	18	21	1.61
60-90	5	9	13	8	9	4	20	22	9	16	1.86
90-120	4	5	5	6	4	4	9	13	7	5	1.72
120-150	4	5	6	5	4	4	6	9	6	5	1.64
150-180	4	4	4	4	4	4	5	7	5	5	1.32
Total**	36	62	79	95	81	39	79	123	61	72	1.34

*LSR = Least significant ratio. **Totals may not add due to rounding and logarithmic transformation.

Summary and Conclusion

In this experiment, we investigated two fertiliser management options to reduce N leaching, the use of slow release urea (N_3) and splitting N fertiliser into three applications (N_4). These were compared with a control (N_1), worst practice (N_2) and standard industry practice (N_3). All fertilisers were applied at 325 kg N ha^{-1}, a rate which exceeds crop requirements, so N movement via leaching from irrigation would be easier to detect and to help us approximate a near worst case scenario for N leaching. We would expect, in a commercial crop, around half this amount of N would be applied.

The negative effects of the worst practice (N_2), observed early in the season due to irrigation, were nullified by the time of grain harvest. Standard practice (N_4) reduced N leaching risk from heavy rainfall only until side dressing. By grain harvest, soil N at all depths was the same as in the other treatments that received standard urea. Splitting N into three applications (N_5) reduced N leaching risk at both irrigation events but final soil N levels were the same as in the other standard urea treatments.

Slow release urea (N_3) was the most effective fertiliser practice for retaining N in the soil. At the first irrigation, N_3 greatly reduced soil N compared with N_2 but not as much as N_4 and N_5, which had only received one-third of the fertiliser N. After the second irrigation, slow release urea had the same total N as the other fertilised treatments but had less N at depth (90-150 cm). At grain harvest there was more soil N in N_3 than in all of the standard urea treatments.

Regardless of fertiliser N treatment, this trial demonstrated that even with high simulated rainfall, on an extremely free draining soil, N movement down the soil profile was restricted to within the maize rooting zone. This was estimated by both intensive soil moisture monitoring and soil mineral N measurement. Therefore, for most heavy rainfall events, fertilizer reapplication is unnecessary.

Movement of N into lower soil horizons raises questions about the long-term effect of high rainfall events. Maize grain paddocks are often left in fallow over winter and movement of N down the soil profile may continue in the absence of crop uptake. The movement of N down the soil profile may affect subsequent fertiliser decisions. As the top 15 cm is usually sampled to determine fertiliser N applications, available soil N may be underestimated and fertiliser N inputs overestimated for soils subject to high rainfall events in previous seasons. The use of deeper soil sampling depths to better estimate soil N availability is currently being explored.

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