Nitrogen uptake and nitrogen use efficiency of forage kale crops grown under varying amounts of water and nitrogen fertiliser rates in shallow soils

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Abstract
Grazing of forage kale can cause ground-water pollution through nitrate leaching, particularly in wet conditions. To minimise nitrogen (N) loading, N supply should be matched with crop requirements to achieve an optimum combination of yield and N content for given soil water conditions during crop growth. An experiment was conducted on a stony silt loam soil to investigate dry matter (DM) yield, N uptake and apparent N use efficiency (*a*NUE) under varying water and N inputs. Treatments comprised a factorial combination of two water treatments [rain-fed (control) and full irrigation] and four N rates (0, 75, 150 and 300 kg N/ha), applied three times during the first 13 weeks after sowing. With rain-fed treatments, DM yield increased from 5 t DM/ha for the 0 kg N/ha crops to 11 t DM/ha for the 300 kg N/ha crops. Similarly, DM yield increased from 10 to 25 t DM/ha for the same respective treatments under irrigation. Total N uptake differed with N application rate and increased from 86 kg N/ha for the 0 kg N/ha crops to 350 kg N/ha for the 300 kg N/ha crops but was unaffected by the irrigation treatments. Apparent NUE increased with water application, from 5 kg DM/kg N in the rain-fed treatment to 54 kg DM/kg N when irrigated, but was unaffected by the N application rate. Management practices that increased the *a*NUE achieved the best environmental outcome as productivity was maintained at high levels, herbage N concentrations achieved acceptable levels and residual N in soil decreased.

Key words
Brassica oleracea var. *acephala* L.; apparent nitrogen use efficiency, leaching, N uptake.

Introduction

Forage kale (*Brassica oleracea* var. *acephala* L.) is an important crop for winter feeding, particularly in the dairy production systems of the South Island, New Zealand (Chakwizira *et al*. 2015a, b) and Tasmania, Australia (Pembleton *et al*. 2015). Forage kale crops have large nutrient requirements, particularly for nitrogen (N) (Wilson *et al*. 2006), and these authors have shown that suboptimal N and water supply results in poor yields. Under high fertiliser N inputs yield is enhanced, but excess amounts of N can lead to the accumulation of nitrate-N in the plant (Chakwizira *et al*. 2015b), potentially leading to animal health issues and/ or environmental pollution. The risk of nitrate leaching is high on soils with low water holding capacity (WHC) and if winter grazing occurs during periods of high rainfall. Management of crops to match N supply and crop N demand is a logical approach; however, N application rates will depend on background soil fertility, soil moisture and yield potential (Wilson *et al*. 2006). There are quantitative data on N uptake and partitioning (Wilson & Maley 2006), apparent N use efficiency (aNUE; Chakwizira *et al*. 2015a) and water use efficiency (Chakwizira *et al*. 2014) for deep soils with moderate to high WHC. However, there is little research on the combined effects of water and N on growth of forage kale crops grown on shallow and stony soils in New Zealand, where most of these crops are grown for winter grazing. The objective of this experiment was to determine responses to irrigation and N fertiliser and their interactions on DM yield, N uptake and aNUE of forage kale crops grown in shallow soils.

Materials and Methods

The experiment was conducted at the Lincoln University dry-land research farm, Ashley Dene (43°38'45.5"S 172°20'34.4"E, 30 m a.s.l.). The site was situated on a shallow Balmoral stony silt loam soil (Webb & Bennett 1986), with shallow topsoil (0.2 m in depth) over gravel. The soil has a WHC of about 90 mm/m of depth, recalculated from Sim *et al*. (2012). The site was previously in lucerne (*Medicago sativa* L.) from 2008 to 2011 followed by kale from 2011 to 2013. The climate at Ashley Dene is temperate, with mild to cool winters and warm summers. Mean annual rainfall is 600 mm, distributed evenly throughout the year (NIWA 2014). Weather data from a temporary weather station at the experimental site and long-term data from the Broadfields meteorological station (NIWA 2014) at Lincoln (~10 km from the site) are shown in

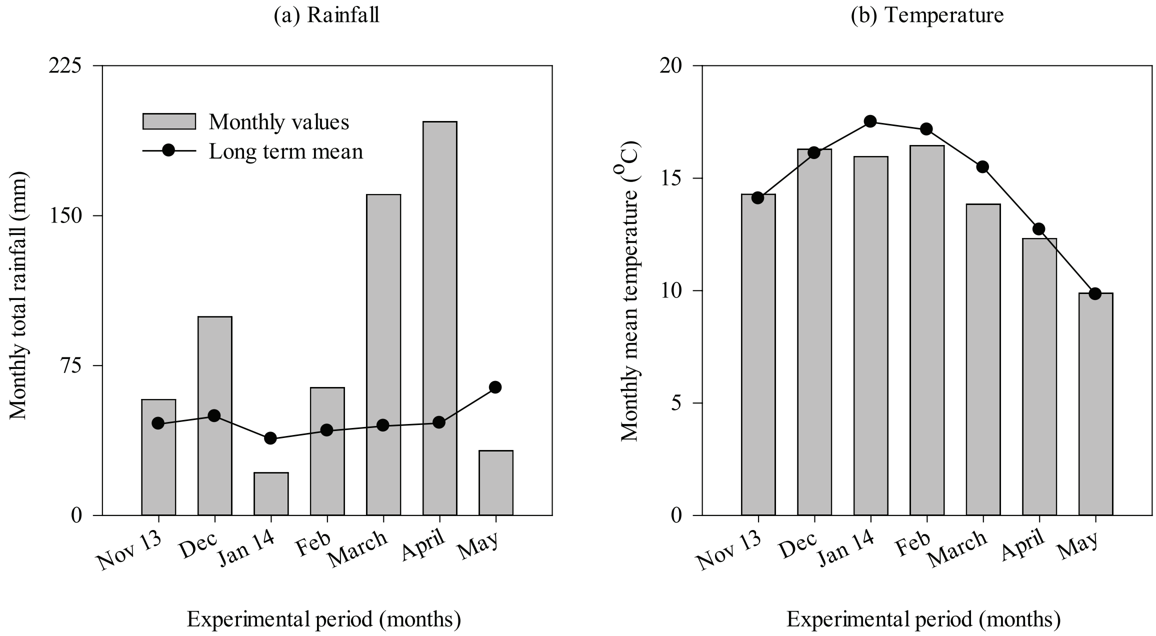

Figure 1: Monthly (a) total rainfall and (b) average temperature at Ashley Dene, Canterbury, New Zealand. Long-term data are from 1970 to 2010 (NIWA 2014).

The experiment was a randomised block design, consisting of eight treatments: a factorial combination of four nitrogen rates (0, 75, 150 and 300 kg N/ha) and two rates of irrigation [rain-fed control and full irrigation replacement of potential evapotranspiration (ET)]. Irrigation was applied twice weekly (maximum = 50 mm/week if no rain) to replace ET. Cultivation involved deep ploughing followed by power harrowing. Soil samples to 0.15 m depth were collected on 30 July 2013 and the average soil test results were: pH 5.8, P 16 mg/kg, K 160 mg/kg, Ca 1000 mg/kg, Mg 45 mg/kg, Na 25 mg/kg, sulphate-S 5 mg/kg soil and available mineral N 78 kg/ha. Basal fertiliser comprising 250 kg/ha triple superphosphate (0-20.5-0-1) and 10 kg/ha borate 46 (15% boron) was broadcast and incorporated into the soil before sowing. Soil mineral N (nitrate and ammonium) tests were taken from individual plots before the application of the N fertiliser treatments and also at the end of the season to a depth of 0.3 m. Nitrogen fertiliser treatments were applied as urea (46% N) on three dates [30, 57 and 91 days after sowing (DAS)] with 20%, 40% and 40% of the total N per treatment (0, 75, 150, and 300 kg N/ha) applied on each date, respectively.

Final dry matter (DM) harvest was performed on 21 May 2014 and involved removing all plants within a 1 m^2 quadrat to approximately 0.1 m height in each plot. The number of plants and total fresh mass per quadrat was determined in the field and a representative five-plant subsample was retained to determine total DM yield. Dry mass was determined after drying at 60°C to a constant mass. Total N concentration was determined by the Dumas combustion using a LECO CNS-200 analyser (LECO Corporation, St Joseph, MI). Total N uptake was then calculated as the product of crop DM yield and the concentration of N. Apparent NUE was defined as the ratio of additional DM yield to fertiliser N input. This differs from the traditional calculations of NUE as a quotient of total DM and total available N (soil N plus fertiliser N) (Moll et al. 1982).

Data were analysed using analyses of variance (ANOVA) in GenStat v.14 (VSN International, Hemel Hampstead, UK). Significant interactions and main effects were separated using Fisher's protected least significant difference (LSD) tests (α=0.05).

Results and discussion

Final DM yield increased ($P < 0.01$) with both water and N supply from 5.2 t DM/ha for the 0 kg N/ha crops to 11.3 t DM/ha for the crops receiving 300 kg N/ha under the rain-fed treatments (Figure 2), and from 10.1 t DM/ha to 25.8 t DM/ha for the same respective N treatments under full irrigation. These results are consistent with literature (Chakwizira *et al*. 2015a, b; Wilson *et al*. 2006).

The amount of N taken up by the crops was unaffected (P = 0.30) by the irrigation treatments (Table 1) but increased (P< 0.001) with N application from a mean of 88.6 kg N/ha for the no N control treatments to 350 kg N/ha for the 300 kg N/ha treatments. These N responses are consistent with Chakwizira *et al*. (2015a); however, the water responses are inconsistent with previous reports for crops grown under deep soils with high WHC, where water availability had strong effects on N uptake (Chakwizira *et al*. 2013). The lack of response to water could be attributed to the high rainfall during March and April (Figure 1) when growth rates recovered in the rain-fed treatments and any surplus soil N was utilised. In shallow soils, the timing of autumn rain can have important consequences for N loading effects on potential N leaching during winter grazing.

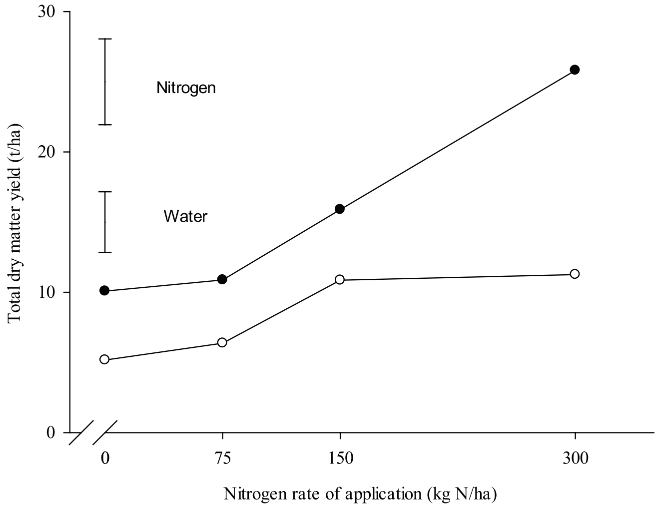

Figure 2: Total dry matter yield of forage kale crops grown with (˜) and without (™) irrigation under different nitrogen rates at Ashley Dene farm, Canterbury, New Zealand in the 2013–14 season.

The aNUE was higher (P<0.001) for the irrigated crops, with a mean value of 54 kg DM/kg N applied compared with 5 kg DM/kg N applied for the rain-fed crops (Table 1). However, aNUE was unaffected (P = 0.88) by N supply, with a mean value of 29 (13-38) kg DM/ kg N applied. This was inconsistent with the results of Chakwizira et al. (2015a) where aNUE was reported to decrease with increasing N supply. The aNUE for the irrigated crops (Table 1) was within the range of 51–112 kg DM/kg N applied (Chakwizira et al. 2015a).The inconsistencies could be attributed to the timing of N application, rainfall distribution, and overall N uptake. For all the treatments, 60% of the fertiliser was applied by 10 December, and this period received about twice the long-term mean rainfall for December (Figure 1). Some of the N fertiliser may have been lost through early leaching. This period was followed by a very dry period in January–February, coincidentally, the period when the remaining 40% of the fertiliser was applied. In the rain-fed crops, N may have been leached at both ends of the season and remained unused during the dry summer period (Jan–Feb), thus compromising DM production. The dry period also coincided with the period of high radiation and therefore high potential growth rate. The high rainfall period, at the end of the season, would have likely allowed the rain-fed crops to take up the N that was resident in soil and hence the similar amounts taken up by the crops under both water treatments. Late-season rain also coincided with decreasing temperatures (Figure 1) and radiation, resulting in lower DM accumulation. Late-season N uptake was higher in the rain-fed crops with comparable final N accumulation in both water treatments.

Table 1.Total nitrogen uptake (kg N/ha) and apparent nitrogen use efficiency (*a*NUE; kg DM/kg N applied) for forage kale crops grown under different rates of nitrogen with and without irrigation, at Ashley Dene, Canterbury, New Zealand in 2013–14 season.

N rate	N uptake		Apparent NUE[a]	
	Irrigated	Rain-fed	Irrigated	Rain-fed
0	109.8	67.4	-	-
75	133.6	93.7	33.8	-7.1
150	189.4	237.4	60.0	16.8
300	374.4	327.4	68.8	3.9
$LSD_{0.05}$				
Water	41		29*	
N rate	58***		35	
Interaction	82		37	

[a]No aNUE for the control plots, as no N was applied.

Conclusions

The DM yield of the rain-fed treatments increased from 5 t DM/ha for the 0 kg N/ha crops to 11 t DM/ha for the 300 kg N/ha treatments. Similarly, DM increased from 10 to 25 t DM/ha for the respective treatments under irrigation. The similar amounts of N uptake between irrigation treatments and the lower *a*NUE for the low yielding rain-fed crops meant that these crops had higher tissue N concentration, and subsequently could lead to higher urinary N deposited into the soil when livestock are fed *in situ* on these crops leading to N leaching during wet winter seasons. Management of N in rain-fed crops is therefore important, and it is therefore recommended to split apply N through the season and following rainfall events. As this experiment was done on a single site and season, the results will need to be confirmed by repeating this study for another season.

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