NITROGEN ACCUMULATION IN BIOMASS AND ITS PARTITIONING IN SUGARCANE GROWN IN THE BURDEKIN

By

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Abstract

THE COMMERCIAL SUGARCANE varieties Q253$^{\phi}$, Q208$^{\phi}$ and KQ228$^{\phi}$, which are grown in the Lower Burdekin, were sampled several times throughout the growing season to study the seasonal changes in nitrogen (N) content in the above- and below-ground biomass. In sugarcane approximately 130 days after planting (DAP), above-ground biomass contained up to 36% of the final above-ground biomass N content. By 200 DAP up to 84% of the total N content of the above-ground biomass had accumulated. From 200 to 270 DAP the rate of N accumulation slowed, and by 365 DAP the above-ground N content had plateaued in Q208$^{\phi}$ and KQ228$^{\phi}$ and decreased slightly in Q253$^{\phi}$. Of the three varieties, Q253$^{\phi}$ appeared to accumulate N more rapidly than the other two varieties during the peak period of N accumulation. Nitrogen utilisation efficiency (kg of dry matter/kg crop N) of each of the three varieties was compared. KQ228$^{\phi}$ appeared to be more efficient than Q253$^{\phi}$ and Q208$^{\phi}$. Below-ground biomass, which included roots and stool, of the variety Q208$^{\phi}$ was sampled at 200 and 365 DAP. At 200 DAP below-ground biomass N was 11% of the above-ground biomass N and by 365 DAP it was 15% of above-ground biomass N. The data presented in this paper provide an insight into the key periods of N uptake and its partitioning during sugarcane development under irrigation in the Lower Burdekin.

Introduction

Nitrogen is a key component of metabolic processes in plants and due to its mobile nature in soils is often a limiting factor in achieving maximum yield in commercial sugarcane crops grown in Australia. Demand for N depends upon a crop's yield potential which is determined by climate, crop age and class and management practices (Muchow and Robertson, 1994).

Determining the correct amount of nitrogen required to achieve maximum cane yield while minimising losses to the environment is a difficult task; however developing a basic understanding of nitrogen accumulation in biomass and the rate at which it accumulates will provide useful insights for agronomists, industry advisors and farmers.

There have been few studies into the accumulation of nitrogen in the above-ground biomass of sugarcane in Australia. Wood *et al.* (1996) investigated the accumulation of N in the above ground biomass of two cultivars (Q117, Q138) and confirmed earlier findings from work in South Africa conducted by Thompson (1988), that most of the N was taken up in the first six months following planting/ratooning. In a recent review, Bell *et al.* (2014) reported that greater than 90% of the total above-ground N uptake occurs in the 200 day period after planting/ratooning.

Few studies have been conducted into the accumulation of nitrogen in below ground biomass (roots and stool) of sugarcane in Australia. Bell *et al*. (2014), summarised the limited data collected to date and suggested that N in stool and root accumulates at about 20 kg N/ha/year while a further 10 kg N/ha/year accumulates in root material down to 60 cm.

The objective of this study was to gain an insight into nitrogen accumulation in the above and below ground biomass of sugarcane and its partitioning in crops grown under irrigation in the Lower Burdekin region of Australia.

Materials and methods

Location and cultural details

The study was conducted on a Sugar Research Australia farm located in the Lower Burdekin region of Queensland (19°30'S, 147°17'E). Three cultivars, Q208(ϕ), Q253(ϕ) and KQ228(ϕ), were grown as plant crops over the 2014–2015 season. The area used for the investigation has a history of being cropped with sugarcane. A bare fallow period of six months occurred prior to planting which took place in August 2014. A split plot design was established with six rows by 10 m in each replicate. Four subsamples (time) were taken randomly from the four middle rows: subplot size was therefore 10 m by 1.52 m.

Altogether there were 48 plots in this trial. On 28 October 2014, sulfate of potash was used to apply 88 and 39 kg/ha of K and S respectively to all blocks as a side dressing banded into the soil. Irrigation water was applied to all blocks via furrows with water supplied from bores. No nitrogen fertiliser was applied to the three main plots (variety) so that the effects of suboptimal N rates on three commercially grown sugarcane varieties could be investigated over a growing season.

Soil sampling and analysis

Prior to planting, a total of 12 soil samples were taken from the three main plots (variety) to a depth of 100 cm. Six cores were taken in each replicate with samples composited for each depth (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm) and analysed for nitrate nitrogen and ammonium nitrogen.

The quantity of mineral nitrogen (sum of nitrate and ammonium) in the top 60 cm of the soil profile (kg N/ha) was calculated for each replicate assuming a bulk density of 1.21 g/cm^3. At 200, 270 and 365 days after planting (DAP) two soil cores were taken from subplots to a depth of 100 cm within the area where above and below-ground biomass samples were taken. Composite samples for 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, 80–100 cm were then analysed for nitrate nitrogen and ammonium nitrogen. This information was used to calculate the mineral nitrogen (kg/ha) in the top 60 cm of the soil profile at each biomass sampling.

Above ground biomass

At the end of the tillering stage (approximately 130 DAP) a 3 m length of a randomly selected 10 m row from each main-plot and replicate was harvested and tillers were counted and weighed (sample time 1). A sub-sample was dried at 60°C to determine dry matter accumulation (t/ha). Subsamples were then ground and analysed using Kjeldahl digestion to determine total nitrogen concentration. Nitrogen accumulation (kg/ha) was determined by multiplying the N concentration of the tillers by the estimated biomass dry weight per hectare.

At 200, 270 and 365 DAP, the sampling was repeated (sample times 2, 3 and 4) as described above. Twelve stalks were then randomly selected from each replicate and partitioned into stalk, green leaf, cabbage (which is the immature top of the stalk plus the green leaf sheaths) and attached dead leaf. At 365 DAP surface trash from the sampling area was also collected. Fresh weight of each component was determined and a subsample was then dried and analysed for total nitrogen as described above. The nitrogen accumulation on an area basis in stalk, leaf, cabbage, attached dead leaf and surface trash was determined by multiplying the N concentration of each component by the biomass of the respective component. Net above-ground N accumulation was calculated as the sum of the N accumulation in the individual components.

Below ground biomass

Below ground biomass sampling took place at 200 and 365 DAP in the plot of Q208(ϕ). Sampling was undertaken in the areas where above-ground biomass was harvested during the same period. A 1 m^2 area was randomly selected within the 3 m length of crop row. Roots and stool were excavated using a shovel down to 0.5 m. All soil was washed from roots and stool which were then weighed to determine the fresh biomass weight. A subsample was taken and dried and analysed for total N as described above. Nitrogen accumulation (kg N/ha) was determined by multiplying the N concentration by the below-ground biomass.

Water sampling and irrigation applications

Irrigation water was sourced from bores and supplied to the crop via fluming which delivered water to each of the furrows. Irrigation water was analysed for nitrate nitrogen. The number of irrigation applications applied to the site and the duration of the irrigations were recorded to calculate volume (ML) of irrigation water applied per hectare over 2014–2015. This information along with the concentration of nitrates in the bore water was then used to determine the nitrogen inputs from irrigation water over the duration of the crop development using the equation: N input (kg N/ha) = mg N/L × ML.

Results

Soil nitrogen

Soil mineral nitrogen levels in the three main plots prior to planting were high in the top 60 cm of the soil profile and relatively uniform across the trial. By 200 DAP soil nitrogen levels had declined and by 270 DAP, levels were very low (Table 1).

Table 1—Mineral nitrogen (kg N/ha) in the top 60 cm of the soil profile.

Days after planting	Variety			
	Q253$^{\phi}$ Mean*	Q208$^{\phi}$ Mean*	KQ228$^{\phi}$ Mean*	P Value
0	102.4	84.6	96.8	0.15
200	46	36.9	31.5	0.32
270	16.3	15.7	15.7	0.88
365	17.8	21.2	15.3	0.12

* Mean of four replications

Soil mineral N levels for the three post-planting samplings were not influenced by variety, however N levels declined over the first 270 DAP in each of the three main plots.

Nitrogen applied via irrigation water

Each of the irrigation events applied approximately 1.55 ML/ha. Water samples taken from the fluming during irrigation events were analysed and found to contain 2.91 ± 0.04 mg/L of oxidised nitrogen as N. The total amount of nitrogen applied to each of the three blocks over the growing season was 68 kg N/ha.

Yield measurement

At 365 DAP, mean and standard error for cane yield (tc/ha) was calculated for each variety. Q253$^{\phi}$ produced 132 ± 5 tc/ha while Q208$^{\phi}$ and KQ228$^{\phi}$ produced 106 ± 10 tc/ha and 97 ± 8 tc/ha respectively. Average plant crop yields across the Burdekin in 2014 for the three varieties, grown in a range of soil types and under a variety of farm management practices, were 160 tc/ha for Q253$^{\phi}$ and 145 tc/ha and 144 tc/ha for Q208$^{\phi}$ and KQ228$^{\phi}$ respectively (Sugar Research Australia, 2015). The relative cane yields of the plots therefore comprise 83% (Q253), 73% (Q208) and 67% (KQ228) of the relevant district average yields.

Crop N accumulation

Above-ground biomass (dry matter) accumulation is shown in Figure 1. The variety Q253$^{\phi}$ accumulated significantly more biomass from 200 days onwards in comparison to Q208$^{\phi}$ and KQ228$^{\phi}$. From 270–365 DAP, above-ground biomass did not change significantly in the three varieties.

The accumulation of nitrogen for the three varieties followed that of above-ground biomass and can be described by a typical non-linear model for the period of the trial (Figure 2). N accumulation appeared to increase from 130 DAP until 270 days after which N accumulation plateaued for Q208$^{\phi}$ and KQ228$^{\phi}$, and declined slightly in Q253$^{\phi}$.

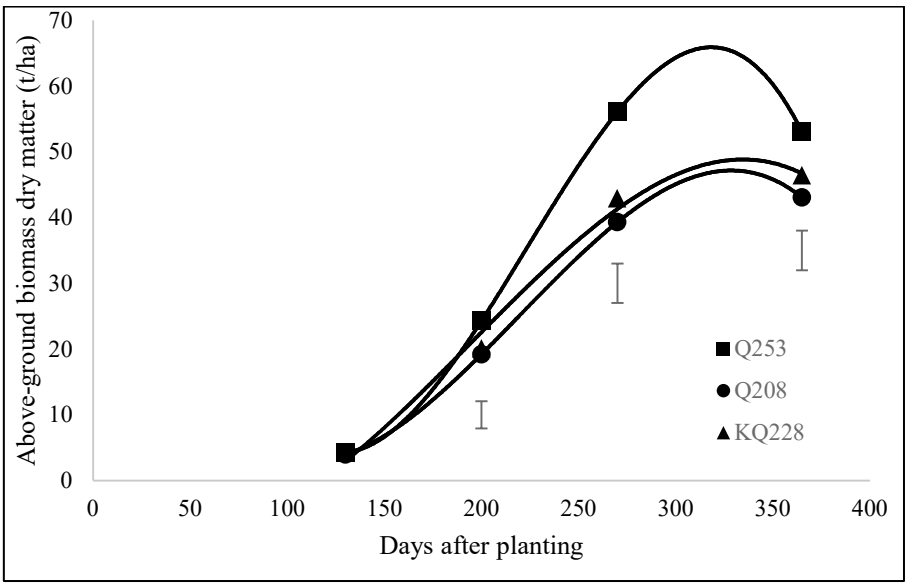

Fig. 1—Crop above-ground biomass accumulation in relation to DAP for three varieties. Vertical bars show the least significant differences of means (P=0.05) of the three varieties. Polynomial functions for three varieties are Q253$^{\Phi}$ (R^2 = 0.99) y = –2E–05x^3 + 0.0118x^2 – 2.1419x + 122.2, Q208$^{\Phi}$ (R^2 = 0.99) y = –3E–08x^4 + 1E–05x^3 –0.0018x^2 + 0.07x, KQ228$^{\Phi}$ (R^2 = 0.99) y = –8E–06x^3 + 0.0056x^2 –0.9227x + 48.11.

Of the three varieties Q253$^{\Phi}$ accumulated significantly more nitrogen from 200 days onwards in comparison to Q208$^{\Phi}$ and KQ228$^{\Phi}$. There appeared to be no difference in N accumulation between Q208$^{\Phi}$ and KQ228$^{\Phi}$. In the first 130 DAP between 24–35% of the total above-ground N accumulated by the crops was captured. By 200 DAP between 65–84% of the total above-ground N accumulated by the crops was captured, and at around 270 days, N accumulation peaked.

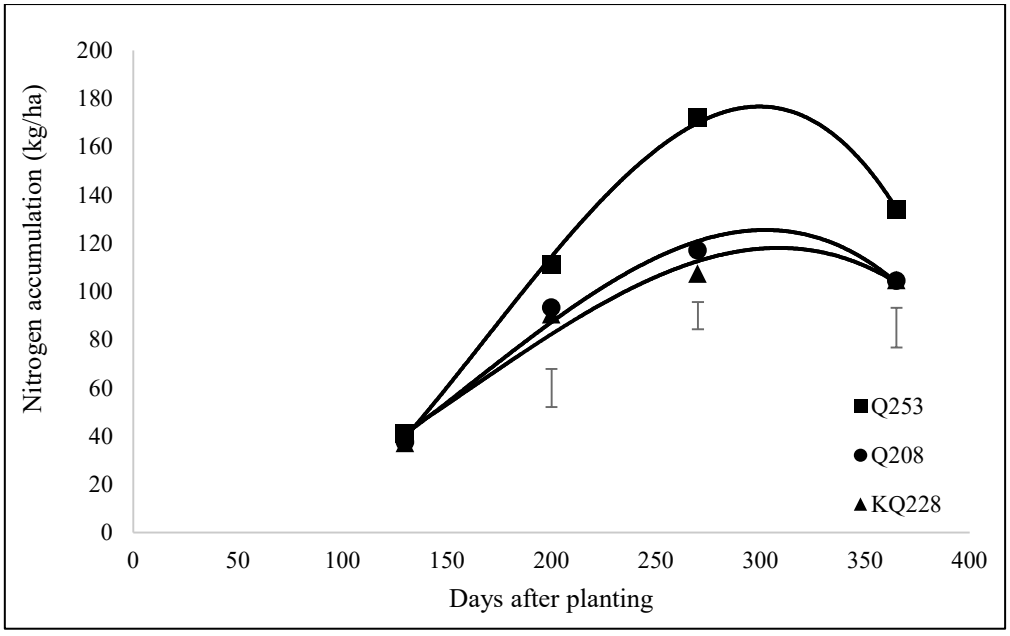

Fig. 2—Crop nitrogen accumulation in relation to DAP for three varieties. Vertical bars show the least significant differences of means (P=0.05) of the three varieties. Polynomial functions for three varieties are Q253$^{\Phi}$ (R^2 = 0.998) y = –2E–05x^3 + 0.011x^2–0.7578x, Q208$^{\Phi}$ (R^2 = 0.9831) y = –1E–05x^3 + 0.0055x^2–0.2116x, KQ228$^{\Phi}$ (R^2 = 0.9645) y = –9E–06x^3 + 0.0042x^2–0.818x.

The production of above-ground biomass per kg of accumulated N (N utilisation efficiency) (Bell *et al.,* 2014) showed little variation between varieties (Table 2), however at 270 DAP, KQ228$^{\phi}$ produced significantly more biomass per kg of crop N than Q253$^{\phi}$ and Q208$^{\phi}$. However, before and after this time there there was no significant (P>0.05) difference between the three varieties.

Table 2—Mean and standard error for nitrogen utilisation efficiency (kg of dry matter/kg crop N) for three varieties.

DAP	Variety			lsd (P=0.05)
	Q253$^{\phi}$	Q208$^{\phi}$	KQ228$^{\phi}$	
130	103.5 ± 5.5	106.5 ± 4.0	116.5 ± 2.8	ns
200	218.1 ± 6.1	206.4 ± 5.2	223.3 ± 10.5	ns
270	326.0 ± 7.2	336.2 ± 3.5	400.7 ± 9.4	27.2
365	396.1 ± 4.4	414.1 ± 17.0	443.6 ± 21.0	ns

N and biomass accumulation in plant components

Nitrogen accumulation in stalk and dead leaf almost follow the trend in biomass accumulation (Figures 3 and 4). However in green leaves there was a decline in accumulated N from 200 DAP for Q208$^{\phi}$ and KQ228$^{\phi}$ while Q253$^{\phi}$ displayed a significant decline in accumulated leaf N at 365 DAP. Leaf N concentration declined significantly from 200 to 365 DAP for the three varieties (Figure 5).

At 200 DAP the highest proportion of above-ground N was accumulated in the leaf, comprising of approximately 50% of the accumulated N (Table 3). Stalks contained approximately 30%, and cabbage and attached dead leaf each contained approximately 10% of the accumulated N. By 365 DAP, the three varieties underwent a significant shift in the proportion of N accumulated in plant components.

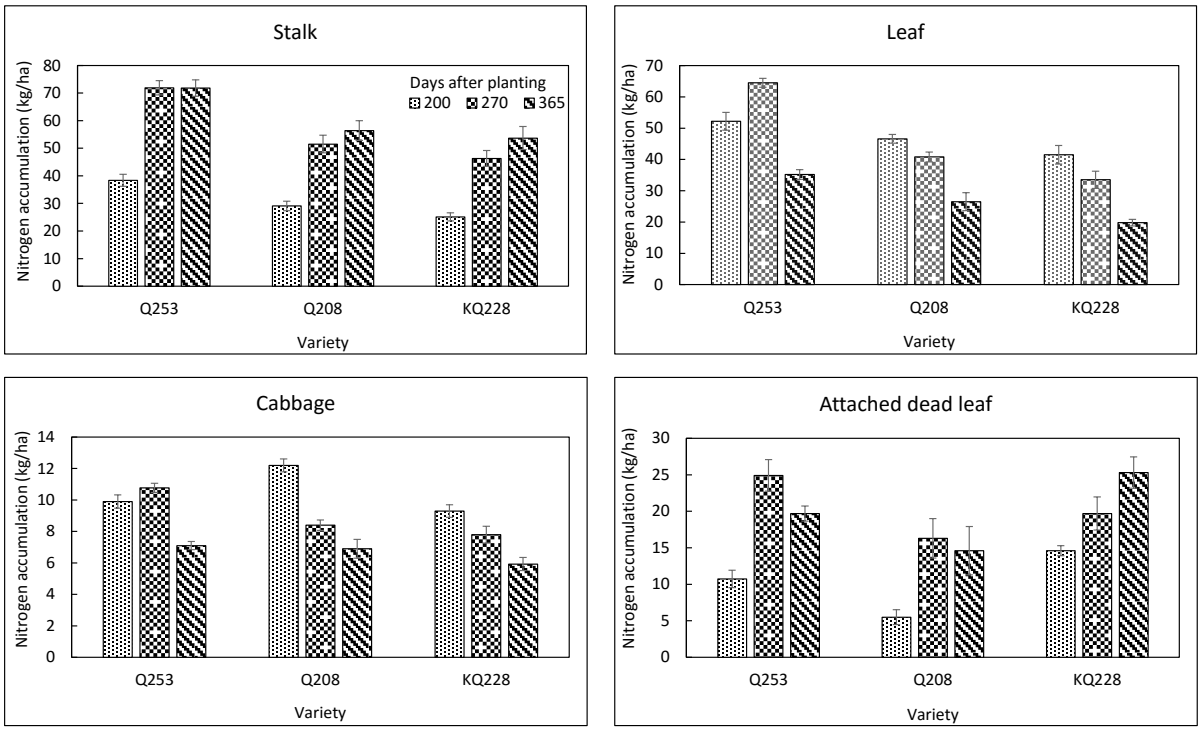

Fig. 3—Mean nitrogen accumulation in crop components in relation to DAP for three commercial varieties Q208$^{\phi}$, Q253$^{\phi}$ and KQ228$^{\phi}$ (vertical line indicates standard error).

At this time, more than 50% of the accumulated above-ground N was located in the stalk while N in leaves declined to less than 30% of the total accumulated N. Accumulated N in cabbage also declined following the general decline in cabbage biomass. Attached dead leaf accumulated N increased significantly mirroring the increase in attached dead leaf biomass (Table 4).

Table 3—Proportion of N accumulated in plant components at 200, 270 and 365 DAP.

Cultivar	Days after planting	Proportion of N accumulation in plant component			
		Stalk	Leaf	Cabbage	Attached dead leaf
Q253$^{\phi}$	200	0.35	0.47	0.09	0.09
	270	0.42	0.38	0.06	0.14
	365	0.54	0.26	0.05	0.15
Q208$^{\phi}$	200	0.31	0.5	0.13	0.06
	270	0.44	0.35	0.07	0.14
	365	0.54	0.25	0.07	0.14
KQ228$^{\phi}$	200	0.28	0.46	0.10	0.16
	270	0.43	0.31	0.08	0.18
	365	0.51	0.19	0.06	0.24

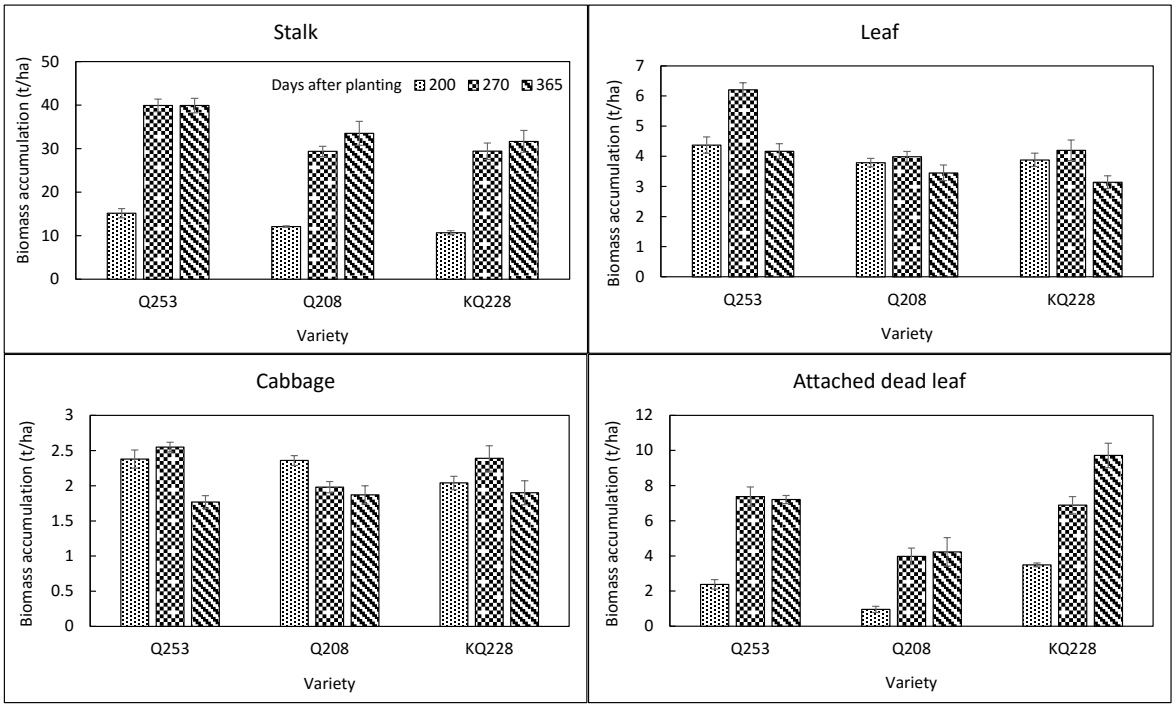

Fig. 4—Mean biomass dry matter accumulation in crop components in relation to DAP for three commercial varieties Q253$^{\phi}$, Q208$^{\phi}$ and KQ228$^{\phi}$ (vertical line indicates standard error).

Table 4—Proportion of biomass accumulated in plant components at 200, 270 and 365 DAP.

Cultivar	Days after planting	Proportion of biomass accumulation in plant component			
		Stalk	Leaf	Cabbage	Attached dead leaf
Q253$^{\phi}$	200	0.62	0.18	0.10	0.10
	270	0.71	0.11	0.05	0.13
	365	0.75	0.08	0.03	0.14
Q208$^{\phi}$	200	0.63	0.20	0.12	0.05
	270	0.75	0.10	0.05	0.10
	365	0.78	0.08	0.04	0.10
KQ228$^{\phi}$	200	0.54	0.19	0.10	0.17
	270	0.69	0.10	0.05	0.16
	365	0.68	0.07	0.04	0.21

During the period when N concentrations in plant components were monitored, leaf N concentration was found to be the highest followed by cabbage, attached dead leaf and then stalk. In general concentrations of N in all components declined to some degree over time, however the greatest decline was observed in leaf N concentration (Figure 5).

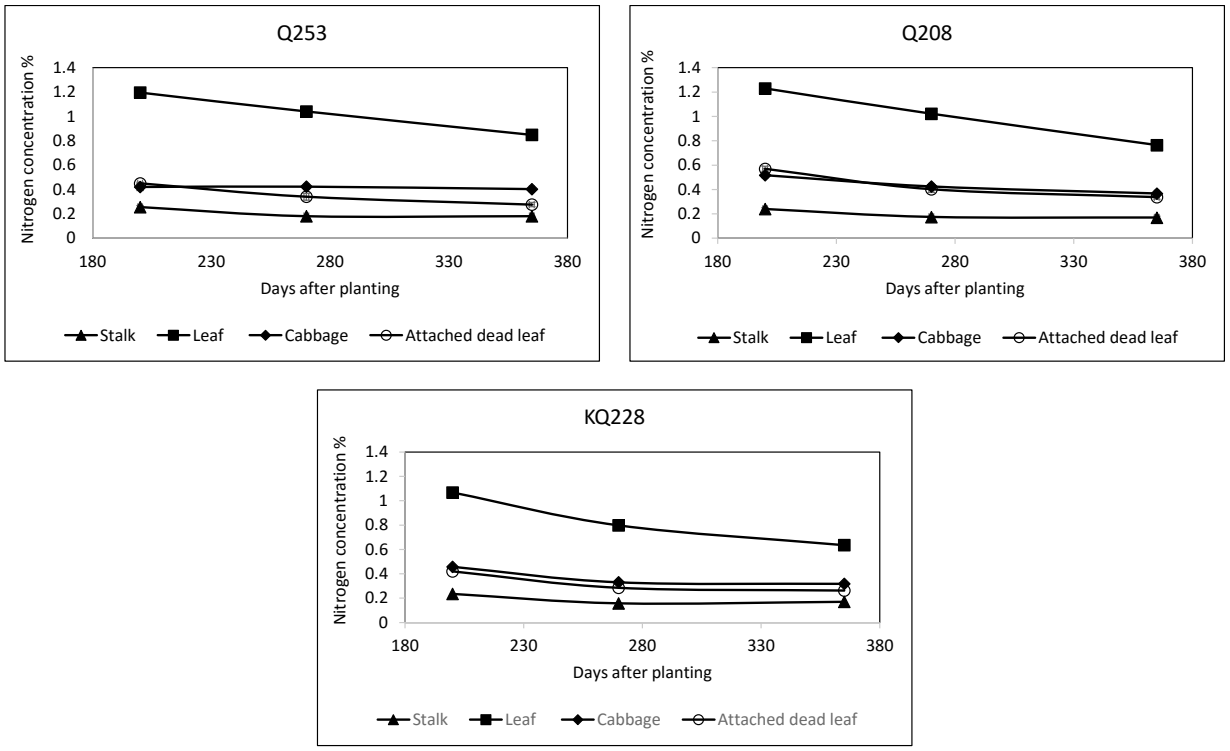

Fig. 5—Mean nitrogen concentration in crop components in relation to DAP for Q253$^{\phi}$, Q208$^{\phi}$ and KQ228$^{\phi}$.

Surface trash

Surface trash biomass collected at 365 DAP varied between varieties. Q208$^{\phi}$ had considerably more surface trash biomass, resulting in more accumulated N than the other two varieties. This was also reflected in the estimated kg N/ha calculated for each variety (Table 5).

Table 5—Mean and standard error of surface trash biomass and N accumulation in three varieties sampled 365 DAP.

Variety	Surface trash dry weight (t/ha)	Nitrogen (%)	Nitrogen (kg N/ha)
Q253$^{\phi}$	0.96 ± 0.08	0.52 ± 0.02	4.9 ± 0.2
Q208$^{\phi}$	2.36 ± 0.26	0.45 ± 0.03	10.8 ± 1.5
KQ228$^{\phi}$	1.39 ± 0.08	0.51 ± 0.04	7.1 ± 0.9

The concentration of N in surface trash was found to be considerably higher than the concentration of N found in attached dead leaf (Figure 6).

Below-ground biomass N accumulation

Below-ground biomass samples were taken from the block containing the variety Q208$^{\phi}$ at 200 and 365 DAP. Below-ground biomass N at 200 DAP was 11% of the above ground biomass N (Table 6). At 365 DAP, below ground-biomass N increased up to 15% of the above ground biomass N in Q208$^{\phi}$.

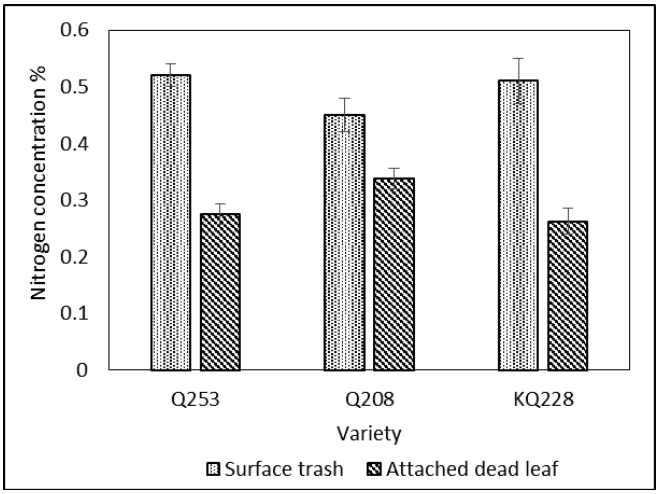

Fig. 6—Mean nitrogen concentration in surface trash and attached dead leaf 365 DAP (vertical line indicates standard error).

Table 6—Mean and standard error of below-ground (roots and stool) biomass and nitrogen accumulation in Q208$^{\phi}$.

Days after planting	Biomass dry weight (t/ha)	Nitrogen (%)	Nitrogen (kg N/ha)	kg biomass/kg of N
200	3.6 ± 0.33	0.29 ± 0.01	10.3 ± 1.1	350
365	4.3 ± 0.07	0.36 ± 0.04	15.2 ± 2.0	283

Discussion

Nitrogen accumulation in the three varieties peaked around 270 DAP with the majority of N accumulated within the first 200 DAP. A similar pattern of N accumulation in sugarcane was reported by Thompson (1988) in South Africa and Wood *et al.* (1996) in Australia. The variety Q253$^{\phi}$ accumulated significantly more biomass and N than Q208$^{\phi}$ and KQ228$^{\phi}$ throughout most of the growth period.

Each variety was grown in blocks with uniform soil N which suggests that Q253$^{\phi}$ may be more efficient at extracting available N from soil than Q208$^{\phi}$ and KQ228$^{\phi}$. Soil N supply was depleted by 270 DAP, which coincided with the cessation of N accumulation in the three varieties. Q253$^{\phi}$ lost accumulated N during the final 95 days however Q208$^{\phi}$ and KQ228$^{\phi}$ showed no changes in accumulated N over this period. Q253$^{\phi}$ appears to have lost accumulated N from leaf and cabbage due to a loss of biomass and a significant decline in leaf N concentration.

Attached dead leaf accumulated N remained the same over this period. Taking into account the accumulated N in surface trash, the loss of N observed in Q253$^{\phi}$ remains unexplained. Part of the accumulated N loss observed in Q253$^{\phi}$ could possibly be due to the cycling of N into the below-ground biomass. However there is not enough data in this study to confirm this.

In general, the four plant components displayed a decline in N concentration from 200 DAP until the final assessment at 365 DAP, the most noticeable of which was leaf nitrogen concentration.

This trend was also observed by Wood *et al.* (1996). The concentration of N in surface trash from each variety was found to be generally higher than that of attached dead leaf. This result was unexpected however it may be due to a lower C/N ratio of the trash as a result of microbial breakdown and CO_2 evolution or possibly the trash absorbing nitrates from the irrigation water. Although the N concentration of surface trash was considerably higher than attached dead leaf, the surface trash biomass and accumulated N in this component was minor in comparison to the sum of the four plant components.

The nitrogen utilisation efficiency (kg dry weight of the above-ground biomass produced per kg of accumulated above ground N) of the three varieties was compared. It was found that KQ228$^{\phi}$ produced significantly more biomass per kg of accumulated N than Q253$^{\phi}$ and Q208$^{\phi}$ at 270 DAP, however given that this occurred only at 270 DAP, further more extensive studies may be required to determine if KQ228$^{\phi}$ is actually a more efficient utiliser of accumulated N than the other two varieties.

There has been very little work investigating the accumulation of below-ground biomass and N in Australia. Bell *et al.* (2014) reported a range of values from ratoon crops sampled at 9 months and at harvest. The below-ground biomass produced per kg of accumulated N was calculated using the reported data, and ranged from 104–274 kg which is lower than the observations from Q208$^{\phi}$ in this study.

Conclusion

This study confirms the findings of a review by Bell *et al.* (2014) that the majority of N uptake occurs in the 200 day period after planting. It has demonstrated that there are differences in the ability of varieties to obtain N from soil and there are some indications that KQ228$^{\phi}$ may be better able to utilise the accumulated N within the plant to produce more biomass per kg of accumulated N in comparison to Q208$^{\phi}$ and Q253$^{\phi}$.

Partitioning of N in plant components above and below ground varies during the season and has highlighted a need for more work to understand how below-ground biomass accumulates N and its cycling within the plant. The effects of late planting or late harvest on the pattern of N accumulation by the crop also requires investigation.

Acknowledgements

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