Author: M. Gardner, J. Condon, L. Guangdi, M. Conyers, R. Hayes, J. McCormick and B. Dear

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Author Address: jcondon@csu.edu.au

Mineralisation of chicory and lucerne residues under field conditions

Matthew Gardner[1,3], Jason Condon[2,3], Guangdi Li[2,3], Mark Conyers[2,3], Richard Hayes[2,3] Jeff McCormick [2,3], Brian Dear[2,3]

[1]NSW Department of Primary Industries, Tamworth Agricultural Institute, 4 Marsden Park Road, Tamworth, NSW 2340, matthew.gardner@dpi.nsw.gov.au
[2] EH Graham Centre for Agricultural Innovation (an alliance between NSW Department of Primary Industries and Charles Sturt University), Wagga Wagga Agricultural Institute, Pine Gully Rd, Wagga Wagga NSW 2650,
[3] CRC for Future Farm Industries, 35 Stirling Highway, Crawley, WA 6009, Australia

Abstract
The incorporation of chicory into phased farming systems requires an understanding of N mineralisation of chicory residues and the supply of N to subsequent crops. A field experiment was conducted to determine the relative rates of N mineralisation from chicory, chicory/subclover and lucerne/subclover residues. Existing pastures were removed by spraying with herbicide in either spring or autumn and mineral N was measured at the time of spraying, and then 6 and 12 months later. Chicory/subclover had the greatest mineralisation rate during the first 6 months after spraying in either spring (0.54 kg mineral N/ha/day)or autumn (0.64 kg mineral N/ha/day), whilst lucerne/subclover had the lowest at 0.07 and 0.08 kg mineral N/ha/day for spring and autumn, respectively. However, 12 months after spraying, the mineralisation rate increased for lucerne/subclover, but began to slow for chicory and chicory/subclover. Compared to chicory alone, growing chicory with subclover significantly increased the release of mineral N by 28 and 47 kg N/ha, 6 and 12 months after pasture removal, respectively. The mass of N mineralised 12 months after pasture removal was similar for chicory/subclover (219 kg N/ha) and lucerne/subclover (234 kg N/ha). However, as high rates of mineralisation occurred for chicory treatments within the first 6 months after spraying, chicory-based pastures could potentially be sprayed out later (eg autumn) than lucerne pastures allowing more grazing time without the risk of N deficiency to the following crop. Therefore chicory/subclover pastures are well suited to phased farming systems, particularly where pasture phases are shorter, as the N benefit can be readily utilised by following crops.

Key Words
Cichorium intybus, lucerne, mineralisation, immobilisation, C:N ratio

Introduction
Utilising plant residues and soil organic matter as a major source of nitrogen (N) for crops and using fertiliser N to supplement to optimise yield and protein has been proposed as the best strategy for meeting crop N demand (Angus 2001; Angus *et al.* 2006). The availability of N in the soil for the following cropping phase depends on the quantity of N mineralised and immobilised during the decomposition of the pasture residues (Angus 2001; Angus *et al.* 2006; Thompson and Fillery 2002).

Understanding of the mineralisation of chicory pastures is essential for better managing the N supplied to crops following the pasture phase in phased farming systems. In a 16 week incubation study, Gardner *et al.* (2010) reported that chicory taproots mineralised at a faster rate than lucerne taproots due to the lower level of structural carbohydrates and the presence of a *Rhizopus* spp. fungi during the incubation. Although the N mineralisation rate was greater for chicory under optimal conditions compared to lucerne, the chicory residues only released about 70 % of the mineral N released by lucerne residues (Gardner *et al.* 2010). Further work is needed to determine N mineralisation on a whole plant basis under field conditions where chicory is grown with a companion legume species. The current study tested the following hypotheses: (1) chicory grown with a companion legume species would increase the overall N mineralisation rate and improve the supply of mineral N for the following crops; (2) chicory pastures mixed with annual legumes will release more mineral N in a relatively shorter time and hence could be removed in early autumn before cropping compared to lucerne pastures.

Methods
Site description
A representative site, Cowra (148°41'29"E, 33°50'2"S), was selected in the medium to high rainfall wheat belt of central-southern New South Wales. The soil at the site was a yellow Chromosol (Isbell 1996). Soil pH, exchangeable cation capacity and Colwell P were assessed and are presented in Table 1.

Table 1. Exchangeable cations [cmol (+)/kg], effective cation exchange capacity (ECEC), soil pH (1M KCl) and available phosphorus (Colwell P)(ppm) in the 0-10 and 10-20 cm depths in the establishment year.

Depth	Na	K	Ca	Mg	Al	Mn	ECEC	pH (1M KCl)	Colwell P
0-10 cm	0.71	2.06	9.10	1.25	0.28	0.02	13.41	5.52	49
10-20 cm	0.73	1.36	6.08	1.49	0.41	0.01	10.08	4.48	32

Treatments

The original experiment had 7 treatments with 4 replicates in a complete randomised block design, in which 3 treatments were selected for this study, namely a pure stand of chicory (cvs Puna II, Chico and Grouse), chicory/subclover (cv. Riverina) mixture, and a lucerne (cv. Aurora)/subclover mixture. The experiment was sown on 20 May 2008. The orginal plot size was 12 m × 4 m. From 20 October 2009, each plot was split into 4 sub-plots (3 m × 4 m) in order to superimpose new treatments. Pastures were removed either in spring or autumn by killing the pasture with herbicide.

Spring removal treatment. Pastures were killed by applying Roundup Powermax (540 g/L) at 2 L/ha and Lontrel at 100mL/ha with wetter TX (200mL/100L water) at 91 L water/ha on 20 October 2009. Pastures were relatively weed free at the time of removal and the proportion of perennial species was 94%, 68% and 69% for the chicory, chicory/subclover and lucerne/subclover treatments, respectively. The proportion of subclover was 26% and 29% for chicory/subclover and lucerne/subclover pastures, respectively. Following pasture removal, plots were maintained free of weeds through herbicide fallow for the remaining period of experiment. Autumn removal treatment. The pastures on the second set of subplots were removed 6 months later on 13 April 2010 with Roundup Powermax (540 g/L) at 1.2 L/ha, Grazon at 0.8 L/ha, and Uptake (1 L/100L water) at 87 L water/ha. The proportion of perennial species was 79%, 74% and 82% with negligent subclover as it had yet to germinate in the chicory, chicory/subclover and lucerne/subclover treatments at the time of removal. Following pasture removal, plots were maintained free of weeds through herbicide fallow for the remaining period of experiment.

Soil sampling and analysis

Soil samples were taken at 3 times on 20 October 2009, 14 April 2010 and 30 September 2010 for spring removal treatments and 2 times on 14 April 2010 and 30 September 2010 for autumn removal treatment. Four deep cores (5.0 cm in diameter) were also taken from each plot and subdivided into 7 depths (20 - 30, 30 - 40, 40 – 60, 60 – 80, 80 – 100, 100 – 120 and 120 - 140 cm), bulked into a composite sample for each depth. Samples were dried at 40°C for 48 hours before being passed through a 2 mm sieve ready for analysis. All samples were analysed for soil pH and mineral N.

Results

Annual rainfall received at Cowra in 2009 was below average (597 mm) with 419 mm and well above average in 2010 with 954 mm, which represented a drought year followed by one of the wettest years on record.

Soil mineral N availability

Lucerne/subclover treatments had the highest available soil mineral N to 120 cm at the time of removal for both spring and autumn removal (Table 2). There was no difference in soil mineral N between the chicory and chicory/subclover pastures in the spring removed treatment, while soil mineral N on the chicory/subclover pasture was higher than that on the chicory pasture at the time of removal in autumn next year (Table 2). When lucerne/subclover was removed in autumn there was 26.5 mg/kg more mineral N available compared to when lucerne/subclover was removed in spring at the time of removal (Table 2). Lucerne/subclover had approximately 70% and 152% more mineral N available than chicory at the time of removal in spring and autumn, respectively (Table 2).

Six months after either spring or autumn removal large increases in mineral N were observed for chicory and chicory/subclover whilst the increase in mineral N for lucerne/subclover was minimal (Table 2). Approximately a 2.8 fold increase in mineral N during the initial 6 months for both removal times was observed for the chicory (Table 2). Six months after spring removal chicory/subclover had a 3.3 fold increase in the mineral N available in the top 120 cm of the soil profile (Table 2). In contrast, 6 months after lucerne/subclover was removed in spring and autumn, mineral N in the top 120 cm of the profile had only increased by approximately 17% and 12%, respectively (Table 3). Chicory/subclover had the greatest mineral N available after 6 months for both the spring and autumn pasture removal compared to chicory and lucerne/subclover (Table 3).

There were significant increases in mineral N in the top 120 cm for all pasture treatments between 6-12 months after spring removal (Table 3). The lucerne/subclover pasture released more mineral N than the chicory and chicory/subclover (Table 3). The increases in mineral N for the lucerne/subclover between 6-12 months after spring removal was 2.7 fold compared to only about a 1.3 fold increase in mineral N for chicory and chicory/subclover over the same period (Table 3).

Table 2. Soil mineral N (mg/kg) to 120 cm at time of spraying, 6 months and 12 months after spray application for the spring pasture removal and at time of spraying and 6 months after autumn pasture removal.

	Spring removal			Autumn removal		
	Chicory	Chicory/Sub	Lucerne/Sub	Chicory	Chicory/Sub	Lucerne/Sub
At Spraying	27.1a	28.5a	46.3c	28.3a	36.2b	72.8e
6 months	76.8ef	94.3g	54.7d	79.7f	103.6h	81.5f
12 months	106.0h	135.8i	146.6j	-	-	-

* Treatments designated with different letters within the table are significantly different (*P* = 0.05).

Carbon/Nitrogen (C/N) ratio in root

Although there was little variation in the quantity of root dry matter between pasture treatments (data not shown) there were significant differences in the C/N ratio of root material (Table 3). At all depths lucerne/subclover root material had a significantly lower C/N ratio (approximately 15-35%) than the chicory and chicory/subclover root material (Table 3). Chicory/subclover root material had a lower C/N ratio than chicory root material at both pasture removal times and at all depths (Table 3).

Table 3. Carbon/nitrogen ratio of root material from the 0-20, 20-40, 40-80 and 80-120 cm depths at the time of pasture removal in spring and autumn.

Depth	Spring removal			Autumn removal		
	Chicory	Chicory/Sub	Lucerne/Sub	Chicory	Chicory/Sub	Lucerne/Sub
0 – 20 cm	25.6c	21.7b	17.4a	26.8c	22.9b	18.2a
20 – 40 cm	26.7c	22.4b	19.2a	25.4c	25.6c	21.2a
40 – 80 cm	32.7b	29.7b	22.8a	39.3c	32.6b	24.1a
80 – 120 cm	48.0c	36.1b	30.6a	45.1c	36.2b	29.3a

* Treatments designated with different letters within each row are significantly different (*P* = 0.05).

The mineral N accumulated 6 and 12 months after pastures were removed was expressed as a rate of mineralisation in relation to time and rainfall in Table 4. During the first 6 months after pasture removal, mineralisation rate was greatest for chicory/subclover (Table 4). The mineralisation rate for lucerne/subclover was approximately 80% and 90% lower than chicory and chicory/subclover, respectively, during the 6 months after either spring or autumn pasture removal (Table 4). However, mineralisation rate on the lucerne/subclover pastures was approximately 70% and 55% greater than the chicory and chicory/subclover, respectively, from 6 to 12 months after were removed in spring (Table 4). Mineralisation rates for chicory and chicory/subclover both declined between 6-12 months compared to the initial 6 months following spring pasture removal (Table 4). In comparison between times of pasture removal, mineralisation rates for chicory and chicory/subclover were higher following autumn removal compared to spring removal (Table 4).

Table 4. Rates of N mineralisation based on time (kg mineral N/ha/day) in soil 0-6 months following spring or autumn pasture removal and also 6-12 months following spring pasture removal.

	Spring removal			Autumn removal		
	Chicory	Chicory/Sub	Lucerne/Sub	Chicory	Chicory/Sub	Lucerne/Sub
0-6 months	0.41d	0.54f	0.07a	0.49e	0.64g	0.08a
6-12 months	0.24b	0.34c	0.76h	-	-	-

Discussion

One of key findings of this study was that the mineralisation rate of chicory based pastures was between 80-90% greater than lucerne/subclover pastures during the first 6 months following either spring or autumn pasture removal in the field. Mineralisation rates observed for the chicory/subclover pastures during the initial 6 months after removal were similar to the mineralisation rates reported by Angus *et al*. (2006) for a lucerne/perennial grass pasture (0.64 kg mineral N/ha/day) during the first 12 months after the pasture removed. The greater mineralisation rate observed for chicory based pastures compared to lucerne during the 6 months following pasture removal supports the results from an incubation study conducted by Gardner et al. (2010) who found that chicory root residues mineralised at a faster rate than lucerne residues. Gardner *et al*. (2010) reported that chicory taproots released in excess of 32% and 24% more applied N and carbon (C), respectively, compared to all other chicory and lucerne plant fractions despite having a C/N ratio greater than 30. Although, the C/N ratio of chicory based pasture root residues is slightly lower in the current study, the results from Gardner et al. (2010) suggested that a lower structural carbohydrate content in chicory may be contributing to higher mineralisation rates under field conditions.

Mineralisation rates between 6-12 months after spring pasture removal for lucerne/subclover significantly increased from 0.07 kg mineral N/ha/day (0-6 months) to 0.76 kg mineral N/ha/day, which was the greatest mineralisation rate observed for all pastures at both removal times. Others have either reported a slow or delay in the onset of mineralisation of lucerne residues (Bolger *et al.* 2003; Harris *et al.* 2006; Hirth *et al.* 2001). Lucerne root residues have been reported to mineralise at a slower rate than annual clovers due to their sparse, thick and woody taproots, which limit the capacity for lucerne to contribute to labile organic matter (Bolger *et al.* 2003). Dear *et al*. (2009) reported that available mineral N at sowing after removal of lucerne/subclover pasture in the previous spring was 30% lower than annual legumes and similar to perennial grasses. Consequently, the N taken up by wheat directly following lucerne/subclover pastures at Kamarah and Junee were similar or lower than perennial grasses such as phalaris and cocksfoot, while being significantly lower than all annual legume treatments (Dear *et al.* 2004).

Conclusion

Incorporating a companion legume such as subclover with chicory can increase the N mineralisation rate following either spring or autumn pasture removal compared to pure chicory swards. The greater mineralisation rate for the chicory/subclover compared to chicory was attributed to the reduced C/N ratio of root residues where subclover was included. The N mineralisation for chicory pastures was significantly higher than lucerne during the first 6 months after pasture removal compared to lucerne/subclover, which indicates that there is the opportunity to remove chicory pastures later than lucerne whilst still receiving the N benefit immediately after the pasture phase. Incorporating a companion annual legume into chicory pastures will meet N demands of chicory during the pasture phase and enable a larger 'pool' of mineralisable N to meet the N demands of the crops immediately following the chicory/legume pasture.

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