Soil nitrogen and water dynamics in crops following perennial pastures under drought conditions.

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Abstract
Perennial pasture phases may increase the sustainability of cropping rotations by increasing out of season water use, reducing leakage to the water table, and improving ground cover over the summer months. The dominant perennial pasture species used is lucerne (*Medicago sativa*). The perennial grasses phalaris (*Phalaris aquatica*) and cocksfoot (*Dactylis glomerata*) are broadly adapted but have been studied less extensively in cropping rotations. The effects of lucerne, phalaris, cocksfoot and mixtures of these species, on soil mineral N and water was studied in the field at Junee Reefs in southern NSW (530 mm annual rainfall) by deep coring at sowing and harvest. Potential N mineralisation was assessed by incubation studies in the laboratory.

During three dry seasons (2001-3) soil water was very low for most treatments, having been depleted prior to the beginning of the experimental period. Nitrogen mineralisation dynamics were strongly influenced by residue decomposition, explained by time of pasture removal and summer rainfall. In 2001 the rate of N mineralisation was significantly higher following pastures containing cocksfoot. In following seasons substantial amounts of N were mineralised following all perennial pastures. The rates were not significantly different. There was little correlation between potential mineralisation measured in the laboratory and actual mineralisation measured in the field. Drought conditions prevented soil N mineralisation over summer. In-crop mineralisation and crop N accumulation was high after lucerne, leading to haying-off of wheat crops, but perennial grass pastures provided sufficient mineral N to following wheat crops under drought conditions.

Key Words
Phase farming, rotation, phalaris, cocksfoot, lucerne, nitrogen

Introduction
Across southern Australia perennial pasture phases are widely recommended to increase the environmental sustainability of cropping systems. The ability of perennial pastures to use water over the summer can increase water use compared to annual pastures by 50 mm or more per year (Ward *et al.* 2001). This may directly reduce drainage to ground water and create a buffer of dry soil, which helps prevent leakage for up to 4 years upon return to annual pastures or crops (eg. Ridley *et al.* 2001, McCallum *et al.* 2001, Ward *et al.* 2006). This may ameliorate or delay the onset of dryland salinity but can negatively impact the yield of following crops reliant on stored soil moisture (Hirth *et al.* 2001, McCallum *et al.* 2001). Lucerne (*Medicago sativa*) is the main perennial pasture species grown and has been extensively studied in cropping rotations (eg. McCallum *et al.* 2001, Ridley *et al.* 2001, Ward *et al.* 2001, Ward *et al.* 2006). The perennial grasses phalaris (*Phalaris aquatica*) and cocksfoot (*Dactylis glomerata*) are broadly adapted to the cropping regions of south eastern Australia (Oram and Hoen 1967) but do not dry the soil as quickly, nor to the same extent as lucerne (Sandral *et al.* 2006). Lucerne is able to fix substantial amounts of N (eg. Peoples *et al.* 1998), however there are reports of low soil mineral N in the first cropping season following a lucerne pasture, presumably due to the slow mineralisation of the woody, recalcitrant residues (eg. Hirth *et al.* 2001). Perennial grass pastures have been shown to promote high rates of N mineralisation under laboratory conditions (Ellis *et al.* 2003).

Methods
The interactions between perennial pasture species and following crops were studied using a phased rotational experiment in the field at Junee Reefs in SE NSW. The site was a lightly stony red loam soil (red kandosol). Characteristics of the top 0.1 m of soil were: pH 6.0 (H_20), pH 5.2 ($CaCl_2$) and EC 0.11 dS m^{-1}, total N 1.06 g kg^{-1} and Colwell extractable P 11 mg kg^{-1}. The site had grown unfertilised subterranean clover (*Trifolium subterraneum*) + annual grass pasture for 6 years. Grasses were removed with paraquat at 0.1 kg

ai./ha in August 1998, and lime applied at 2.5 t/ha in April 1999. Five perennial pastures: lucerne; phalaris; cocksfoot; a phalaris + cocksfoot mixture (ph/co) and lucerne + phalaris + cocksfoot mixture (triple), several annual crops and a chemical fallow were established in a four-replicate design in May 1999. All pastures retained a volunteer subterranean clover component. The ungrazed pastures were mown and residues returned to the surface.

The trial was designed to have an advancing frontier of crops over the previous perennial pastures, allowing a 'first year out' crop to be grown in each of 3 different seasons. A sub-plot of each pasture was removed with herbicides and cropped to *Triticum aestivum* cv. Diamondbird in 2001, 2002 and 2003. In 2001 the pasture sub-plot was sprayed out on 22 March, two months prior to cropping. Thereafter, pastures were removed on 4 Oct 01 and 10 Oct 02 six months prior to cropping in 2002 and 2003. Soil mineral N was assessed by deep soil coring (0 – 1.4 m) in the field in April and December. Mineral N was extracted using 2M KCl and measured using an automated colorimetric method (Rayment and Higginson 1992). Soil water was measured gravimetrically for all soil samples. Crop biomass and N accumulation data were presented in Ellis *et al.* (2006).

Laboratory based incubations of surface soil (0-0.1 m) were carried out each season using the method described in Ellis *et al.* (2003). Briefly, soil was wetted to 18% gravimetric water content, packed to 1.4 g/cm^3 bulk density inside PVC rings, incubated at 15°C constant temperature and sampled for mineral N over time (30 weeks duration). The mineral N was extracted as described above, graphed over time and regressions fitted for each incubation ring.

Statistical analyses

The data were analysed using linear mixed models using preceding treatments for the 3 previous years and adjacent treatments as fixed effects, and Year / Replicate / Plot as random effects. An auto-regressive model was fitted within plots to account for spatial effects. Data presented are estimated means from the fitted model, plus or minus the standard error of the difference (SED). Individual seasons were analysed separately by taking a subset of the data based on ‘year’.

Results and Discussion

Seasonal conditions

The local climate is warm temperate, with 530 mm long-term average annual rainfall, distributed approximately equally over the full 12 months and 330 mm average growing season rainfall (Apr – Oct) (Table 1). Wetter than average conditions occurred in 1999, and 2000 was close to average rainfall, which was conducive to high yields and good pasture growth. There was below average rainfall in 2001, 2002 and 2003 with significant periods of water stress, particularly during spring, resulting in lower yield potential. In 2002 and 2003 there was almost no post-anthesis rainfall, with rain early in October followed by several weeks of hot, dry weather. Thunderstorms in February 2002 resulted in 183 mm of rain. In contrast summer 2003 was extremely dry with only one significant rainfall event after September 2002 of 50 mm in late February.

Table 1. Rainfall for the experimental site (source: BOM datadrill)

	Longterm	1999	2000	2001	2002	2003
Annual rainfall	530	720	520	410	368	363
Growing season rainfall	330	365	359	258	151	235

Soil mineral N and stored moisture in the field

Differences in timing of pasture removal, and occurrence of summer rainfall created substantial differences in soil mineral N at the beginning of each cropping phase. In 2001 there was little stored water and mineral N following the recent removal of perennials (Table 2). Later there was high in-crop mineralisation, N uptake (101 kg N/ha *vs*. an average 50 kg N/ha) and haying-off following lucerne pastures (Ellis *et al.* 2006). Significant rainfall in February 2002 increased soil water and led to substantially more soil N mineralisation over summer. The wheat crop had high tiller numbers and N accumulation, but grew less biomass by anthesis due to the severe drought and haying-off did not occur (Ellis *et al.* 2006). In 2003 there were moderate amounts of soil mineral N at the beginning of the cropping season, but again there was a large amount of in-crop N mineralisation, high N uptake by crops (wheat after lucerne 132 kg N/ha, triple 108 kg

N/ha, perennial grasses 71 kg N/ha, SED 9) and subsequent haying-off after lucerne. Stored soil water was very low following all perennial pastures (Table 2).

Table 2. Soil water and mineral N (surface and profile) in the field measured in autumn following pasture removal and before cropping in each season

Treatment	2001			2002			2003		
	N (0–0.1m) kg/ha	N (0–1.4m) kg/ha	Water (0–1.4m) mm	N (0–0.1m) kg/ha	N (0–1.4m) kg/ha	Water (0–1.4m) mm	N (0–0.1m) kg/ha	N (0–1.4m) kg/ha	Water (0–1.4m) mm
Fallow	116 [a]	330 [a]	362 [a]	100 [ab]	264 [a]	368 [ab]	81 [b]	211 [a]	356 [a]
Lucerne	23 [b]	48 [c]	298 [b]	107 [ab]	192 [b]	356 [ab]	104 [a]	148 [bc]	261 [b]
Triple	24 [b]	42 [c]	331 [ab]	112 [a]	189 [b]	334 [b]	124 [a]	163 [ab]	253 [b]
Ph/co	35 [b]	80 [bc]	351 [a]	83 [ab]	163 [bc]	358 [ab]	48 [c]	101 [c]	286 [b]
Phalaris	39 [b]	114 [b]	352 [a]	74 [b]	145 [cd]	371 [ab]	59 [bc]	113 [c]	283 [b]
Cocksfoot	30 [b]	90 [bc]	350 [a]	83 [ab]	171 [bc]	381 [a]	51 [c]	97 [c]	285 [b]
SED	15	24	22	18	20	22	11	25	17

The soil profile was dried to depth for all treatments by December of each year, averaging 284 mm of stored moisture. This is not significantly more than the site lower limit (248 mm). Mineral N averaged 50 kg/ha within the profile for all perennial treatments however there was higher mineral N in the surface soil (25 *vs* 17 kg/ha, SED 2) after wheat crops following lucerne and triple pasture suggesting in-crop mineralisation had exceeded the crop N uptake capacity. There was continued higher N release over time in seasons 2 and 3 following lucerne removal (data not shown) consistent with the literature (eg. Hirth *et al.* 2001, McCallum *et al.* 2001, Ward *et al.* 2006).

Soil N mineralisation in the laboratory

In 2001 there were significant differences in the amount and rate of N mineralisation under controlled conditions following different annual crops, fallow and perennial pasture treatments. Soil that had previously grown cocksfoot had a surprisingly high rate of N mineralisation and there was a low rate of mineralisation following fallow and annual crop treatments (full results see Ellis *et al*. 2003). In 2002 and 2003 there were no differences in total amount or rate of N mineralised although there was more initial soil mineral N following lucerne and triple than after phalaris or cocksfoot (Table 3). Gross differences were seen in the soil N mineralisation between the three seasons due to over-summer weathering and decomposition of residues (Figure 1), however differences were not statistically significant. The quadratic rate term was relatively insensitive and difficult to model statistically, particularly the 2002 data which had a reduced rate of mineralisation.

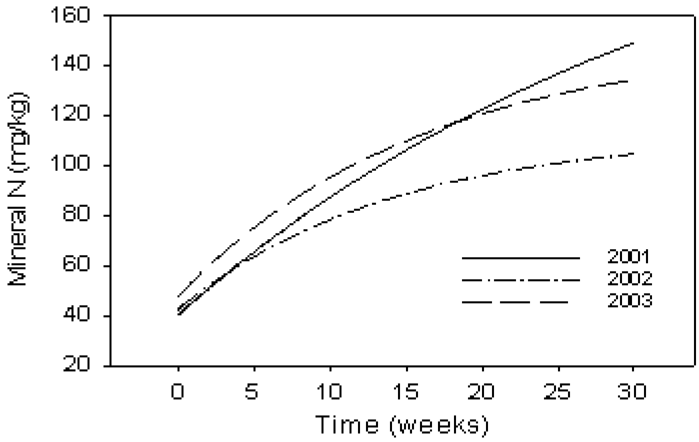

Figure 1. Example (cocksfoot) of N mineralisation dynamic under laboratory conditions in each season.

Table 3. Laboratory soil mineral N incubation results (mg/kg) averaged across the three years

Treatment	Initial N		Final N	
Fallow	67	ab	95	b
Lucerne	78	a	114	ab
Triple	80	a	154	a
Ph/co	51	bc	137	ab
Phalaris	50	bc	120	ab
Cocksfoot	45	c	130	ab
SED	9		24	

In 2001 the soil was sampled soon after the late herbicide removal of the perennial pastures with little time for residue decomposition and the laboratory incubation captured the early stages of decomposition and N mineralisation. In contrast, during 2002 there was a good opportunity for residue decomposition and N mineralisation to occur in the field in response to summer rainfall, reflected in the mineral N available in the soil profile (Table 2). A later, more subdued stage of mineralisation was observed in the incubation study as readily labile material had already mineralised over summer. In summer 2003 there was extremely low rainfall, so less pre-mineralisation occurred (lower N in the soil profile, Table 2) but the mineralisation pattern (Figure 1) indicates that the residues had partially weathered compared to fresh residues.

Across three dry years there was little stored soil moisture following perennial pastures. All treatments, including fallow, had significantly less water than the drained uppper limit (425 mm), reflecting the dry seasons. There was a tendency for soil following lucerne based pastures to be driest. However, additional water following perennial grass pastures was deep in the soil profile and inaccessible to wheat crops. Wheat crop roots were unable to grow and extract water below 1.0 m due to a layer of hard, dry soil. Crops grew using only the limited moisture in the upper soil layers and in-season rainfall.

Nitrogen mineralisation was significantly affected by pasture removal, summer rainfall and residue decomposition. Mineral N in the soil profile was increased by more time for residue decomposition, with low mineral N soon after pasture removal (2001). The contrasting wet (2002) and dry (2003) summers demonstrated the significant impact of sufficient soil moisture to facilitate the residue decomposition and N mineralisation processes. In contrast to the result of Hirth *et al*. (2001) there was no delay in N mineralisation observed following lucerne. Indeed, enough N was released during in-crop mineralisation to cause the wheat crops to hay-off in two out of three dry seasons (Ellis *et al*. 2006). Although lucerne is known to contribute large amounts of N to farming systems (eg. Peoples *et al*. 1998) the speed and magnitude of the in-crop N mineralisation was unexpected, and difficult to predict from the pre-sowing mineral N data.

Conclusions

Consistently across seasons there was low initial soil mineral N following cocksfoot compared to lucerne based pastures and fallow. Overall, soil following perennial grasses mineralised a surprisingly large amount of N. Under the very dry growing conditions, with little or no access to stored moisture, the most significant influence on crop growth was mineral N availability which was best predicted by preceding perennial pasture species. There was more N following lucerne than following perennial grasses. In the dry seasons experienced there was sufficient mineral N after the perennial grasses for good crop growth, and excessive, detrimental amounts of N following lucerne.

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