

Accumulation and recovery of nitrogen in mixed farming systems

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Rationale for research

The economic and political pressure within the UK for efficiency in crop production has driven the re-examination of crop nutrition and provided a basis for this investigation. Green manures as organic nutrient sources offer the opportunity to alleviate the economic burden of inorganic nutrient sources and mediate a proportion of losses from the system by maximising the capture of post harvest available N (Thorup – Kristensen *et al.*, 2003). Their usage is mainly seen by the agricultural and research communities as being applicable to “organic” systems. However the ability to transcend to conventional systems and aid their challenges has not been so extensively studied. Cuttle *et al.*, (2003) concluded that further research and clarity was required accurately to assess nitrogen availability from legumes in relation to the nutrition of subsequent crops. The emphasis for this research is to refine and utilise the knowledge and principles of “organic” agriculture green manuring and apply to a conventional agricultural system.

The primary aim of green manure is in the supply of nutrients to a subsequent crop and Cherr *et al.*, (2006) concluded that they possess the potential to have a significant impact on yield. However many authors such as Ladha *et al.*, (1998) and Singh *et al.*, (1991) found no consistent relationship between green manuring and yield. This inconsistency in yield response may be related to the quantities of biomass incorporated and the quantities of N accumulated. The literature supports this as both leguminous and non leguminous green manures vary significantly in accumulation figures. Non-legume species such as rye (*Secale cereale*) and buckwheat (*Fagopyrum esculentum* Moench.) show variation between 10 kg N ha⁻¹ (Jensen, 1991; Richards *et al.*, 1996; Rannells and Wagger. 1997c) to upper levels of 300 kg N ha⁻¹ (Francis *et al.*, 1998). Extreme legume figures include studies by LaRue and Patterson, (1981) and Peoples *et al.*, (1995) where annual cropping of clover and vetch supplied between 50-370 kg N ha⁻¹. These significant variations within the research indicate an area for further clarification, and an imperative for the commercial adoption of green manuring practice. Hence the accurate assessment of nitrogen accumulation under UK growing systems will be a fundamental component of this research.

Another key feature in green manure performance in terms of N accumulation is the response of different species to specific climatic, soil, and management conditions (Cherr *et al.*, 2006). As Thorup - Kristensen *et al.*, (2003) stated there appears to be very little efficacy data applicable to temperate areas and therefore this research intends to increase the provision of UK-applicable information.

The inclusion of mixed stands of N-fixing and non N-fixing, or varying species within the sector can have a significant impact on accumulation levels and the timing and extent of net N mineralization

(Yadvinder-Singh *et al.*, 1992; Ranells and Waggoner, 1997B). Mixtures of legumes can induce more aggressive nodulation and thereby increased levels of N accumulation and yield, *via* increased fixation (Bergtold *et al.*, 2005). For example mixtures of *Sesbania* + pigeon pea (*Cajanus cajan*. (L.)) produced greater nitrate and ammonium N than pure swards of either component (Sileshi *et al.*, 2008). The nutrient release from a rye – legume bi-crop was 3 weeks slower than that from a legume monoculture (Ranells and Waggoner, 1997B). Mixtures of selected N-fix and companion species has been incorporated into the investigation, to study the modification of accumulation and recovery by the test crops.

Another key feature obtained from the literature is the vital role of the recovery crop in accessing the released nutrients. Tonitto *et al.*, (2006) found that, under comparable green manure inputs, the yields of maize (*Zea Mays*) was 12% lower and that of sorghum (*Sorghum bicolor* - (L.) Moench) or vegetables were equivalent, to the yields from recommended inorganic fertilisers. This highlights the requirement for optimal synchronization between residue release and crop uptake. This has been a subject of research and identified as a critical component of optimising crop utilisation. Sarrantonio, (1991), Holderbaum *et al.*, (1990) and Decker *et al.*, (1994) indicate the need for identifying optimal green manure – cash crop pairings.

Investigations on release and uptake synchronisation should feature in view of their commercial applicability. Within the UK, one of the most widespread commercially utilised cash crops is winter wheat (*Triticum aestivum*) accounting for 35% of Englands arable area in 2009 (DEFRA. 2009) and Clothier (2001) attributed to this crop 61% of arable farmers' incomes. Fychan *et al.*, (2006) utilised winter and spring barley as test crops and indicated that spring cropping following spring cultivation was likely to be the best practice for recovery of nitrogen. In this trial winter and spring wheat are used as test crops, better to reflect current cropping practices.

The main problem, limiting commercial adoption is the unpredictable nature of the quantities and timing of nitrogen release. Fixation by legumes and mobilisation of SOM N through microbial activity are difficult to predict and control, and, depending on husbandry practices, may result in losses which represent an environmental hazard, as well as being economically expensive. Soil microbial activity is particularly affected by disturbances, moisture and temperature. Thus season interacts with husbandry increasing the unpredictability of N supply and limiting the opportunity for control (Stopes *et al.*, 1996). Further complications are that annual cropping systems often require pulsed delivery of N, which is challenging to crop management, especially in the light of incomplete understanding of complex biological processes which govern N availability (Tonitto *et al.*, 2006).

As management practices are a controllable element, it was felt that the investigation needed an attempt at increasing the understanding of how common practices may influence N accumulation and recovery. The timing of incorporation of green manure residues, particularly if cash crop establishment is delayed can ultimately impact on yield (Clark *et al.*, 1997; Thorup-kristensen *et al.*, 2003). Differences in seasonal incorporation patterns may leave the soil more predisposed to losses, for

example pre winter incorporation as opposed to spring incorporation will increase the levels of highly vulnerable N in the profile potentially increasing leaching loss (Stopes *et al.*, 1996; Philipps and Stopes, 1995). This provides the basis for the decision to split test cropping into winter and spring sown varieties, and also the leaching investigation to provide an idea of underlying soil mechanisms.

The effect of tillage at or post residue incorporation can have a pronounced effect on residue behaviour within the soil matrix. Tillage hastens the breakdown of soil residues and raises the level of available N (mainly as nitrate) (Sarrantonio and Scott, 1988; Drinkwater *et al.*, 2000), which is potentially plant available to the emerging crop (Hardarson and Atkins, 2003). Reduced tillage systems, conserve vital soil moisture and reduces nitrate levels in the profile. This potentially causes deficiency issues in establishment but prolongs the residue release pattern (Hardarson and Atkins, 2003). Another mechanism that can modify residue behaviour is the usage of glyphosate, which commences the breakdown of residues prior to incorporation (Cuttle and Goodlass, 2004).

Critical to optimising residue utilisation via N mineralization are the development of management schemes which adjust timing and intensity of tillage and soil disturbance to improve synchronization of N mineralisation and optimise N mineralization (Wagger, 1989; Drinkwater *et al.*, 2000). The effects of differing incorporation timing and mechanisms are a fundamental element that farmers are able to control in the release of nutrients from the residues and for this reasoning the investigation incorporates agriculturally applicable tillage and chemical mechanisms to investigate their influences on test crop nutrient recovery.

As environmental and practical interactions may discourage commercial usage, modelling offers one potential solution (Arihara and Srinivasan, 2001). Nitrogen accumulation and subsequent release has been subject to various models, each attempting to predict differing elements. Cuttle *et al.* (2003) is one example. This study will enable further development and refinement of this model with information regarding a range of legume species and cropping regimes.

Trial objectives

The objectives are to investigate the effects of long term N-fixation by red clover (*Trifolium pratense* L.) with companion grasses on nitrogen accumulation in the sward and soil, combined with the subsequent recovery after incorporation by wheat test crops. In addition, the influence of cultivation techniques and timing pre-drilling, namely partial incorporation by rotavating or desiccation (glyphosate) on rate of nitrogen release and recovery is being studied.

Materials and methods

The initial phase of the study was conducted between July 2007 and October 2008, the second extension phase was conducted November 2008 to the present on established trial blocks at Cotswold Seeds Ltd facility Moreton-in-Marsh, Gloucestershire.

The trial site consisted originally of three blocks (51.5m x 11.6m) of mature red clover (*Trifolium pratense* L.) with companion cropping of perennial ryegrass (*Lolium perenne* L.) (RC/RG); cocksfoot (*Dactylis glomerata* L.) with red clover (*Trifolium pratense* L.) (CF/RC) and a fallow treatment following cropping with *Phacelia* Juss (Fal). Test cropping for nitrogen recovery was undertaken in October 2007 with winter wheat (*Triticum aestivum* L.) cv. Claire and spring wheat cv. Ashby in March 2008 and crops taken through to harvest in September 2008.

Sample photographs of the vegetation present in the three blocks prior to the initialisation of treatments in 2007 are shown below.



1

2

3

1 – RC/RG

2 - CF/RC

3 – Fal

Blocks were subdivided to create randomised replicated plots (18.5m²), to test the treatments, namely:

1. Desiccation (glyphosate) summer 2007, plough and establish autumn 2007
2. Cultivation summer 2007, plough and establish autumn 2007
3. Desiccation (glyphosate) autumn 2007, plough and establish autumn 2007
4. Cultivation autumn 2007, plough and establish autumn 2007
5. Desiccation (glyphosate) autumn 2007, plough and establish spring 2008
6. Cultivation autumn 2007, plough and establish spring 2008
7. Desiccation (glyphosate) spring 2008, plough and establish spring 2008
8. Cultivation spring 2008, plough and establish spring 2008



Desiccation was achieved by application of glyphosate at 4L/ha and cultivation by a small tractor mounted rotavator.

Photograph demonstrating the effects of the cultivation regimes on the field plots prior to spring drilling

Measurements

Vegetation was assessed in July and September 2007 for biomass yield, 10 and 5 respectively random 0.25m² quadrats per block. Quadrat content was segregated into its components of legume, companion and admixture (weeds plus mulched material), the dry matter yield, carbon and nitrogen content of each component was analysed.

Soil nitrogen mineralisation measurements were monitored at 4-week intervals post test crop drilling, commencing December 2007 to July 2008. On the day of sampling, the initial mineral nitrogen analysis was completed on the day of soil sampling. Soil sampling was carried out using small T corers (30cm depth) in designated zones (1.0m x0.5m) within each plot. 10 cores were taken per plot, hand crumbled, mixed by hand and sub sampled. Once in the laboratory, samples were passed through a 6.7mm sieve, and any further plant material removed. Analytical replications of each sample were weighed 25g (+/- 0.02g) onto a tarred weigh-boat and transfer to a labelled extraction bottle. 100ml 0.5M K₂SO₄ were dispensed into each extraction bottle, including two blanks per batch (36 bottles). Bottles were shaken vigorously for 30mins and allowed to stand with loosen tops for 15mins. Soil solution was filtered through Whatman GFA 40 filter papers, and extract collected after the initial 3 drops were discarded. Extracts were frozen in preparation for analysis for NH₄⁺ and NO₃⁻ on FIA. The fresh soil samples were dry matter analysed, 50g (+/-0.05g) of fresh soil was oven dried at 100°C for 24hrs and the weight retaken. The remainder of the sample was retained for the potential mineralisation technique.

Potential mineralisation rates were determined by an anaerobic incubation method (Lober and Reeder. 1993) Soil was air dried at 30°C and ground to pass through a 2-mm sieve; 5g was placed into 60ml polypropylene syringes with 2 glass beads fitted with Luer-Lok taps. Deionized water (13ml) was added, the syringe gently moved to saturate the soil and the plunger advanced to eliminate air until the soil slurry reached the tip of the Luer-Lok tap and the tap was rotated preventing further air entry. The syringes were arranged in batches of 48 in a stand were incubated at 37°C for 7 days. Post incubation, 37ml of 0.63M K₂SO₄ was added to each syringe, resulting in a soil extract ratio of 10:1. The plungers were retracted to induce a headspace and shaken vigorously for 1 hr. In addition two blank syringes were included with 13ml Deionized water and 37ml 0.63M K₂SO₄. The solutions were filtered with Whatman GFA 40, the initial extract discarded, frozen and analysed for NH₄⁺ and NO₃⁻.

Data was examined by analysis of variance (ANOVA) using Genstat 12 software.

Results

Table 1. Potential nitrogen mineralization in soil sampled from December 2007 to November 2010.

Block Description	Sampling date (kg N / ha)								
	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Nov-10
CF/ RC	59.23 a	30.99 a	63.74 a	56.08 a	81.93 a	24.19 b	38.36 b	46.92 b	70.49
RC / RG	91.31 c	35.54 a	74.86 b	79.43 b	66.21 b	20.19 a	33.25 a	40.13 a	72.88
Fal	77.32 b	55.60 b	75.36 b	69.22 c	66.44 b	21.95 ab	34.71 a	46.57 b	
LSD P<0.05	11.06	11.25	6.78	9.99	10.53	3.30	2.94	3.56	6.72

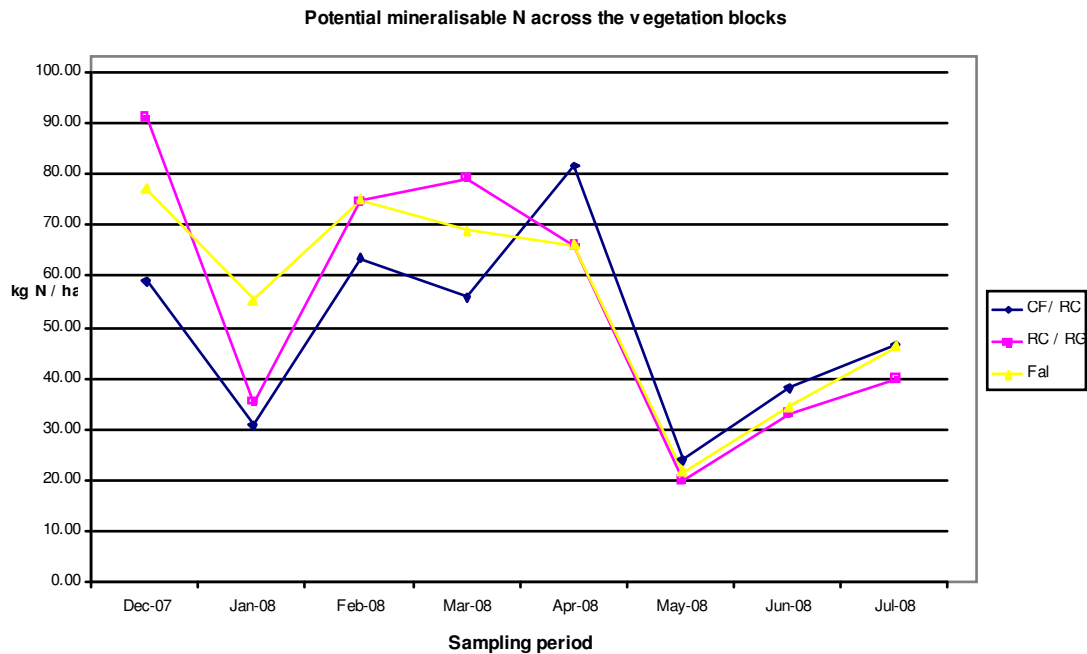


Figure 1 Graph of potentially mineralisable N for the three main blocks between December 2007 and July 2008

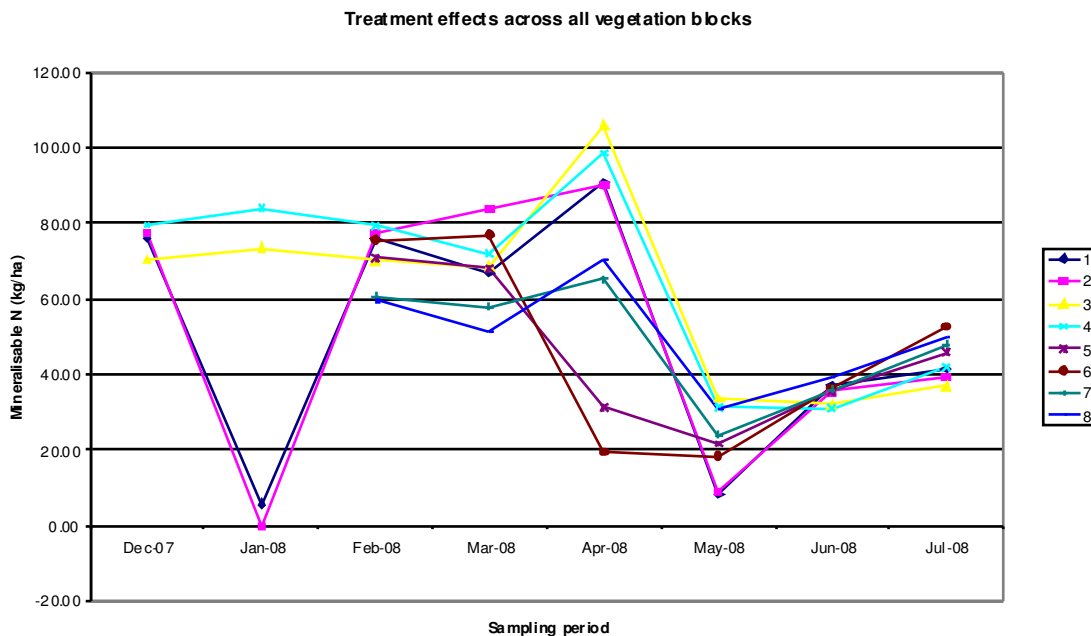


Figure 2. Graph of treatment effects across all of the vegetation blocks for the sampling period.

Summary of Results

- The peak mineralisation varied between vegetation blocks but spanned December 2007 to April 2008. May 2008 indicated a major drop in all blocks mineralisation potential, to approximately a 1/3 of the April 2008 figures, thereafter the figures progressively increase month on month.
- CF/RC exhibited the lowest potential mineralisable N figures from December 2007 to March 2008. Statistically different ($P < 0.05$) to RC/RG and Fal at all timings within this period except January 08.
- RC/RG, December 2007 measured the highest potential N mineralisation figures over the sampling period at 91.31kg/ha significantly different ($P < 0.05$) to CF/RC and Fal blocks.

- RC/RG potential nitrogen mineralisation figures are significantly ($P < 0.05$) lower than CF/RC in April 2008 – July 2008 period and mostly comparable to the Fal block.
- RC/RG, in May 2008 exhibited the lowest potential nitrogen mineralisation figure at 20.19kg/ha, statistically ($P < 0.05$) equivalent to Fal, but inferior to CF/RC
- By November 2010, CF/RC and RC/RG, potential nitrogen mineralisation figures had returned to levels similar to February 08, but not significantly different from each other.
- The Fal block, exhibited relatively high levels of nitrogen from December 2007 to March 2008, statistically superior to the other treatments in January 2008 and equitable to RC/RG in February 2008.
- April 2008 onward CF/RC exhibited the highest potential nitrogen mineralisation significantly greater ($P < 0.05$) than both RC/RG and Fal, except July 08 when it was not significantly different to Fal.
- Pre establishment treatments had substantial effects on potential mineralisable N, with both glyphosate and cultivation treatments significantly ($P < 0.05$) reducing soil N levels in Jan 2008 (autumn treatments) and April 2008 (spring treatments).

Discussion

Potential mineralisable nitrogen provides an indication of the likely nutrient release from the vegetation residues under the three vegetation blocks. The significant ($P < 0.05$) differences indicate that green manure or companion cropping does have a significant impact on nitrogen levels post incorporation, as indicated by Eriksen's (2001) study.

The statistical differentiation in potentially available nitrogen expressed in the study, is consistent with the literature, (Ranells and Wagger, 1997), that residue behaviour once incorporated is in part governed by its properties, as well as soil type and management practices. Properties include quality characteristics, such as carbon nitrogen ratio (Kuo and Jellum, 2000), lignin content (Mueller *et al.*, 1988), and polyphenol to lignin and nitrogen ratios (P/L/N) (Constantinides and Fournes. 1994). The CF/RC block with the statistically lowest potential N mineralisation from December 2007 to March 2008 could be attributed to temporary immobilisation or a slower nutrient release pattern due to the higher carbon content than the other vegetation blocks. The literature suggests that the majority of green manures / cover crops span the mineralisation/immobilisation balance point (Thorup-kristensen *et al.*, 2003)

This could also aid the understanding of the results from the RC/RG, whereby peak potential release was December 2007 to April 2008 the converse of the CF/RC block. Although both CF/RC and RC/RG both contain red clover (*Trifolium pratense* L.) the proportion of red clover was substantially higher (80-90% red clover) in the RC/RG sward, as well as late perennial ryegrass (*Lolium perenne*. L) being less lignified than cocksfoot (*Dactylis glomerata* L.) counterpart. The combination of these factors means residues are more liable to rapid mineralisation.

The fallow block, a long term green manured block with *Phacelia* Juss, followed by a fallow year the year before incorporation, consistently yields in terms of potentially available nitrogen, from April 08 –

June 08 statistically ($P < 0.05$) equivalent to RC/RC, statistically ($P < 0.05$) better than CF/RC from Dec 07-March 08. The fallow period pre incorporation suggests that the influence of the long term green manures extends beyond the first year.

The initial results are very encouraging, ongoing work includes investigating if the statistical differences expressed by the soil potential nitrogen mineralisation in the vegetation blocks transcend to the test crop vegetation recovery harvest, grain yield and quality analysis. In addition preliminary statistical analysis indicates that the impact of cultivation timings and glyphosate treatment timings on mineralisation levels may be substantial. This resonates with the literature, which indicates management practices such as primary tillage, or glyphosate treatment may induce rapid or modified net mineralisation (Thorup-Kristensen. 1994; Drinkwater *et al.*, 2000).

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