Nitrogen accumulation by *Ulex gallii* (Planch.) in a forest ecosystem

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SUMMARY

Accumulation of nitrogen was assessed under naturally occurring, 5 year old *Ulex gallii* (Planch.), dwarf furze, on impoverished soils formed from Old Red Sandstone. Nitrogen accumulation in *U. gallii* and non-*Ulex* vegetation (including litter), in roots and soil (25 x 25 x 20cm cores) was estimated within 5 x $2n^2$ subplots chosen subjectively on the basis of legume occurrence within a single, phosphate-fertilised plot of a forest experimental site at Kilworth, Co. Cork. The influence of *U. gallii* on and nitrogen mineralisation in litter and soil (A1 horizon) was also evaluated.

A close correlation (r=0.99; p < 0.05) was found between U. gallii cover (2.4 to 19.9 t DM ha⁻¹) and the nitrogen content of the total vegetation (220 to 495kg N ha⁻¹, resp.). The relationships between U. gallii occurrence and soil nitrogen (2325 to 2588kg N ha⁻¹, resp.) or soil plus vegetation N (2545 to 3085kg N ha⁻¹, resp.) were weaker (r=0.72 and 0.86, resp.). The correlation between legume cover and the nitrogen content (% DM) of the non-Ulex vegetation was r=0.83. The annual accumulation of nitrogen within the vegetation was estimated to be 55kg N ha⁻¹.

Only Ulex litter released appreciable quantities of nitrogen after 80 days incubation at 20° C — 5.89 compared to 1.17 and 2.28mg N g⁻¹ total –N by senescent Ulex spines and non-Ulex litter, respectively. Mineralisation of soil nitrogen after 112 days incubation at 20° C was considerably greater under U. gallii than under other vegetation (Calluna-Molinia spp) — 3.3% and 0.4% of soil –N, respectively. These results were corroborated by CO₂ evolution studies.

The results are discussed in the context of the nitrogen requirements of Sitka spruce stands on these soils and the distribution and exploitation of U. gallii as a nurse crop.

INTRODUCTION

Biological nitrogen (N_2) fixation by both legume and non-legume plants has long been exploited in forestry (Baule and Fricker, 1967; Gordon and Dawson, 1979) Currently, there is much interest in the development of nitrogen fixation for forest production to the level achieved in agriculture (Haines and de Bell, 1979).

In the Republic of Ireland, potential exploitation of nitrogen fixation is of critical interest because 75,000 ha, approximately, of

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State forests are planted on very poor, nitrogen-deficient soils formed on Old (Devonian) Red Sandstone (ORS). Many of these forests commonly achieve only very slow growth rates (i.e. are in "check") due to nitrogen deficiency (Carey and Griffin, 1981). The soils include moderately well drained or gleyed podzols associated with the absence or presence of indurated irons pans (Dillon *et al.*, 1977). Their poor nitrogen status results, at least in part, from previous removal of peaty layers for fuel. Moreover, responses by Sitka spruce (*Picea sitchensis* (Bong.) Carr) to nitrogen fertilisers on these soils have been disappointing and are generally considered uneconomic (Carey and Griffin, 1981).

Tree lupin (*Lupinus arboreus* Sims.) and common broom (*Cytisus scoparius* L. syn. *Sarothamnus scoparius* Wimm.) have been evaluated as nitrogen-fixing nurse-crops for Sitka spruce in field trials set up on ORS sites in the early 1960s (O'Carroll, 1982). Although legume establishment was satisfactory, the lupins persisted for only 3-5 years, in agreement with New Zealand experience (Gadgil, 1977). Nevertheless, highly significant growth responses to lupin and broom mixtures are clearly evident after 20 years (O'Carroll, 1982). This duration of response to legumes has been noted previously and contrasts sharply with that to nitrogenous fertiliser (Baule and Fricker, 1967; Carey and Griffin, 1981). The benefit of these legumes, however, is not fully established under Irish conditions as yet.

O'Carroll (1982) and others (e.g. Carey and Griffin, 1981; Dillon et al., 1977) have noted marked improvement of Sitka spruce growth on sites/plots spontaneously colonised by the shrub legume, furze or gorse (*Ulex* spp). Similar observations have been reported in the United Kingdom by Nimmo and Weatherell (1962). A number of workers have reported on nitrogen fixation by gorse (*U. europaeus* L.) in forestry and in land reclamation (Nimmo and Weatherell, 1962; Skeffington and Bradshaw, 1980). Of the two-species, *U. galli* is the more attractive under Irish conditions because of its smaller (<1m), less vigorous growth habit and its widespread distribution especially on the ORS soils in Munster (Fig 1). *U. gallii*, thus, offers a widely distributed hardy legume which is less likely to suppress tree growth than *U. europaeus* (Nimmo and Weatherell, 1962) and which is apparently adapted to very infertile soils.

To the authors' knowledge, however, there have been no reports concerning nitrogen accumulation by *U. gallii*. Furthermore, there is little reliable information on the factors which govern its distribution. Compared to *U. europaeus*, *U. gallii* is apparently favoured by relatively cool temperatures and low light intensities



Fig 1 Distribution of U. gallii in Ireland.

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and is seemingly confined to moderately to well drained, acid soils while being very responsive to fertiliser phosphate (Moore, 1960).

The purpose of this investigation was to establish whether *U*. *gallii* can make a nitrogen contribution to forest crops on ORS sites, to attempt to quantify this contribution and to assess whether biological activity and nitrogen mineralisation are enhanced by its presence in the ecosystem.

MATERIALS AND METHODS

Vegetation and soil samples were collected at a site in Kilworth Forest, Co. Cork (grid ref. RO5 83) which had been clearfelled and laid out in experimental plots by the Forest and Wildlife Service in 1976, when Ground Rock Phosphate fertiliser was applied. Site particulars include 160m O.D., SSE aspect, gentle slope, moderately good drainage and 1,000mm annual rainfall. The major soil type is a podzol of sandy loam texture, with a non-indurated B2ir at 15-25cm, formed on Old (Devonian) Red Sandstone (ORS) glacial drift (Table 1). The dominant vegetation comprises *Calluna vulgaris* — *Erica tetralix* — *Molinia caerula*. Following fertiliser application, the phosphate-treated plots became extensively colonised by the two gorse species, *U. gallii* and *U. europaeus*. Control plots were not invaded by the legumes.

Horizon	Depth cm	Textural Class	Org. C	%	Total N	pН	CEC meq 100g ⁻¹
A1	0-5	sandy loam	6.2		0.29	3.8	5.2
A2	5-15	sandy loam	0.7		0.09	3.9	4.2
B2	15-16	sandy loam	1.5		0.08	4.2	4.9
B3	>16	loam	0.1		0.03	4.3	4.0

Table 1: Selected properties of a "modal profile", Kilworth Forest.

Sampling for nitrogen accumulation study

Sampling for this study was done in December 1981 within a single phosphate-fertilised ($30 \text{kg P} \text{ha}^{-1}$) plot planted with Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and displaying a wide variation in the extent of *U. gallii* occurrence.

Five 1.43 m x 1.4 m subplots were chosen subjectively on the basis of variation in *U. gallii* cover and the absence of trees and

U. europaeus. All above ground material, which included both vegetation and litter, within each subplot was harvested and separated into its *Ulex* and non-*Ulex* components which were then dried at 105° C for 48 hours and weighed.

Four randomly located 25cm x 25cm soil cores were taken to 20cm depth within each subplot. After air-drying, the entire core sample was weighed. Oven-dry weights of coarse (>8mm) and fine (>2 to <8mm) roots, soil (<2mm) and gravel (>2mm) were recorded. Soil bulk densities were calculated from the weight and volume of material in each core (cf Table 2).

Subplot Soil Core Bulk Total Organic C:NNo. Densitv N C Ratio wt – % o.d. g o.d. cm⁻³ kga.d. 1 16.6 (1.61) 2.1(0.67)18 1.19 (0.16) 0.11(0.03)2 15.2(1.55)1.07(0.12)0.10(0.02)1.7(0.46)17 3 15.7(1.92)0.99 (0.19) 0.13(0.03)2.7(0.73)21 4 18.5 (1.59) 16 1.28(0.20)0.11(0.03)1.7(0.50)5 15.4 (1.75) 1.10 (0.15) 0.13 (0.02) 2.2 (0.35) 16

Table 2: Properties of soil cores (mean of four cores)

Standard Deviations in parentheses.

Sampling for nitrogen mineralisation study

Samples were taken in March 1982 from a replicate of the above plot. Two subplots were sampled, one with almost complete *U.* gallii cover and one virtually devoid of the legume — "high" and "low" *Ulex* plots, respectively (cf Table 4). *U. europaeus* was absent from both subplots. Plant tops and "litter" were collected separately. Three "litter" types were collected viz. *Ulex* (UL) and non-*Ulex* (NUL) litter and senescent spines from live *Ulex* shrubs (SU). The litters were stored at 4°C until used. The vegetation was dried and weighed as described above.

Six 25cm x 25cm soil cores were taken from the A1 horizon (4 to 9cm) in each subplot — "high" (HUS) and "low" *Ulex* (LUS) soil, respectively (Table 4). These samples were also stored at 4°C until used. The samples were well mixed prior to incubation.

Incubation methods

Both biological activities (estimated as CO_2 evolution) and patterns of nitrogen mineralisation of litter and soil samples were studied. For the CO_2 evolution studies, *Ulex* and non-*Ulex* litter materials were air-dried and finely ground in a Glen Creston mill and the soils, which were not dried, were passed through a 3.5mm sieve. Samples of the litters ($\equiv 10g$ o.d. material) and of the soils ($\equiv 60g$ o.d. material) were adjusted to 80% water-holding-capacity (WHC) and then incubated at 20°C for 91 days in 250ml Ehrlenmeyer flasks fitted with a CO₂ trap modified from Nömmik's (1971) design. Determinations of evolved CO₂ and corrections for sample moisture losses were conducted weekly. The results are means of 4 replicates and are expressed on an o.d. basis in mg CO₂-C evolved per g organic-C incubated.

Nitrogen mineralisation in the materials was studied using unground (but < 8mm), undried samples (=8g o.d. material) of litter incubated in 1,000ml containers and using undried soil samples (=20g o.d. soil; <3.5mm) incubated in 220ml jars. The incubation vessels were covered with polythene and all samples were incubated for 80 days at 20°C and 80% WHC. Moisture deficits were corrected every 8 days where necessary. Four replicates of each treatment were destructively analysed for NH₄⁺ – and NO₃ – N at 16 day intervals. Results are expressed as mg mineral (NH₄⁺ + NO₃) –N per g total –N incubated (o.d. basis).

Analytical

Organic–C was determined by Ball's (1964) procedure and CO_2 –C by Nömmik's (1971) method. Ammonium and nitrate nitrogen were measured as described by Bremner (1965). Available phosphorus was determined according to the method of Olsen and Dean (1965). The WHC is expressed as the volume of water (% o.d. wt) retained by samples under 100cm tension using a sandbox (Stakman *et al.*, 1969). Totol –N, pH, exchangeable Al, H and bases and textural analyses were conducted by conventional procedures. Cation-exchange capacities (CEC) were calculated as the sums of exchange acidities plus total exchangable bases.

RESULTS

Nitrogen accumulation under U. gallii

Estimated accumulation of nitrogen in the vegetation and of nitrogen in soil cores from the individual subplots, extrapolated to a per ha basis, are given in Table 3. The data show that estimated U. gallii DM production ranged from 2.4t DM ha⁻¹ in Subplot 1 to 19.9t DM ha⁻¹ in Subplot 5. The latter represents a rather higher density of the legume than commonly observed in phosphate-treated plots at this site. Growth of other vegetation was affected by U. gallii invasion only in Subplot 5 where a reduction in its DM production was recorded (Table 3).

	Vegetation			Estimated N Content (kg ha ⁻¹)				
Subplot No.	Туре	% N DM	t DM ha ⁻¹	Surface Vege- tation	Roots	Total Vege- tation	Soil	Soil+ Vege- tation
1	<i>Ulex</i> Other Total	1.31 0.83	2.4 13.3 15.7	32 110 142	78	220	2325	2545
2	<i>Ulex</i> Other Total	1.14 0.69	4.9 13.7 18.6	55 94 149	121	271	1942	2213
3.	<i>Ulex</i> Other Total	1.27 0.89	6.3 12.9 19.2	81 115 196	74	269	2037	2306
4	<i>Ulex</i> Other Total	1.13 0.98	9.5 13.4 22.9	107 131 238	118	356	2274	2630
5	<i>Ulex</i> Other Total	1.33 1.08	19.9 9.9 29.8	264 107 371	124	495	2588	3085

Table 3: Extrapolated dry matter weights of vegetation (including
litter) and estimated nitrogen contents of vegetation,
roots and soil cores in experimental subplots

 Table 4: Some properties of litter materials and soils for incubation experiments

		Litter Mater	Soil		
	Ulex ^{1/}	Senescent Ulex ¹	Non-Ulex ^{2/}	High Ulex ^{1/}	Low Ulex ^{2/}
Total –N (%)	1.69	1.48	0.82	0.42	0.3
Organic –C (%)	51	52	ND	9.6	8.6
C:N	30	35	ND	23	29
pH	5.6	5.7	4.9	4.1	4.1
Extr. P (ppm)	_		—	11.7	2.8

1/, 2/: estimated U. gallii cover: 14,325 and 5kg DM ha⁻¹, resp.

ND: Not determined.

-: Not detectable.

There was little pattern apparent in the fluctuations in nitrogen concentration in the *U. gallii* vegetation (1.31% to 1.33% DM) across the subplots (Table 3). The nitrogen concentration in the other vegetation, however, tended to increase progressively with increasing legume cover, i.e. from 0.83% to 1.08% DM. Although the number of data points are rather few for meaningful statistical analysis, it is interesting to note that the correlation coefficient found between the weight of *U. gallii*/subplot and the nitrogen concentration of the other vegetation was r=0.83, which is quite strong albeit non-significant.

The data in Table 3 also show that increases recorded in *U. gallii* cover between Subplot 1, in which the legume comprised 15% of the vegetation DM weight, and Subplot 5, which contained 67% *Ulex* by weight, were associated with progressive increases in the nitrogen contents of the total (*Ulex* plus non-*Ulex*) vegetation (including roots) from 220 to 495kg N ha⁻¹, respectively. Bearing in mind the small number of data points, the correlation found between the weight of *Ulex* and total vegetation nitrogen proved highly significant (r=0.99, p < 0.05).

The nitrogen contents of the soil and the soil plus total vegetation also tended to increase with increasing *Ulex* cover (Table 3). These relationships, however, were also non-significant viz. r=0.72 and 0.86, respectively. A number of factors possibly weakened these relationships. Real effects of *Ulex* on nitrogen content of the soil during the comparatively short timespan since invasion of the site by the legume (5 years) were difficult to detect against a large background of $\geq 2,000$ kg soil N ha⁻¹ (Table 3). Furthermore, the soil nitrogen contents (kg ha⁻¹) were calculated from nitrogen concentration (% o.d. soil) and soil bulk density values. The wide range of soil bulk densities encountered (Table 2) probably reflected, at least in part, the large variations in soil organic matter content at this site (Table 2) caused by previous removal of peaty layers.

Incubation Studies

Selected properties of the litters and soils used in the incubation studies are listed in Table 4. The results (Fig 2) indicate similar patterns of CO₂ evolution in the two litter materials. Weekly rates of CO₂ evolution from *Ulex* litter, however, significantly (p<0.01; p<0.001) exceeded those from non-*Ulex* litter at each sampling period, except week 12 (data not shown). After 91 days, cumulative CO₂ evolution amounted to 90 and 77mg CO₂–Cg⁻¹ organic–C from these materials, respectively (Fig 2).



Fig 2 Cumulative evolution of CO₂ (mg C g⁻¹ organic C) from *U. gallii* (UL) and non-*Ulex* (NUL) litter during incubation (means of 4 replicates)



Fig 3 Mineralisation of nitrogen (mg NH₄⁺+NO₃⁻-N g⁻¹ total -N) by Ulex (UL) and senescent Ulex (SU) litter and by non-Ulex litter (NUL) (means of 4 replicates).

Although there was a lengthy delay prior to onset of active nitrogen mineralisation in the *Ulex* litter (UL; Fig 3), this material released significantly (p < 0.001) more mineral-nitrogen during 80 days incubation than either senescent *Ulex* (SU) or non-*Ulex* (NUL) litter. Cumulative mineralisation of nitrogen in these materials was 5.9, 1.2 and 2.3mg Ng⁻¹ total–N, respectively (Fig 3). Ammonium –N comprised >90% of the nitrogen released by each material. The increase in the rate of mineralisation in *Ulex* litter after 48-64 days was confirmed in a further 112 day incubation in which 17.2mg Ng⁻¹ total –N were mineralised under otherwise identical conditions.

In contrast to the litter samples, similar patterns, rates and quantities of CO_2 emission were observed from the "high-*Ulex*" (HUS) and "low-*Ulex*" (LUS) soils. Although significant differences between weekly CO_2 evolution rates were detected between the two soils at some sampling times, the actual differences were small and were not consistent throughout the incubation. Cumulative CO_2 production was 27.2 and 23.2mg CO_2 – Cg^{-1} organic–C from the "high" and "low" *Ulex* soils, respectively.

The patterns and quantities of nitrogen mineralisation from these soils, however, differed markedly (Fig 4). Release of soil nitrogen commenced without delay in the "high-*Ulex*" (HUS) soil and increased significantly (p < 0.001) up to c. 96 days of incubation. In contrast, nitrogen mineralisation rates in the "low-*Ulex*" soil (LUS) remained very low throughout incubation and were very much (p < 0.001) inferior to rates in the "high-*Ulex*" soil (Fig 4). Cumulative mineral-nitrogen production after 112 days incubation comprised 3.3% of total–N in the "high-*Ulex*" soil compared to only 0.4% in the "low-*Ulex*" soil (p < 0.001). Again, little nitrate–N was produced in either soil.

DISCUSSION

The results (Table 3) provide good presumptive evidence that the presence of *U. gallii* can substantially increase the nitrogen content of an ecosystem and improve site fertility through enhanced nitrogen availability. All *Ulex* plants excavated were nodulated, although quantitative studies were not undertaken. Other nitrogen-fixing plants were not present and non-biological inputs of atmospheric nitrogen at this site should be minimal, i.e. <5kg ha⁻¹ yr⁻¹ (Matthews and McCaffrey, 1977). Progressive increases in *U. gallii* cover were strongly, albeit not significantly (r=0.83), associated with enhanced nitrogen concentrations in the other vegetation. Hence, it is reasonable to infer that the observed accumulation of nitrogen in this ecosystem resulted from the nitrogen-fixing activities of the legume.



Fig 4 Nitrogen mineralisation (mg NH⁺₄+NO₃-N g⁻¹ total –N) in soil dominated by *U. gallii* (HUS) or other (LUS) vegetation (means of 4 replicates).

The alternative hypothesis that invasion of the site by *U. gallii* occurred in response to higher levels and/or availability of soil nitrogen appears less tenable. *U. gallii* is a hardy legume, adapted to infertile conditions, and possesses the considerable ecological advantage of the ability to utilise atmospheric nitrogen and thus be independent of soil supplies for its growth and site colonisation, especially where phosphate is not limiting.

Accumulation of nitrogen associated with *U. gallii* growth (Table 5) was calculated on the assumption that the increases in the nitrogen contents of the *U. gallii* plus non-*Ulex* vegetation and soil recorded between the subplots with highest (subplot 5) and lowest *Ulex* cover (subplot 1) represent accumulation of nitrogen by the legume. On this basis, 540kg N ha⁻¹ were accumulated in soil plus vegetation (Table 5). Of this extra nitrogen, roughly 50% (263kg N ha⁻¹) was found in the soil and 50% (275kg N ha⁻¹) in the vegetation (including roots), while the estimated nitrogen accumulation in *U. gallii* shrubs was 232kg N ha⁻¹ (Table 5). These estimates may be compared to observations on *U. europaeus* growing on Cornish clay wastes reported by Dancer *et al.* (1977), although it should be noted that these wastes were extremely deficient in nitrogen (approx. 450kg N ha⁻¹).

The accumulation of 275kg N ha⁻¹ in total above ground vegetation (Table 5) represents a maximum rate of nitrogen accumulation of 55kg N ha⁻¹ yr⁻¹ since clearfelling. This estimate compares favourably with nitrogen fixation rates of 26kg N ha⁻¹ yr⁻¹ estimated from field-conducted acetylene (C_2H_2)-reduction assays of 1-3 year old *U. europaeus* growing on china clay wastes (Skeffington and Bradshaw, 1980). Reported rates of nitrogen fixation by other legumes and non-legumes, however, are considerably greater e.g. 185kg N ha⁻¹ yr⁻¹ by *Lupinus arboreus* on china clay wastes (Palaniappan *et al.*, 1979).

Whether an accumulation rate of 55kg N ha⁻¹ yr⁻¹ is sufficient to meet the requirements of Sitka spruce plantations growing on impoverished ORS soils is uncertain. Unfortunately, little information is available on the nitrogen requirements of Sitka spruce during the early stages of the rotation. However, recent data for a 7 year old stand of Sitka spruce growing on mineral soil suggests a requirement as low as 7kg ha⁻¹ yr⁻¹ at this stage of crop development under Irish conditions (Carey *et al.*, in press).

The present results also indicate a considerably greater availability of the nitrogen stored in litter and soil in sites dominated by U. gallii compared to the sites dominated by heath vegetation (Figs 3 and 4). However, the nitrogen mineralisation patterns observed imply a delayed transfer of *Ulex* nitrogen to associated

NITROGEN ACCUMULATION BY ULEX GALLII

Component	kg N hæ ¹		
Vegetation+Soil		540	
Soil		263	
Vegetation (including roots)		275	
U. gallii		232	
Other vegetation		-3	
Roots		46	

 Table 5: Calculated quantities of nitrogen accumulated in components of the ecosystem at Kilworth Forest

Data calculated from results in Table 3.

trees. Such a delay in nitrogen release might be anticipated in view of he rather wide C:N ratios (30 and 35:1; Table 4) and woody nature of the *Ulex* litter materials (Alexander, 1977). Similar nitrogen release patterns have been reported previously for woody legumes. Active nitrogen transfer from tree lupin (*L. arboreus*) commenced only after four years growth on china clay wastes (Palaniappan *et al.*, 1979). Conservation of accumulated nitrogen in *Ulex* vegetation and litter and in underlying soil and its subsequent release predominantly in the NH⁴₄-N form at rates to meet tree requirements, however, would confer considerable silvicultural advantages by minimising losses of nitrogen from the system.

Exploitation of *U. gallii* as a forest nurse crop presents a number of problems, not least of which is the fact that it is regarded as an unwelcome weed by forest managers. A more fundamental problem is the paucity of information concerning the soil factors which govern the shrub's widespread but unpredictable distribution on the ORS soils. It is clear, however, that phosphate plays a major role and growth of both *Ulex* species at Kilworth Forest (and other sites) is virtually confined to phosphate-fertilised plots. The effects of phosphate, and indeed of a number of trace elements (e.g. Co, B, Mo), on *Ulex* growth, rhizobial activity, effective nodulation and nitrogen fixation in these soils is entirely unknown. Nevertheless, *U. gallii* offers a number of advantages. In contrast to its sister gorse species, broom or some alders, it is less likely to suppress tree growth and, consequently, should not require periodic removal. A primary advantage of *U. gallii* is its natural occurrence on many nitrogen deficient soils in the south of Ireland. Successful understanding and exploitation of its natural distribution could be of considerable advantage to forestry on these soils.

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