Nitrogen leaching from gorse – Final Report

by
G.N. Magesan
Hailong Wang

February 2008

EXECUTIVE SUMMARY

Environment Bay of Plenty requested Scion (previously Ensis – the joint forces of CSIRO and Scion) to conduct a research study on "nitrogen leaching from gorse". The overall objective of this research was to assess the contribution of nitrate leaching to ground water from stands of gorse growing in the Rotorua lakes catchment.

Two sites with typical mature gorse stands were chosen at Wharenui Station (>10 years old gorse stands) managed by Ngati Whakaue Tribal Lands Inc and Tikitere Forest (>20 years old gorse stands) managed by PF Olsen Ltd. On both experimental sites, under mature gorse stands, litter collectors were installed for monitoring nitrogen input to soil from gorse litterfall. Ceramic suction cup soil solution samplers were installed for monitoring nitrate leaching loss from gorse stands. The field work started in March 2006 and was completed in October 2007. A glasshouse experiment was also set up to assess the effect of available nitrogen on N-fixation in gorse using acetylene reduction assay (ARA).

Monthly litter collection indicated that returning of gorse litter to soil varied with time. The annual dry biomass returned from gorse plants to soil was approximately 10 700 kg ha^{-1} on the Wharenui Station site, and 9200 kg ha^{-1} on the Tikitere Forest site. Average nitrogen concentrations in the litter materials were 2.08% on the Wharenui Station site and 1.97% on the Tikitere Forest site. The annual nitrogen input from the litterfall was estimated to be 223 and 182 kg N ha^{-1} on the Wharenui Station and Tikitere Forest sites, respectively.

Monthly soil solution sampling and analysis indicated nitrate concentration in soil solutions below the rooting zone under gorse stands remained at a relatively high level year round on both trial sites, ranging from 3 to 17 g N m^{-3}. As expected, the concentration was high in autumn and decreased during the winter drainage period. Based on the monthly drainage volume and nitrate concentration, it was estimated that from March to December 2006, 59 and 64 kg N ha^{-1} was leached from Wharenui Station and Tikitere Forest sites, respectively. From January to October 2007, less drainage occurred, particularly during the autumn season when the nitrate concentration in soil solution was relatively high. Subsequently 36 and 40 kg N ha^{-1} was leached from Wharenui Station and Tikitere Forest sites, respectively. In contrast to gorse stands, during the entire 20-month experimental period, only 0.8 and 0.7 kg N ha^{-1} was leached from the nearby *P. radiata* forest stands on Wharenui Station (about 20 years old pine stands) and Tikitere Forest sites (about 7 years old pine stands), respectively.

Acetylene reduction assay (ARA) showed that the rhizobia in the root nodules of gorse plants fixed less N from the atmosphere when available N supply was increased. Results suggest that nitrogen fixation by the rhizobia in gorse roots would not be severely inhibited when available nitrogen concentration in the growth media solution is less than 100 g N m^{-3}, indicating that the rhizobia in the root nodules of gorse plants are likely to continue fixing nitrogen in the field conditions. As a result, gorse stands can continue releasing nitrate to soil and then to groundwater and the lakes.

To protect lake water quality, we recommend that effective methods be developed to eliminate gorse in the Rotorua lakes catchment areas.

NITROGEN LEACHING FROM GORSE
- FINAL REPORT FEBRUARY 2008

TABLE OF CONTENTS

INTRODUCTION

Nitrogen (N) is often the most growth-limiting nutrient in both terrestrial and aquatic systems. Widespread concern about increasing concentrations of nitrate in surface and ground water has focused attention on nitrate leaching in recent years (e.g., Magesan et al. 1994; 1996). Identification of the source and extent of nitrate leaching losses on a catchment scale has been difficult because of N inputs from various sources: agricultural lands, fertilisers, grazing animals, land application of wastes, and contribution of leguminous plants, particularly weeds such as gorse and broom.

Egunjobi (1969) studied nine ecosystems in New Zealand, involving gorse (*Ulex europaeus* L.) and associated shrubs and trees. He found gorse was superior to other species in its ability to accumulate dry matter, litter and nitrogen content. The dry matter accumulation of gorse stands was at an average annual rate of 10,000-15,000 kg ha^{-1} yr^{-1} when the stands were young (less than 10 years old). It decreased with age (c. 3,000-4,000 kg ha^{-1} yr^{-1} for stands between 16 and 33 years old).

Egunjobi (1969) also reported that the N concentration was high (range: 0.23 – 0.34%) in the topsoils (0-7 cm depth) under gorse stands because of the nitrogen-fixing ability of gorse and the large quantities of litter it produced. The gorse-dominated stands accumulated more nitrogen per unit area than older stands dominated by non-nitrogen-fixing shrubs and trees. Nitrogen accumulated at a rate of 100 to 200 kg ha^{-1} yr^{-1} in gorse stands which were less than 10 years old.

In another study, Dyck et al. (1983) studied nitrate losses from several types of disturbed ecosystems. They found that under controlled conditions more nitrate was leached from sites under gorse, than from sites under other species. For example, nitrate-N concentrations from the gorse area averaged 5 g m^{-3} whereas nitrate-N from radiata pine averaged 0.006 g m^{-3} (Table 1). In the same study, Dyck et al. (1983) suggested that decomposing gorse tissue released fairly large amounts of N which are nitrified and enter the groundwater.

Table 1. Average nitrate-N concentrations leaching from control sites under various plant species (adapted from Dyck et al. 1983).

Plant species	Age (years)	Stocking rate (stems ha^{-1})	Soil type	Monitoring Period (year)	Average nitrate-N conc. (g m^{-3})	Leaching* (kg^{-1} ha^{-1} yr^{-1})
Radiata pine	20	250	Kaingaroa silty sand	2	0.006	0.04
Douglas fir	56	200	Te Rere sand	2	0.272	1.9
E. saligna	18	100	Manawahe coarse sand	1	0.08	0.56
Gorse	20	Dense	Galatea sand	2	5.1	35.7

* assuming 700 mm drainage per year.

The overall aim of this research programme was to assess the contribution of nitrate leaching to ground water from release of accumulated N in litter and soil under stands of gorse. It was expected that these experiments would quantify the annual nitrogen input to soil through gorse litter production and nitrate leaching from soil under a gorse stand.

MATERIALS AND METHODS

Field experiment

Field experiments at two sites in the Lakes catchment under typical gorse stands were set up to monitor nitrate leaching.

Site selection

As reported previously (June 2006, August 2007), establishment of field sites took more time than we had expected. More than ten potential sites were visited and explored between June and November 2005. Most of the sites were around Lake Rotorua, Lake Okareka, and Lake Rotoiti. Although some sites were suitable for the field experiments, they were not chosen because either the farm owners were not cooperative, or there was no easy access to sites. After a number of farm visits, and meetings with farmers and Maori land trusts, two sites with "typical" gorse stands were identified, and field trials established thereafter. The two sites chosen were Wharenui Station (managed by Ngati Whakaue Tribal Lands Inc) and Tikitere Forest (managed by PF Olsen Ltd). We acknowledge the assistance from Environment Bay of Plenty staff in terms of providing aerial maps and suggestions about meeting various farmers and Maori land trusts.

Soils on both sites are classified as pumice soil (Hewitt, 1998). Detailed descriptions of the soil profiles are shown in Appendix A. Soil samples were analysed for pH in water. Soil total organic C and total N were determined by dry combustion using a Leco2000 CNS analyser. Plant available phosphorus (P), sulphur (S), calcium (Ca), magnesium (Mg), potassium (K), and boron (B) in soils were extracted with Melich-3 solution and analysed using ICP-AES.

Annual litter production

Annual litter production was estimated by monthly collection of litterfall within litter collectors (0.25 m $\times$ 0.25 m), made of fibre-glass screen with 2-3 mm mesh size, in a typical gorse stand. The litter collectors were placed 20 cm above the ground to allow wind to pass through them so that the litter dried and did not become damp. There were five litter collectors placed in each trial site. Litter samples collected were oven-dried, weighed, and total N in the samples was determined to monitor seasonal change of N concentration.

Nitrate leaching

On both experimental sites, five porous ceramic suction cup soil solution samplers were installed at a depth of 90 cm. A similar number of suction cup samplers were installed at the same depth nearby but outside the gorse stands to serve as the control treatment. These control samplers were installed either upslope of or beside the gorse field, to avoid possible N transported from gorse stands.

A vacuum of approximately -60 kPa was applied to each suction cup, and soil-water samples were collected the following day. The first samples were collected in January 2006 to see if the system was working and to see what volumes were collected. Solute concentrations in those initial samples were not measured. Monthly soil solution sampling started from March 2006 onwards. Sampling continued until October 2007, to incorporate seasonal differences. The results are discussed later (page 12).

To calculate the amount of N leached, the sample N concentration was multiplied by the volume of water that drained beyond the depth of the ceramic cups. The drainage at the experimental site was calculated using a water balance model (Woodward et al. 2001), using climatic data obtained from NIWA's Rotorua airport meteorological station which is within a few kilometers from the trial sites. The drainage data for the period of the study were supplied by AgResearch, Hamilton.

Glasshouse experiment

Acetylene reduction assay (ARA) to assess the effect of available nitrogen on N-fixation in gorse and broom

The growth and development of gorse and broom plants may result in accumulation of biologically available N in soil, as well as N being leached to groundwater. It has been reported that the application of N fertiliser often suppresses the rhizobia's ability to fix N_2 in plant species such as clover (Crush et al. 1982; Bolan et al. 2004). However, there is little information on the effect of existing soil-available N on the fixation of N_2 by the rhizobia in the root nodules of woody leguminous plants. The objective of this study was to assess the effect of available N on N_2-fixation in gorse and broom.

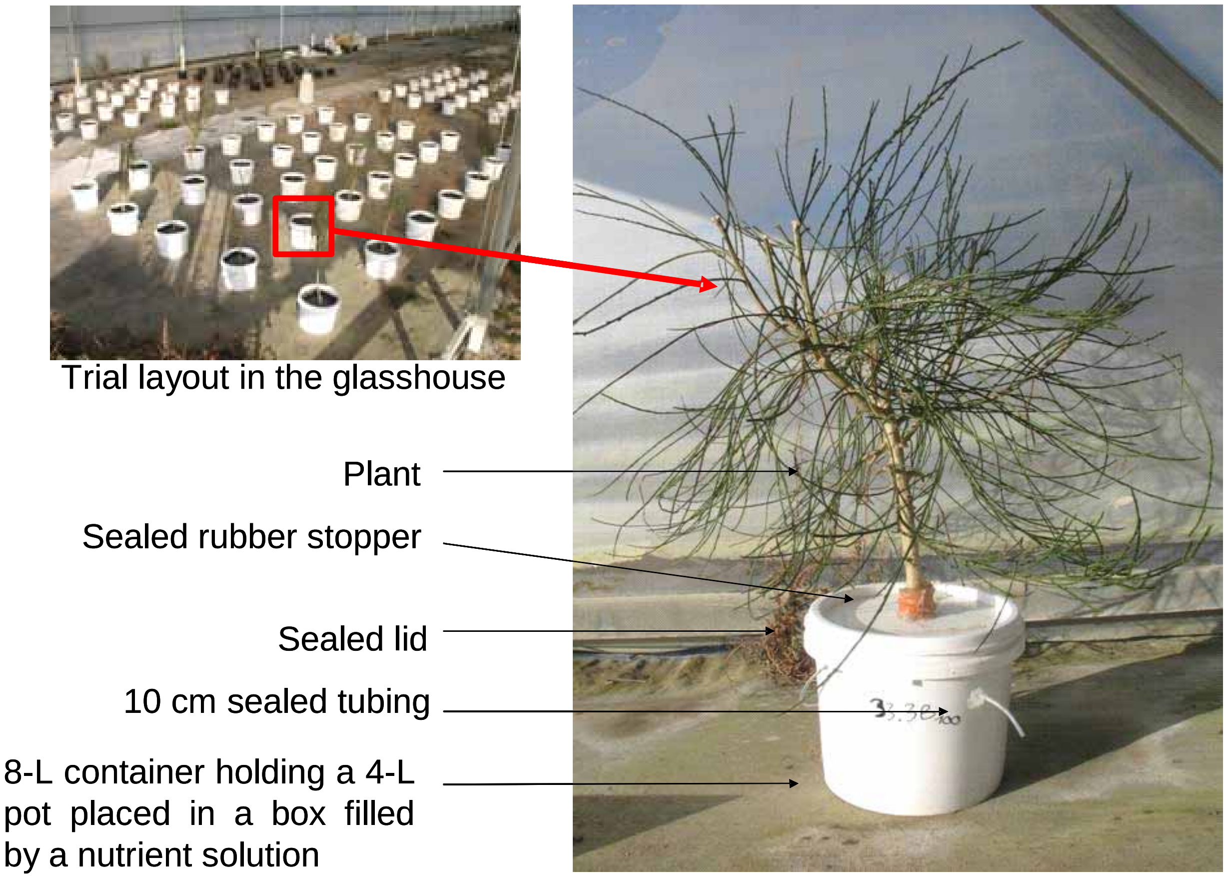


Figure 1. A typical set-up for acetylene reduction assay (ARA) measurement.

Acetylene reduction assay (ARA) (Koch and Evans, 1966; Reid, 1973; DeLuca et al. 2002) was used to assess the relationship between available N concentration in the growth media and fixation of N_2 in gorse and broom plants in a glasshouse experiment (Figure 1). Gorse and broom plants were 2-year-old seedlings grown from cuttings. Manuka (*Leptospermum scoparium* L.) and blackberries (*Rubus fruticosus* L.) were used as the non-leguminous reference plants, because they are widespread in the same locality. The plants were grown in 4-L square plastic pots (one plant per pot) filled with washed small gravel (10 to 20 mm). A treatment without plants was included as a control. Each pot received 800 mL of modified Hoagland solution containing different N concentrations. The nutrient solution was replenished weekly. There were five treatments, including 0, 25, 50, 100, 200 mg N L^{-1} as ammonium sulphate. Each treatment had six replications with a total of 120 pots being laid out in a randomised complete block design. Temperature and humidity in the greenhouse were monitored regularly. A non-destructive method using intact plants (Laws and Graves, 2005) was used for ARA measurement. The experiment was conducted twice, first in July – August 2006, and second in October – November 2006, representing the winter and spring seasons in New Zealand.

RESULTS AND DISCUSSION

Field experiment

Soil fertility

Top soil was acidic on the Tikitere Forest site and slightly acidic on the Wharenui Station site (Table 2). Soil pH values increased with depth on both sites. Concentrations of total organic carbon and nitrogen in the Tikitere Forest soil were greater than those in the Wharenui Station soil (Table 2). However, the Tikitere Forest soil had a greater carbon to nitrogen (C:N) ratio in the subsoil layers, indicating a lower potential for N to be mineralised by microorganisms. Compared with other forest sites, the soils under gorse stands on both sites contained relatively high N concentration. Concentrations of important plant nutrients, such as P, S, Ca, Mg, K and B were at moderate to high levels (Table 2) which are unlikely to limit gorse growth significantly.

Table 2. Selected chemical properties of soil from the trial sites.

Site	Depth	pH	C	N	C:N	P	S	Ca	Mg	K	B
	cm		%	%		mg kg^{-1}					
Tikitere Forest	0-15	4.79	5.50	0.38	14	31	49	295	41	207	69
Tikitere Forest	15-20	5.22	3.02	0.15	20	47	33	234	22	87	67
Tikitere Forest	20-29	5.42	1.35	0.10	13	70	34	88	8	71	70
Tikitere Forest	29-39	5.45	0.32	0.03	10	64	41	88	4	62	70
Tikitere Forest	39-76	6.08	1.70	0.13	13	3	56	354	38	101	65
Tikitere Forest	76-100	6.05	0.38	0.03	15	4	46	188	33	44	63
Wharenui Station	0-8	5.51	3.12	0.30	10	60	60	885	138	670	66
Wharenui Station	8-27	5.74	0.56	0.05	12	39	65	795	116	505	84
Wharenui Station	27-29	5.74	5.44	0.29	19	28	156	4685	477	326	109
Wharenui Station	29-40	5.63	1.99	0.13	15	82	84	1169	102	165	110
Wharenui Station	40-55	6.11	2.22	0.18	12	12	94	1857	176	228	104
Wharenui Station	55-100	6.18	1.74	0.12	14	7	84	1280	127	273	114

Gorse litter production and nitrogen concentration

Field collection indicated that returning of gorse litter to soil varied with time (Figure 2). Total dry biomass of gorse litterfall collected during the 18-month experimental period was 16 049 ± 271 and 13 867 ± 152 kg ha^{-1} on the Wharenui Station and Tikitere Forest site, respectively. Annualised litterfall biomass was, approximately 10 700 kg ha^{-1} on the

Wharenui Station site and 9200 kg ha^{-1} on the Tikitere Forest site, indicating large amounts of gorse plant material returned to the ground due to litterfall.

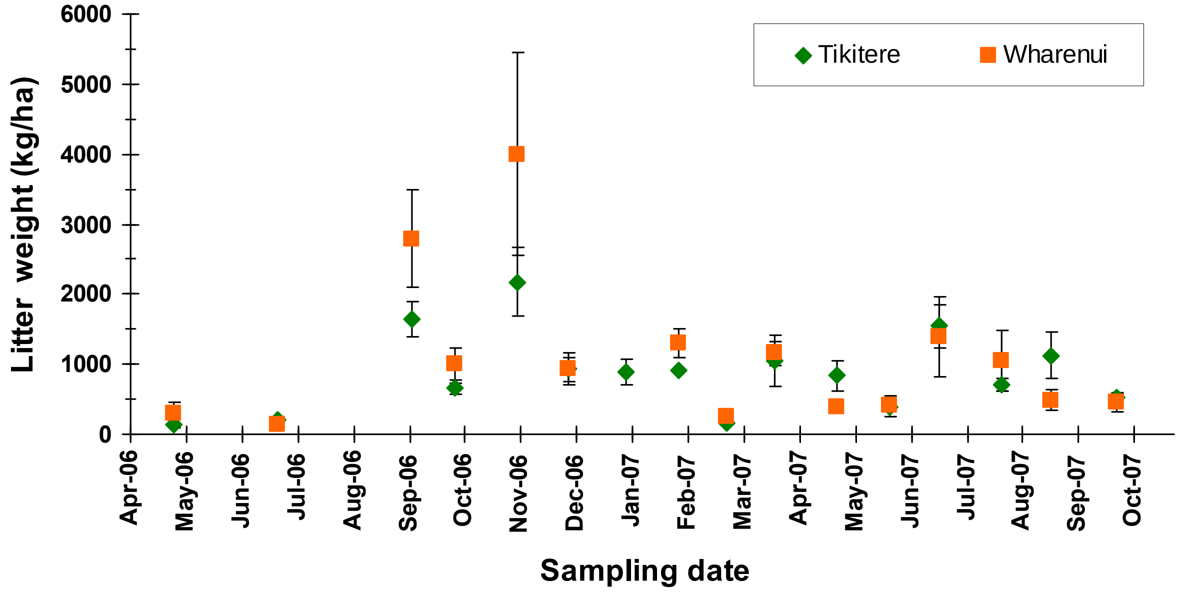


Figure 2. Monthly litterfall collected under gorse stands (error bars indicate standard errors).

Average nitrogen concentration in the freshly dropped litter materials was 2.08% with a standard error of 0.09% on the Wharenui Station site and 1.97% with a standard error of 0.10% on the Tikitere Forest site (Figure 3). The annualised nitrogen input from the litterfall was estimated to be 223 and 182 kg N ha^{-1} on the Wharenui Station and Tikitere Forest sites, respectively. These results indicate that each year approximately 200 kg N ha^{-1} was added to the soil under the mature gorse stands on these sites.

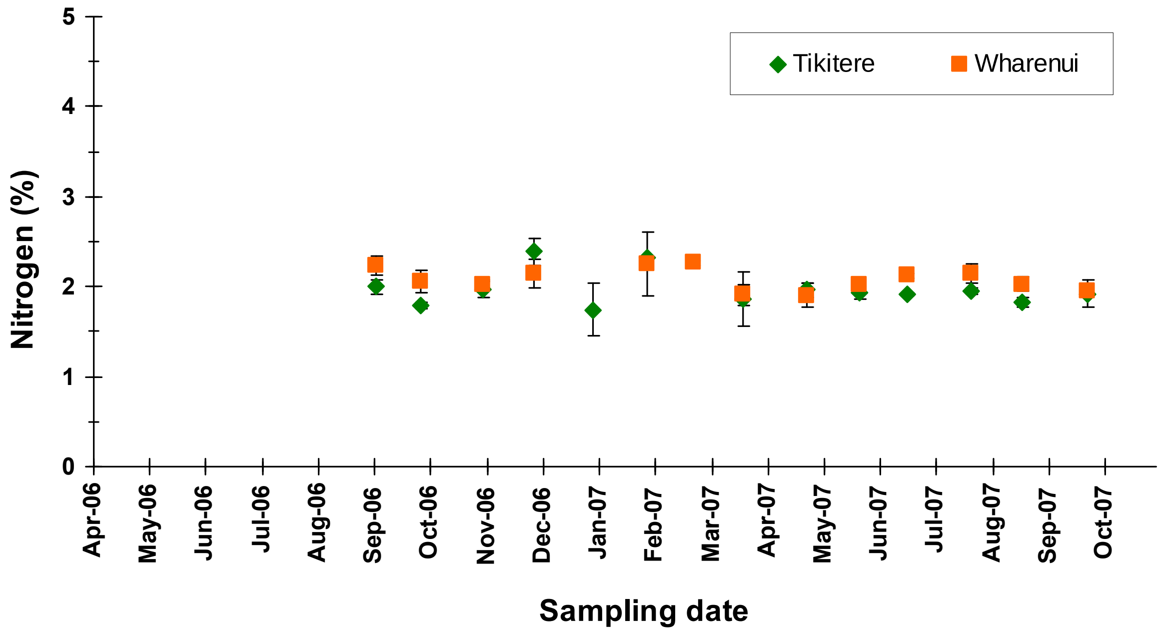


Figure 3. Nitrogen concentration in litter materials collected under gorse stands (error bars indicate standard errors).

The average carbon concentrations in the litter materials were 51.9% and 51.5% on the Wharenui Station and Tikitere Forest sites, respectively (Figure 4). The resulting carbon to nitrogen ratio (C:N) was approximately 25.3 ± 1.0 and 26.6 ± 1.5 on the Wharenui Station and Tikitere Forest sites, respectively (Figure 5). Organic materials with a C:N ratio of around 25 are generally considered an optimum substrate for micro-organisms to decompose, indicating that nitrogen in the gorse litter materials can be rapidly mineralised and become available nitrogen, i.e., ammonium. Ammonium nitrogen can be readily oxidised to nitrate, which may be leached if not taken up by plants.

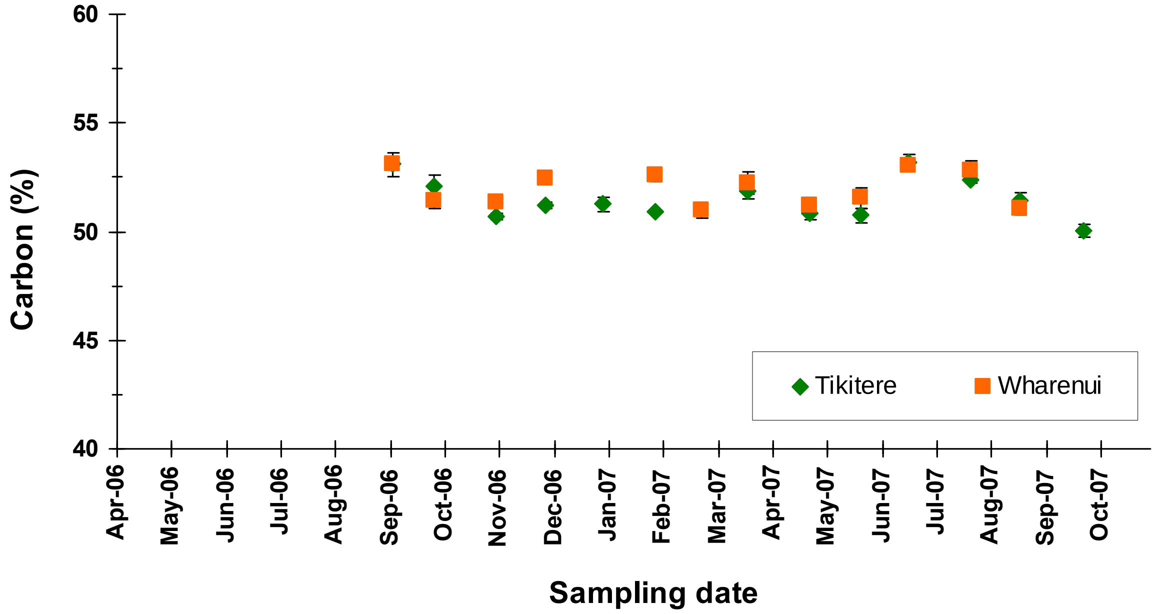


Figure 4. Organic carbon concentration in litter materials collected under gorse stands (error bars indicate standard errors).

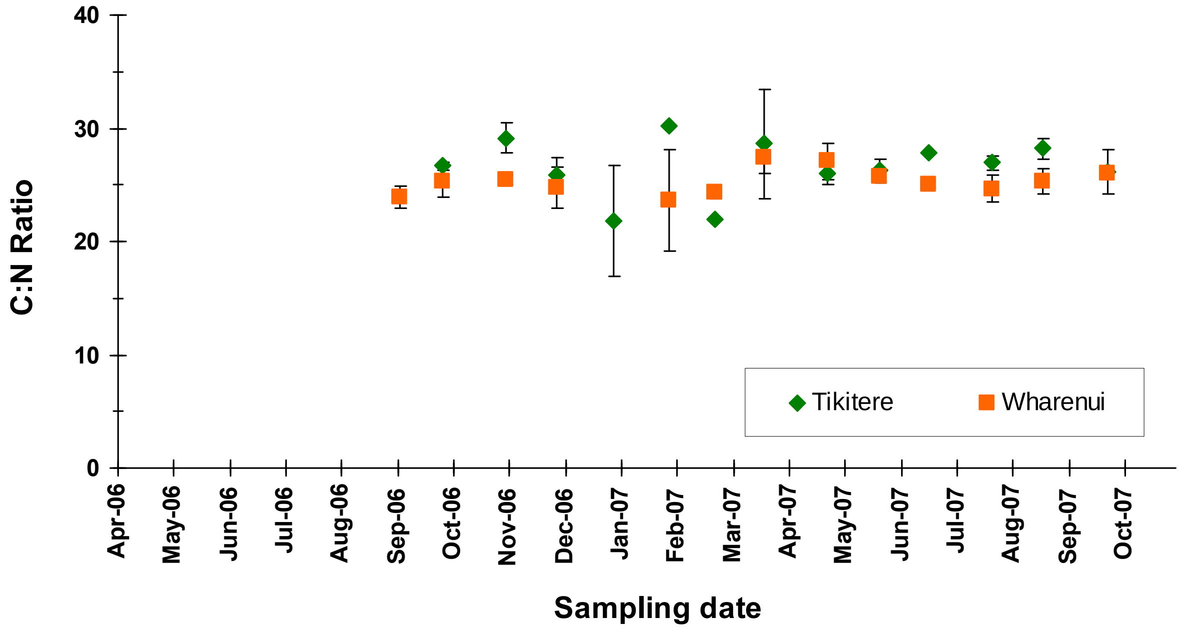


Figure 5. Carbon to nitrogen ratios in litter materials collected under gorse stands (error bars indicate standard errors).

Rainfall and drainage
Rainfall and evapotranspiration data were obtained from NIWA (Figures 6 and 7). Total rainfall from March to December 2006 was slightly below the long-term average (1119 versus 1178). Total rainfall from January to October 2007 was again below the long-term average (1000 versus 1130).

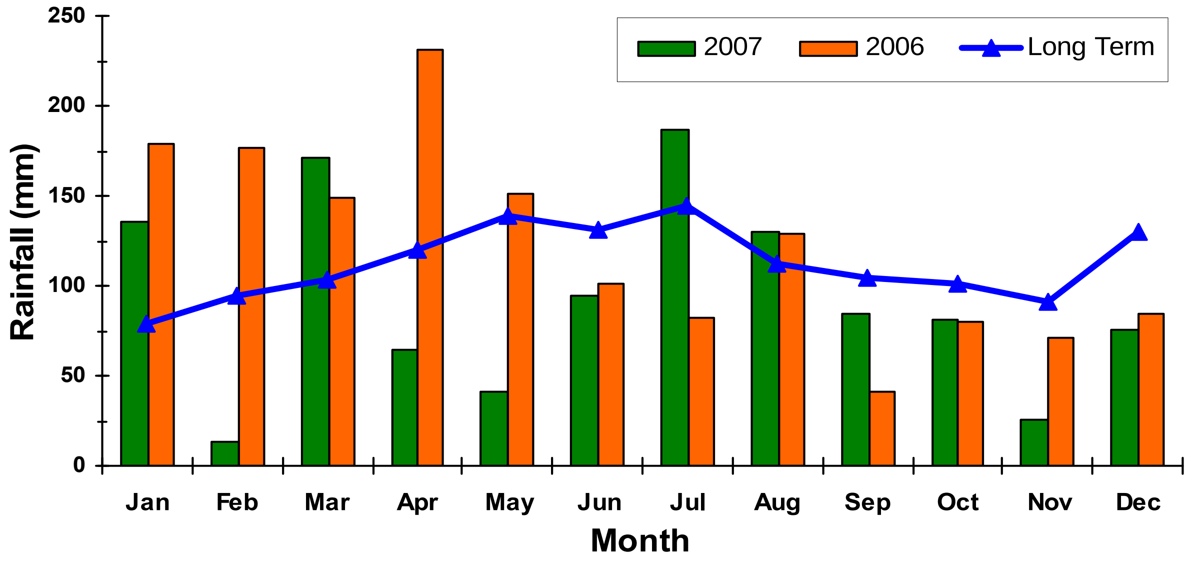


Figure 6. Mean monthly rainfall for 2006 and 2007, and 15-year average (data courtesy of NIWA).

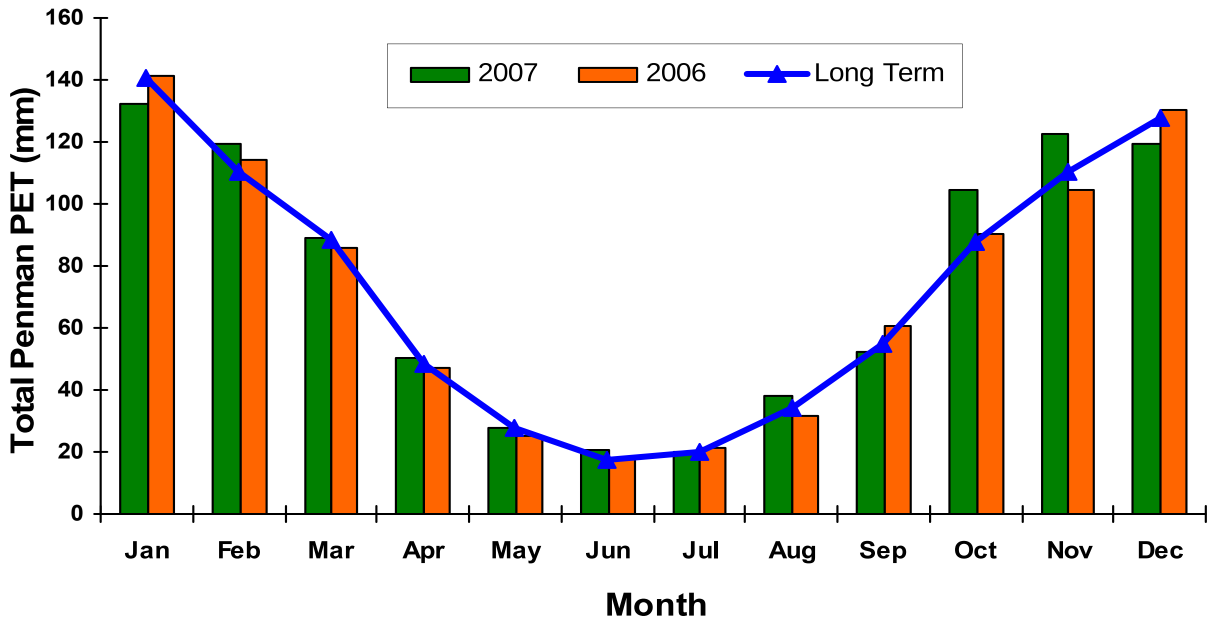


Figure 7. Mean monthly potential evapotranspiration for 2006 and 2007, and 15-year average (data courtesy of NIWA).

The amount of drainage calculated for March to December 2006 was 580 mm, and from January to October 2007 was 500 mm (Figure 8). Drainage data were obtained from AgResearch who had calculated for an adjacent site in Rotorua.

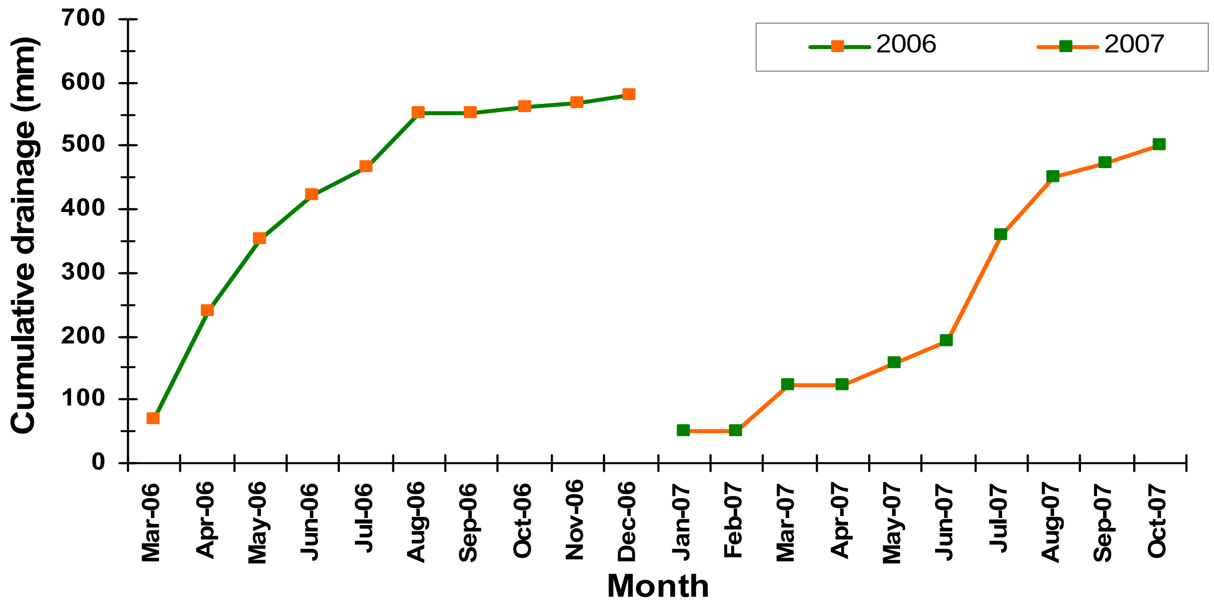


Figure 8. Cumulative drainage for 2006 and 2007 at Rotorua sites (Data courtesy of AgResearch).

Soil solution sampling

Soil solution samples (leachate) were collected monthly from porous ceramic suction cup samplers placed at 90 cm below the soil surface. The leachate collected from both experimental sites was analysed for nitrate-N and ammonium-N as an indicator of nutrient loss. As concentrations of ammonium in the suction cup solution samples were low in the first few months, the measurement was discontinued.

Nitrate leaching

Figures 9 and 10 give the results for nitrate concentrations measured in the suction cup samplers in the field from March 2006 to September 2007.

Leaching results showed that nitrate concentrations in the soil solution samples under the gorse stands were more than 10 g m^{-3} in the first few months of the drainage season. In general, soils do release relatively high concentrations of nitrate in this season due to ‘autumn flush’. As expected, at the Wharenui site, nitrate concentrations in the leachate were about 16 g m^{-3} at the start of the drainage season and decreased during winter and spring. Nitrate concentrations measured in this experiment were at least 2 to 3 times greater than those of Dyck *et al*. (1983).

At the Tikitere site, nitrate concentrations followed the expected pattern in the first year but remained almost constant in the second year. Between November 2006 and March 2007 only one collector contained a sample and therefore no error could be calculated.

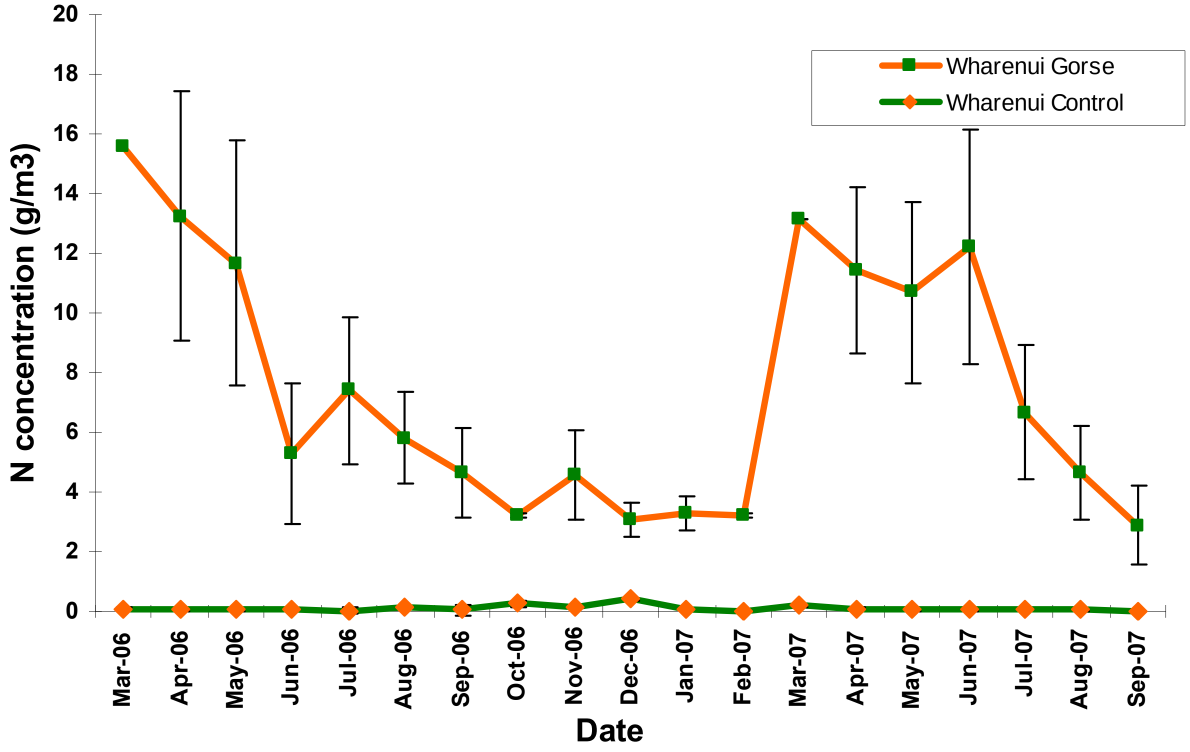


Figure 9. Mean nitrate concentrations in suction-cup samples collected from Wharenui Station site.

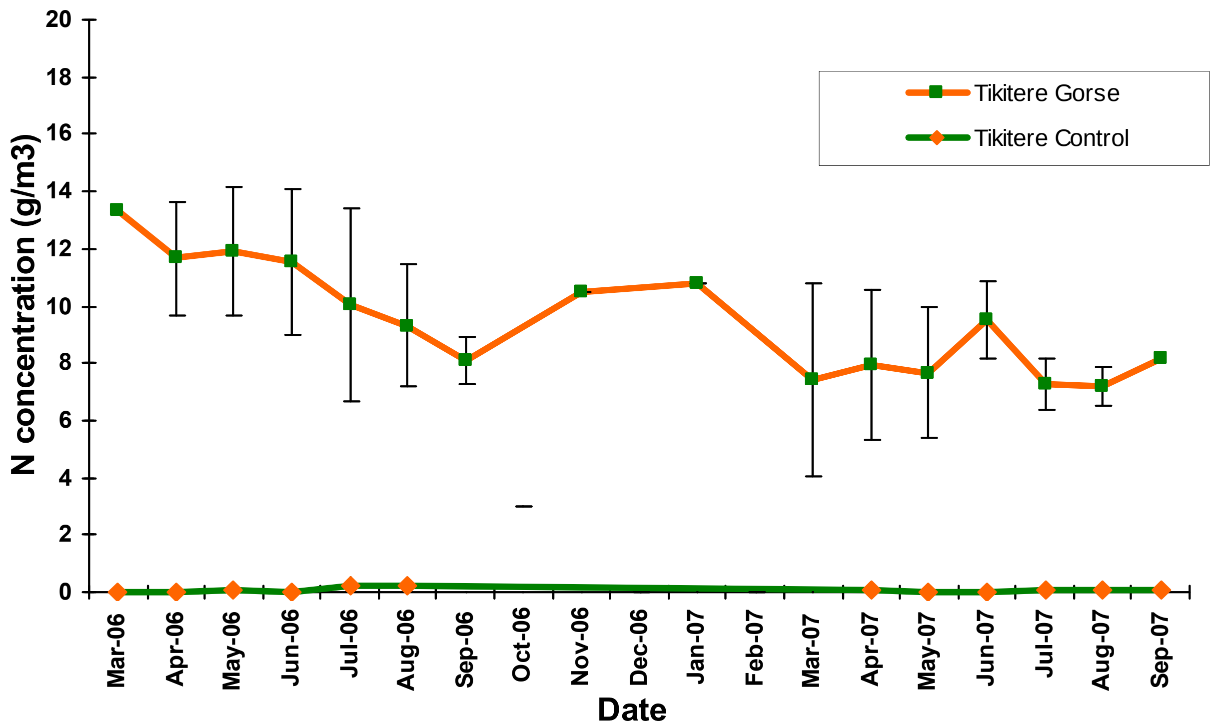


Figure 10. Mean nitrate concentrations in the suction-cup samples collected from Tikitere Forest site.

The trend for the amount of leaching was similar to that for the N leaching pattern. Total nitrate leaching losses under gorse in the Wharenui Station and Tikitere Forest sites in 2006 were 59 and 63 kg N ha^{-1}, respectively. During 2007, the leaching losses were 36 and 40 kg N ha^{-1} for these two sites respectively. The difference in the amounts was due to the difference in drainage between the two years, particularly in the autumn season when nitrate concentrations were greater than in other seasons. In contrast, minimal nitrate leaching occurred from the nearby control sites under pine plantation forest stands. Over the entire 20-month experimental period, total nitrate leaching losses from the control sites on the Wharenui Station and Tikitere Forest were 0.8 and 0.7 kg N ha^{-1}, respectively.

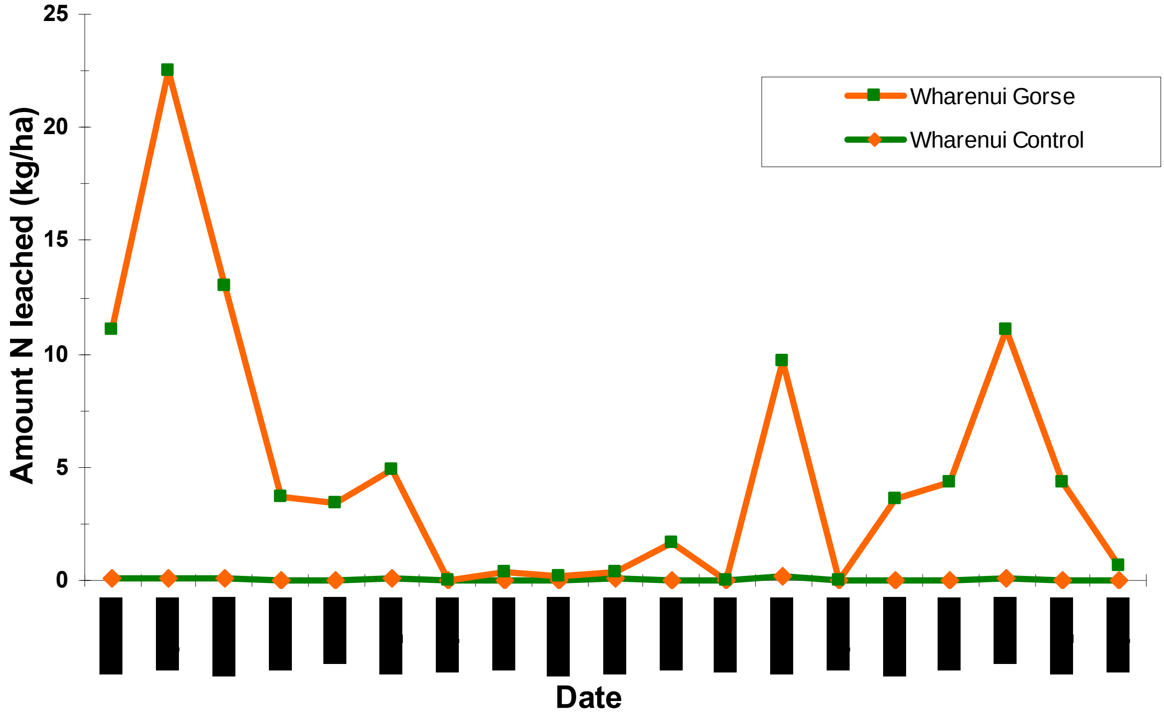


Figure 11. Mean amounts of nitrate leached from the Wharenui Station site as measured by suction-cup samples.

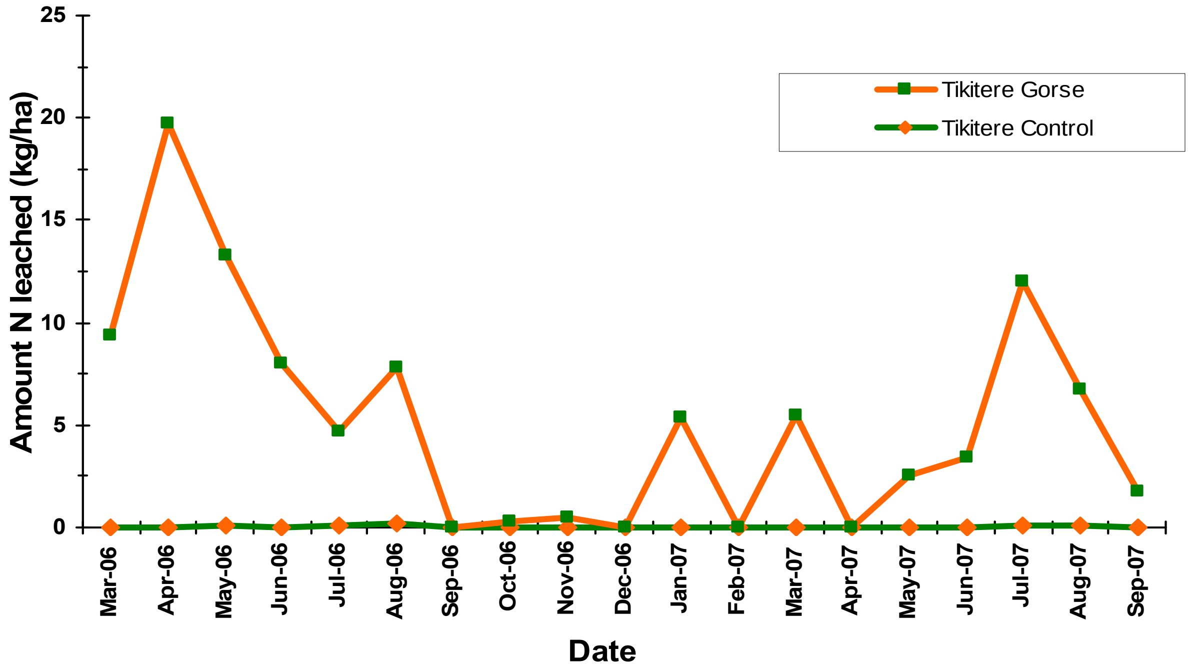


Figure 12. Mean amounts of nitrate leached from Tikitere Forest site as measured by the suction-cup samples.

Field investigations showed that there were minimal roots in the soil below 75 cm depth. When nitrate moves below 90 cm depth it is most likely that it will be leached through to groundwater, as the majority of plant roots are above this depth. That means a substantial amount of N may be entering the groundwater, eventually reaching the lakes.

Glasshouse experiment

Acetylene reduction assay to assess the effect of available nitrogen on N-fixation in gorse and broom

The preliminary results show that the rhizobia in the root nodules of gorse plants seemed to fix more than those in broom. The N_2 fixation in gorse and broom decreased significantly ($P<0.05$) with the increase of available N in nutrient solution. A N_2-fixation threshold was found to be between 100 and 200 mg N L^{-1} for both gorse and broom (Figure 13). However, there were large variations in the results.

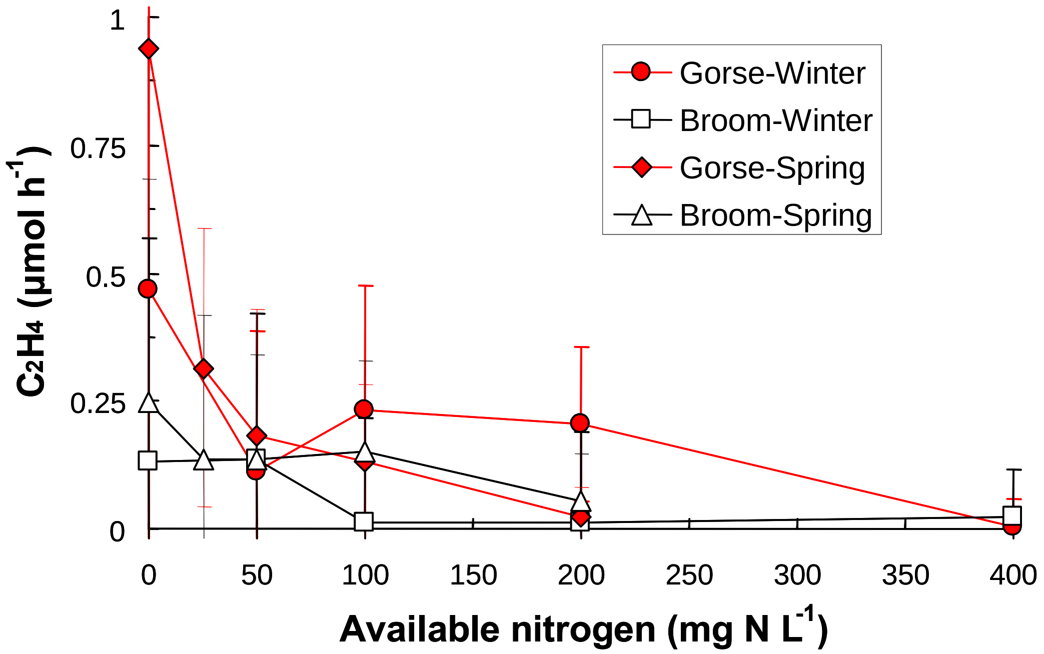


Figure 13. Effect of available nitrogen on acetylene reduction activity, based on ethylene produced from each plant.

The ARA method showed that the rhizobia in gorse and broom fixed less N from the atmosphere when available N supply increased. The high variability of these results implies that further work is required to obtain conclusive thresholds to predict the effect of available N on biological N-fixation in gorse and broom plants.

CONCLUSIONS

Soil solution sampling and analysis indicated nitrate concentration in soil solutions below the rooting zone under mature gorse stands remained at levels relatively above drinking water standards for most of the year, although it decreased during the winter drainage period. Nitrogen supply has been maintained by continued inputs of nitrogen-rich gorse litterfall. As a result, a considerable amount of nitrate has leached below the rooting zone. In contrast to gorse stands, very small amounts of nitrate leached below 90 cm soil depth in the nearby *P. radiata* forest stands.

Acetylene reduction assay (ARA) results indicated that the rhizobia in the root nodules of gorse plants would keep fixing nitrogen from the atmosphere.

The current study demonstrates that gorse stands are producing biologically active nitrogen and releasing nitrate to groundwater, which may then enter the lakes. To protect lake water quality, we recommend that effective methods be developed to eliminate gorse in the Rotorua lakes catchment areas.

ACKNOWLEDGMENTS

We thank Environment Bay of Plenty for funding support and assistance in identifying these sites, Ngati Whakaue Tribal Lands Inc and PF Olsen Ltd for allowing access to experimental sites, H. Jones, A. Hubert, D. Cornes and R. Bagnall for technical assistance, C. van Zyl for data processing, and Veritec Laboratory for chemical analysis. Dr P. Clinton for scientific discussion and comments, and J.Griffith for proofreading.

REFERENCES

Bolan, N.S., Horne, D.J., Currie, L.D. 2004. Growth and chemical composition of legume-based pasture irrigated with dairy farm effluent. *New Zealand Journal of Agricultural Research*, 47: 85-93.

Crush, J.R., Cosgrove, G.P., Brougham, R.W. 1982: The effect of nitrogen fertiliser on clover nitrogen fixation in an intensively grazed Manawatu pasture. *New Zealand Journal of Experimental Agriculture 10*: 395–399.

DeLuca, T.H., Zackrisson, O., Nilsson, M.C., Sellstedt, A., 2002. Quantifying nitrogen-fixation in feather moss carpets of boreal forests. *Nature*, 419: 917-920.

Dyck, W.J., Gosz, J.R., and Hodgkiss, P.D. 1983. Nitrate losses from disturbed ecosystems in New Zealand – A comparative analysis. *New Zealand Journal of Forestry Science*, 13(1): 14-24.

Egunjobi, J.K. 1969. Dry matter and nitrogen accumulation in secondary successions involving gorse (*Ulex europaeus* L.) and associated shrubs and trees. *New Zealand Journal of Science*, 12: 175-193.

Hewitt, A.E., 1998. *New Zealand Soil Classification*. Landcare Research Science Series No. 1. Manaaki Whenua Press, Landcare Research Ltd, Lincoln.

Koch, B. and Evans, H.J. 1966. Reduction of acetylene to ethylene by soybean nodules. Plant Physiology, 41: 1748-1750.

Laws, T., and Graves, W.R., 2005. Nitrogen inhibits nodulation and reversibly suppresses nitrogen fixation in nodules of Alnus maritime. *Journal of American Society of Horticultural Science*, 130: 496-499.

Magesan, G.N., White, R.E. and Scotter, D.R. 1996. Nitrate leaching from a drained, sheep-grazed pasture. 1. Experimental results and environmental implications. *Australian Journal of Soil Research*, 34: 55-67.

Magesan, G.N., White, R.E., Scotter, D.R. and Bolan, N.S. 1994. Estimating leaching losses from sub-surface drained soils. *Soil Use and Management*, 10: 87-93.

Reid, T.C., 1973. Nitrogen fixation by *Ulex europaeus* and *Cytisus scoparius*. *University of Canterbury thesis*, Lincoln College.

Woodward, S.J.R., Barker, D.J. and Zyskowski, R.F. 2001. A practical model for predicting soil water deficit in New Zealand pastures. *New Zealand Journal of Agricultural Research*, 44: 91-109.

APPENDICES

Appendix A – Soil profile descriptions for gorse study

Prepared by Haydon Jones

The soil profile description data collected for the study are presented below. For each description, the reference data are given first, then information describing the nature of the site, and finally the soil morphological data are given (following Clayden and Hewitt, 1994; Milne *et al*., 1995). The land management practices of grazing and fertilization have probably been applied to both sites in the past (whilst under pastoral farming). However, both sites are currently unused in the immediate vicinity of the profile locations. Both sites are surrounded by land used for pastoral farming and production forestry. Note that as part of the geomorphic description, slope shape is given in the format of profile/contour (e.g., linear/convex) shape and that all aspects are given in degrees relative to magnetic north. The soil classifications follow Hewitt (1998), Clayden and Webb (1994), and Soil Survey Staff (1999, 2003).

Profile 1

Reference Data

- Soil name:
    - Series: Rotoiti
    - Type: loamy sand, hill soils
- Soil classification:
    - NZSC: Allophanic Orthic Pumice Soil; Mt, rhyolitic; L/S; r/m
    - Soil Taxonomy: Aquic Udivitrands

Site Data

- Location:
    - Map reference: NZMS 260 U15 2802767 6344494
    - Word description: near main entrance path to gorse patch
- Elevation: 360 m
- Geomorphic position: Profile on a 5.8° linear/convex slope with 0° aspect contained within the summit of a hill in hill country
- Erosion/Deposition: Nil
- Vegetation: Gorse, blackberry, grasses
- Parent material: Various pumice/tephra deposits (e.g., Kaharoa Ash, Taupo Pumice, Rotokawau Ash, Rotoma Ash, Waiohau Ash, and Rotorua Ash)
- Drainage class: Moderately well drained

Soil Data

Ap

0-15 cm Slightly moist; black (10YR 2/1) sandy loam with 4% fine sub-rounded moderately weathered pumice gravels; few fine to medium distinct greyish brown (2.5Y 5/2) mottles; slightly sticky; moderately plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; many microfine to extremely fine fibrous roots and common very fine fleshy roots; weakly allophanic; abrupt wavy boundary.

2bAp

15-20 cm Slightly moist; black (2.5Y 2.5/1) loamy sand with 30% fine sub-rounded moderately weathered pumice gravels; slightly sticky; non plastic; peds very weak and very friable; apedal earthy; profuse very fine polyhedral peds; abundant microfine to extremely fine fibrous roots; strongly allophanic; distinct wavy boundary.

2bBw

20-29 cm Slightly moist; very dark greyish brown (10YR 3/2) loamy sand with 30% fine sub-rounded moderately weathered pumice gravels; non sticky; non plastic; soil very weak and very friable; apedal single-grain; abundant microfine to extremely fine fibrous roots; strongly allophanic; distinct irregular boundary.

2bCu

29-39 cm Dry; light olive brown (2.5Y 5/3) sand with 50% fine sub-rounded slightly weathered pumice gravels; non sticky; non plastic; soil very weak and very friable; apedal single-grain; abundant microfine to extremely fine fibrous roots and few very fine fleshy roots; strongly allophanic; abrupt irregular boundary.

3b2Bw(x)

39-76 cm Slightly moist; dark yellowish brown (10YR 4/5) sandy clay loam; moderately sticky; very plastic; soil weak to slightly firm and brittle; apedal massive; common medium to coarse very dark greyish brown (2.5Y 3.5/2) nodules; few microfine to extremely fine fibrous roots and few very fine fleshy roots; strongly allophanic; distinct wavy boundary.

3b2BC(f)

76 cm –on Slightly moist; light olive brown (2.5Y 5/4) sandy loam; few extremely fine distinct strong brown (7.5YR 5/6) mottles; slightly sticky; non plastic; soil weak and very friable; apedal massive; few microfine to extremely fine fibrous roots and few very fine fleshy roots; weakly to moderately allophanic.

Photograph

Profile 2

Reference Data

- Soil name:
  - Series: Rotomahana
  - Type: shallow sandy loam
- Soil classification:
  - NZSC: Mottled Orthic Pumice Soil; Mt, rhyolitic; L; s/m
  - Soil Taxonomy: Aquic Udivitrands

Site Data

- Location:
  - Map reference: NZMS 260 U16 2802968 6335222

- Word description: near corner of boundary fence with surrounding farm (just over the fence from the vehicle park)

- Elevation: 444 m
- Geomorphic position: Profile on a 6.9° convex/linear slope with 230° aspect contained within the summit bench of a spur-ridge in hill country
- Erosion/Deposition: Nil
- Vegetation: Gorse, grasses
- Parent material: Various pumice/tephra deposits (e.g. Rotomahana Mud, Kaharoa Ash, Taupo Pumice, Rotokawau Ash, Mamaku Ash, Rotoma Ash, and Rotorua Ash)
- Drainage class: Imperfectly drained

Soil Data

Ap

0-8 cm Slightly moist; very dark greyish brown (2.5Y 3/2) sandy loam with 3% fine sub-rounded moderately weathered pumice gravels; slightly sticky; very plastic; peds weak to slightly firm and semi-deformable; very few medium channels; weakly pedal; common fine to medium polyhedral peds; common microfine to extremely fine fibrous roots and few very fine woody roots; non allophanic; distinct smooth (occluded) boundary.

BwC(f)

8-27 cm Dry; olive grey (5Y 5/2) sandy clay loam with 10% fine sub-rounded moderately weathered pumice gravels; common very fine faint brown (7.5YR 5/4) mottles; slightly to moderately sticky; very plastic; peds slightly firm and brittle; very high penetration resistance; weakly pedal; common fine polyhedral peds; few microfine to extremely fine fibrous roots and few very fine woody roots; weakly allophanic; sharp smooth boundary.

2bAp

27-29 cm Slightly moist; black (2.5Y 2.5/1) sandy loam; slightly sticky; moderately plastic; soil very weak and friable; apedal earthy; profuse very fine polyhedral peds; few microfine to extremely fine fibrous roots and few very fine woody roots; non allophanic; abrupt smooth boundary.

2bBC

29-40 cm Dry; very dark greyish brown (2.5Y 3/2) sandy loam with 25% fine to coarse sub-angular slightly weathered pumice gravels; slightly sticky; non plastic; soil very weak and very friable; apedal single-grain; common microfine to extremely fine fibrous roots and common very fine woody roots; weakly allophanic; distinct irregular boundary.

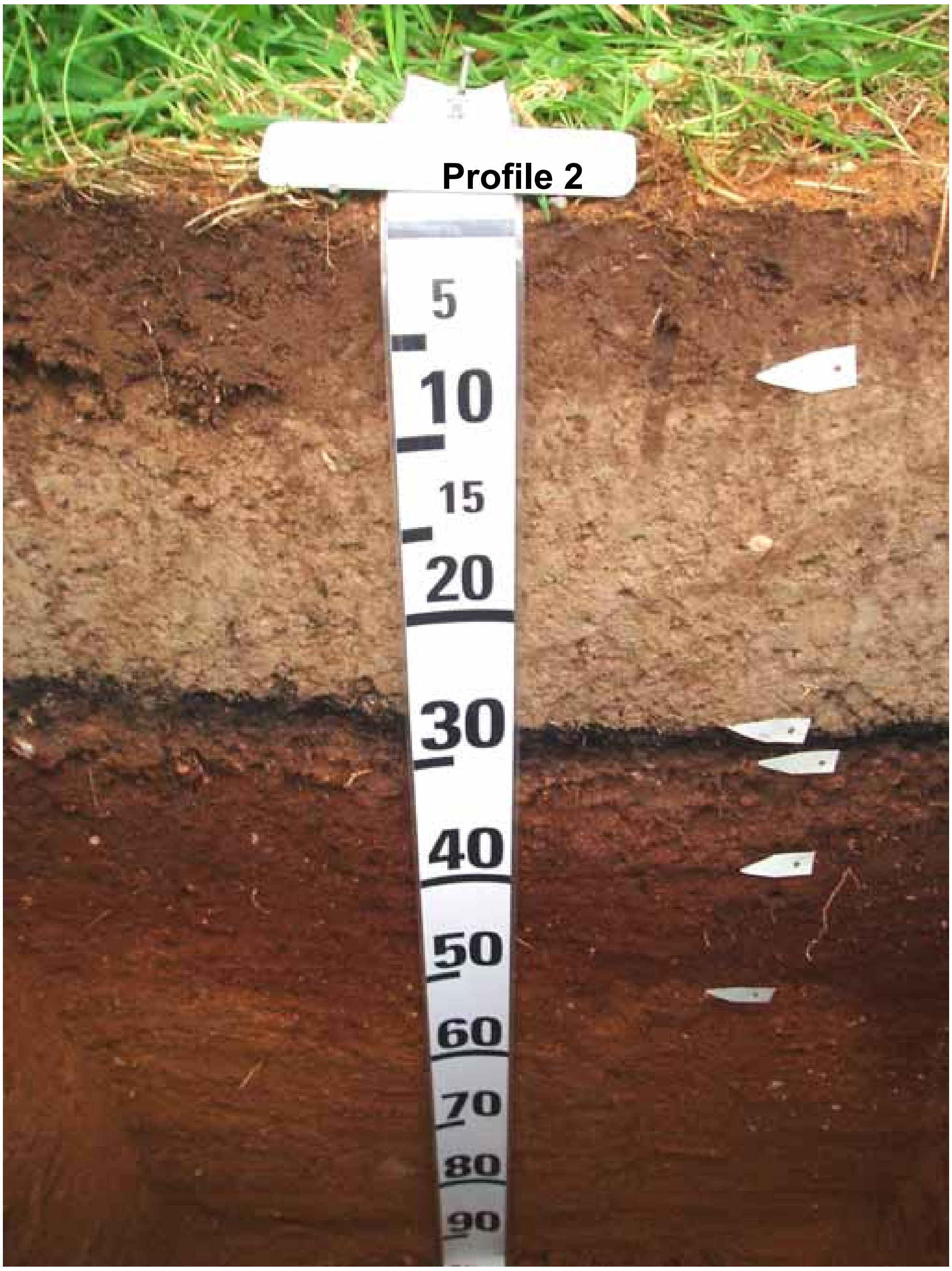
3b2Bw

40-55 cm Slightly moist; very dark grey (7.5YR 3/1) sandy loam with 12% fine sub-rounded slightly weathered pumice gravels; slightly sticky; non plastic; soil weak and friable; apedal earthy; profuse very fine polyhedral peds; few microfine to extremely fine fibrous roots and few very fine woody roots; weakly allophanic; distinct wavy boundary.

3b2BC(f)

55 cm –on Slightly moist; brown (10YR 4/3) sandy clay loam; few very fine distinct dark brown (7.5YR 3/4) mottles; slightly to moderately sticky; moderately plastic; soil weak and friable; apedal earthy; profuse very fine polyhedral peds; few medium to coarse dark yellowish brown (10YR 4/4) soil masses; few microfine to extremely fine fibrous roots and few very fine woody roots; weakly allophanic.

Photograph



References

Clayden, B. and Hewitt, A.E., 1994. *Horizon Notation for New Zealand Soils*. Manaaki Whenua Press, Lincoln.

Clayden, B. and Webb, T.H., 1994. *Criteria for defining the soilform — the fourth category of the New Zealand Soil Classification*. Landcare Research Science Series No. 3. Manaaki Whenua - Landcare Research New Zealand Ltd, Lincoln.

Hewitt, A.E., 1998. *New Zealand Soil Classification*. Landcare Research Science Series No. 1. Manaaki Whenua Press, Landcare Research Ltd, Lincoln.

Milne, J.D.G., Clayden, B., Singleton, P.L. and Wilson, A.D., 1995. *Soil Description Handbook*. Manaaki Whenua Press, Landcare Research Ltd, Lincoln.

Soil Survey Staff, 1999. *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. Agriculture Handbook Number 436. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington D.C.

Soil Survey Staff, 2003. *Keys to Soil Taxonomy*. Ninth Edition. United States Department of Agriculture Natural Resources Conservation Service, Washington D.C.

Appendix B – Literature Review

Prepared by G.N. Magesan, H. Wang and P.W. Clinton

NITRATE LEACHING FROM GORSE IN NEW ZEALAND - A REVIEW

G.N. Magesan[1], H. Wang[1], P.W. Clinton[2]
[1]Scion, Private Bag 3020, Rotorua, New Zealand
[2]Scion, Private Bag, Christchurch, New Zealand

ABSTRACT

Widespread concern about increasing concentrations of bioavailable nitrogen (N) in surface water has focused attention on nitrate leaching in recent years. A number of studies have been carried out to identify the various sources and extent of nitrate leaching on a catchment scale. However, the contributions from leguminous weeds such as gorse and broom have not received much attention.

The aim of this review was to assess the contribution of nitrate leaching to water bodies from gorse sites. The review covers a number of important N cycling processes in a gorse-dominated ecosystem, including N fixation, dry matter and litter accumulation, N content in plants and litter, litter decomposition and mineralization, N content in soil, and extent of N leaching under gorse. In addition, some background information such as arrival and spread of gorse in New Zealand, its environmental impact, and the economic importance of gorse has been added in this review for the benefit of Environment Bay of Plenty.

The literature review shows that there has been no study of long-term inputs of gorse on receiving waters or groundwater. Also, there are no reviews of N balance and loss for gorse ecosystems in the long term.

INTRODUCTION

Nitrogen (N) is often the most growth-limiting nutrient in both terrestrial and aquatic systems. Widespread concern about increasing concentrations of nitrate in surface water has focused attention on nitrate leaching in recent years (e.g. Magesan et al., 1996; Magesan, 2004) – for example, nitrate levels are of key concern for the Rotorua lakes water quality. A number of studies have been carried out to identify the source and extent of nitrate leaching on a catchment scale. Contribution from to receiving waters from various sources including agricultural lands, forests, fertilisers, grazing animals, and land application of wastes have been studied. However, the contributions from leguminous weeds such as gorse and broom have not received much attention despite the fact that these weeds have infested large productive areas such as forests and agricultural lands as well as unproductive areas.

This review covers some background information on gorse such as the arrival and spread of gorse in New Zealand, its economic importance, and related information, and describes important biological processes associated with N fixation, dry matter and litter accumulation, N content in plants and litter, litter decomposition and mineralization, N content in soil, and the extent of N leaching under gorse.

A BRIEF HISTORY OF GORSE IN NEW ZEALAND

Within the *Ulex* genus, there are more than 20 species and they are commonly known as "gorse". Unless specifically mentioned, "gorse" in this review refers to"Common gorse", *Ulex europaeus* L. Gorse is a perennial, evergreen, leguminous shrub and is native to western Europe and northwest Africa. All its stems and leaves are prickly, ending in a sharp spine. It has short stout branches which are green when young but turn brown with age. Gorse produces deep and extensive roots, and the bushes can form large, impenetrable thickets, with golden-yellow flowers. In general, gorse can reach a height of 3 m or more. However, Lee et al. (1986) recorded a mean canopy height of 4 m for middle-aged plants in New Zealand, with a maximum height of 7 m.

Gorse was deliberately introduced to New Zealand over a century ago as a hedge plant and as a fodder crop for domestic stock (Lee et al., 1986; Clements et al., 2001). The actual date of introduction to New Zealand is not accurately known. However, Darwin first documented gorse during his visit to the Bay of Islands in 1835. With time, gorse spread throughout New Zealand covering large areas of marginal and unproductive land (Hill, 1987), as well as highly disturbed areas and over-grazed pastures (Matthews, 1982; Parker, 1984) and roadsides, sand dunes, logged areas, and burnt-over forests (Hermann and Newton, 1968; Lee et al., 1986). In some areas it became a problem – i.e., dominant on 53 000 ha, and forming a constituent of another 650 000 ha of grassland and scrub (Blaschke et al., 1981). In 1859 the provincial legislatures of Taranaki and Nelson passed laws compelling farmers to keep gorse hedges trimmed and to stop planting new hedges (Hackwell, 1980). It was only in 1900 that gorse was declared a noxious weed (Moss, 1960) under the second schedule of the first Noxious Weeds Act.

GORSE AS AN ENVIRONMENTAL WEED

Gorse is regarded as an environmental weed because of its invasiveness, potential for spread, and economic and environmental impacts (Gaynor and MacCarter, 1981; Hill 1987). The main biological features contributing to its weed status are its vigorous growth, N fixation ability, prolific seed production, longevity of seeds in the soil, and its sprouting ability after cutting or fire (Clements et al., 2001; Hill et al., 2001). Gorse has high photosynthetic efficiency and annual dry matter accumulation (Egunjobi, 1969) and can live to an age of 46 years in New Zealand (Lee et al., 1986). In pastoral and bushland areas, gorse is increasingly becoming a threat as it reduces the potential for grazing by cattle and sheep, provides shelter for pests such as rabbits, and increases the risk of bushfires because of its flammability (MacCarter and Gaynor, 1980; Krause et al., 1988). In plantation forests gorse can reduce the height and diameter of forest trees, increase the cost of site preparation (Sandrey, 1985; Richardson et al., 1996), and make access for pruning and thinning operations difficult and therefore more expensive. The bushes grow up with the trees, compete with them for nutrients and minerals, particularly boron and phosphorus, and therefore can cause a wide variation in the growth rates of individual trees and consequently an overall decrease in stand quality and growth rates. Gorse can rapidly invade dry and disturbed areas by suppressing and inhibiting native plant communities (Lee et al., 1986; Clements et al., 2001). Because it generally invades an area gradually, monitoring is often neglected (Hoshovsky, 1986).

Gorse is tolerant of a large range of climates and soil types. In New Zealand, it grows from sea level to 800 m and is most vigorous and effective in the rainfall zones between 500 and 1500 mm (MacCarter and Gaynor, 1980). Many land management practices in New Zealand also favour gorse. The use of fire to clear land encourages the establishment of the plants as they are capable of re-sprouting and temperatures of less than 100 ^{o}C stimulate germination from the seed bank (Zabkiewicz and Gaskin, 1978). The ability of the seed to resist fire and the ability of the plant to resprout have led to gorse's dominance in many pioneer successions throughout the country (Hackwell, 1980).

There are two main flowering periods although the impression is conveyed that gorse is flowering continuously from early autumn to mid summer throughout New Zealand. There are two seeding periods each year and fewer seeds are produced during the minor flowering, i.e., autumn, than during the major one, i.e., spring-summer (Miller, 1970). Gorse is a prolific seed producer and is estimated to produce 500-600 seeds m^{-2} in New Zealand annually (Ivens, 1978). The seeds have a hard, water-resistant coating that allows them to remain dormant in the soil for up to 30 years (Hermann and Newton, 1968). A large proportion of seeds recovered from soil are viable and an average seed bank population of 6 000 seeds m^{-2} in the top 6 cm of soil has been recorded (Partridge, 1989; Zabkiewicz and Gaskin, 1978). Meeklah (1979) estimated that continuous mature gorse sites could generate a seed bank of 100 million seeds per hectare in New Zealand. The ability to produce large seed banks helps gorse to persist in many areas.

The combination of competitive and defensive characteristics of gorse may allow it to remain dominant in an area for 30 years. Lee et al. (1986) observed little establishment of native woody species within 25 years of gorse establishment in New Zealand. As the gorse ages, its canopy becomes more open. The resulting increase in light beneath the canopy, the canopy's stabilizing effect on moisture and temperature fluctuations, and the fertile litter all provide favourable conditions for the germination of native shrub seedlings. Gorse is prone to stem base rot after about 25 years, and at Taita experimental site gorse which was vigorous in 16-year-old stands had become senile in 34-year-old scrub and was dead in 40-year-old scrub (Druce, 1957; Hackwell, 1980).

Since its introduction, gorse has colonised around 900 000 ha or approximately 3.6% of New Zealand as a weed of forestry land, agricultural land, and parks and reserves (Sandrey, 1985; Hill, 1987). However, this figure may be much larger due to the length of time gorse seed can remain dormant in the ground. Once the land is suitably disturbed, a flush of gorse regeneration soon follows.

GORSE BENEFITS

Although considered a weed, gorse does offer some benefits: apart from being used for hedges and stock feed in large areas of the country, it stabilizes, develops, and enriches soils; in New Zealand, gorse flowers for almost the whole year (Miller, 1970) and provides the honey industry with an important source of early spring pollen for bees (Sandrey 1985); it is a source of browse for goats and sheep (Lambert et al., 1989), and in some situations has been used as a nursery crop for native seedlings (Hackwell, 1980; Lee et al., 1986). Some studies have noted its useful function in biological conservation as a pioneer transient successional species in the re-establishment of indigenous forest vegetation (Druce, 1957; Healy 1961), and therefore that it should be left undisturbed in reserve areas (Hackwell, 1980). Because of its ability to rapidly accumulate dry matter (see below) gorse is effective at sequestering atmospheric carbon.

CONTROLLING GORSE IN NEW ZEALAND

A voluminous body of literature on gorse deals predominantly with control measures: mechanical, chemical, fire, and grazing in various combinations (McCracken, 1993). The success and efficacy of these measures are not covered in this review. In spite of massive investment in the past, technology has not been able to provide an effective gorse “control” to prevent re-invasion. Continued intensive management is necessary to effectively control the species (McCracken, 1993), and until 1984 substantial subsidies were in place for its removal. Sandrey (1985) reported annual costs for gorse control in New Zealand of US$17.8 million and US$8 million in the agricultural and forestry sectors, respectively. Assessment of the magnitude and cost of the problem in reserve areas is harder. Government subsidies for gorse control were removed in March 1985. All agricultural subsidies were removed in 1985 because of a change in political philosophy. Cheap, effective, chemical control of scrub weeds ended in August 1988 when 2,4,5-T was removed from the market after a prolonged battle over dioxin contaminants. Mechanical control measures have always been expensive and the “non toxic” chemicals are more expensive than 2,4,5-T, and less effective. Landowners from then on have only been required to limit the spread of gorse. But the costs for gorse control on marginal land have become prohibitive (McCracken, 1993), and in such areas leaving gorse alone may be a wiser and cheaper method of ensuring its eventual elimination than trying to control it by chemical sprays or fire (Hackwell, 1980). Replacement with forest cover may be a long-term solution to the gorse problem in reserves and on marginal farm land. MacCarter and Gaynor (1980), Gaynor and MacCarter (1981) and Richardson and Hill (1998) have produced comprehensive literature reviews on the assessment of the impact of gorse and its control in New Zealand and Australia.

NITROGEN FIXATION

The fixation of elemental N into compounds usable by plants is one of the most important microbial processes in soils (Brady, 1984). N fixation is a process in which inert atmospheric N_2 gas is converted into plant-available N by certain micro-organisms. Bacteria of the genus *Rhizobium* invade the roots of legumes and form a root ‘nodule’ within which they live and fix N_2 (McLaren and Cameron, 1990). The host plant supplies the bacteria with carbohydrates for energy, and the bacteria reciprocate by supplying the plant with fixed N compounds. The amount of N fixation in the nodule depends on soil temperature, moisture, pH, and nutrient availability.

The N fixed by the nodule organisms goes in four directions (Brady, 1984): firstly, it is used directly by the host plant; secondly, as the N passes into the soil itself, either by excretion or more probably by sloughing off of the roots with the nodules, some of it is mineralized and becomes available as ammonium or nitrate compounds; thirdly, when the legume dies, the entire plant including the root system is subject to breakdown and some of the N is converted into ammonium and nitrate; fourthly, the fixed N is incorporated into the bodies of the general-purpose decay organisms and finally into the soil organic matter.

Legume species generally contain more N than other species because of their symbiotic N fixing activity. Gorse (*Ulex europaeus* L) is one of the most widespread N-fixing species, and presence of such species may allow high inputs of N into the ecosystem. Egunjobi (1969) reported the superiority of gorse over the other species in its ability to accumulate N. During the period of rapid dry-matter accumulation, N accumulated at a rate of 100 to 200 kg ha^{-1} yr^{-1} in gorse sites (Egunjobi, 1969). Nitrogen fixation rates associated with leguminous species (e.g. gorse) are at least 10 times greater than those of non-leguminous nitrogen fixing species (Skeffington and Bradshaw, 1980). Gorse possesses perennial nodules that appear to be active in N_2 fixation even during winter (Pate, 1961). Gorse root nodule activity may be three times greater than that of red alder, a common N fixing tree (Zielke et al., 1992). A wide range of estimated values of N fixation by gorse have been reported (Table 1).

Table 1. Nitrogen fixing rates for gorse

Species	Method	Amount (kg ha^{-1} yr^{-1})	Reference
Ulex europaeus	Estimated	200	Egunjobi (1969)
Ulex europaeus	Calculated	26	Skeffington and Bradshaw (1980)
Ulex gallii	Estimated	21	O'Toole et al. (1991)
Ulex gallii	Estimated	55	O'Toole et al. (1984)
Ulex europaeus	Estimated	4 – 88	Augusto et al. (2005)

Nitrogen concentration in naturally occurring, 5-year-old *Ulex gallii*, on impoverished soils under a forest ecosystem ranged from 1.13% to 1.33% (O'Toole et al., 1984). The estimated N accumulation of *Ulex gallii* shrubs was 232 kg N ha^{-1}. In another study, N concentrations of plant tissues collected from the gorse-infested epicentres and the adjacent uninfested peripheries on a volcanic soil were 2.41% and 3.57%, respectively (Leary et al., 2005).

Fertilizer N supply can affect N fixation in gorse. It is well documented that externally applied N inhibits both nodulation and N_2-fixation in legumes (Dixon and Wheeler, 1983). For example, MacConnell and Bond (1957) reported that external application of ammonium decreased the mean dry weight of gorse nodules per plant. Thornton et al. (1995) grew gorse plants over two seasons, manipulating the rate of N_2 fixation by varying exogenously applied nitrate or ammonium. They used ^{15}N as a tracer to estimate total root uptake, N_2-fixation, and the contribution of re-mobilization to the N content of new shoot growth, in the second season. They reported that when nodulated gorse plants were grown in sand, N fixation provided the main source of N for plants supplied with a low level of N but not for those supplied with abundant N.

Some studies have shown that inputs of phosphorus enhance the growth of gorse (Knight, 1969) and result in an increase of the biomass and the N-fixing activity of leguminous shrub species (O'Toole et al., 1984; 1991). *Ulex gallii* has been estimated to accumulate 55 kg N ha^{-1} $year^{-1}$ (in vegetation) in a P-fertilized forest soil formed from Old Red Sandstone (O'Toole et al., 1984). Augusto et al. (2005) estimated that the annual N_2-fixation flux ranged from 0.5 to 5.1 kg N ha^{-1} yr^{-1} in the mature pine stands. But in the young open pine stands, the annual flux ranged from 4.0 to 88.3 kg N ha^{-1} yr^{-1} and increased with P-fertilisation. Augusto et al. (2005) suggested that P-fertilisation promoted both the biomass production of the entire vegetation and the production of nodules for N_2-fixing species. This resulted in a higher N-fixation flux and a better supply of N and P for the *Ulex* species, which then acquired a competitive advantage over the non-fixing species. They suggested that the difference between mature and juvenile pine stands was probably due to the increasing light interception of the tree canopy, the operations of weed control, and the vegetation successions of the understorey.

DRY MATTER AND LITTER ACCUMULATION

When plants grow they accumulate biomass. Egunjobi (1969) studied nine ecosystems in New Zealand, involving gorse and associated shrubs and trees. He found that the young gorse grows very quickly, and the gorse was superior to other species in its ability to accumulate dry matter, and N content (Table 2). The quantity of dry matter (above ground) produced in the first year was comparable with pasture production on the same soil type. After the first year, rapid production and accumulation of dry matter continued lasting some 4 to 5 years. Mean annual accumulation was 15 t ha^{-1}. After the first 5 years, productivity appeared to fall, and between 7 and 10 years, the mean annual accumulation of dry matter was only approximately 10 t ha^{-1}. The productivity would have been considerably greater than this as the annual litter fall for a 7- to 8-year old gorse site was approximately 9 t ha^{-1} yr^{-1}. Egunjobi (1969) reported that the biomass accumulation decreased with age (c. 3-4 t ha^{-1} yr^{-1} for sites between 16 and 33 years old).

Dancer et al. (1977) observed that gorse accumulated N most rapidly, and reported that on sites dominated by legumes two-thirds of the N accumulated in the soil, while the remaining third was found in the biomass and litter. So the process of N accumulation in the soil after the invasion of legumes is considered to be a most important aspect of ecosystem development. In that study, average N accumulation rates in the gorse biomass were 21 kg N ha^{-1} yr^{-1}.

Table 2: Quantity (kg/ha) of dry matter and N contained in gorse sites in Taita, New Zealand (adapted from Egunjobi, 1969).

Age of gorse (years)	Cumulative dry matter (kg ha^{-1})	N (kg ha^{-1})
1 (untopdressed)	5860	89
1 (topdressed)	9940	174
4	62170	677
7	66470	633
10	77270	603

In another study, Lambert et al. (1989) studied 11 scrub species in New Zealand and found that gorse had a high survival rate, and was most productive shrub in the trial. Gorse produced the most forage dry matter, and more than 85% of the annual production was in spring and summer. However, the major proportion of the dry matter was in stem material rather than in the leaf material. Radcliffe (1986) harvested gorse after spelling for 8 months over the growing season, and estimated that gorse accumulated 11 – 46 t ha^{-1} yr^{-1}.

Dry matter production does not necessarily increase with added fertilizer (Egunjobi, 1971a,b) but occasionally phosphate has been reported to produce a growth response (Richardson and Hill, 1998). Augusto et al. (2005) found that the response of the vegetation in pine forest understorey to increasing doses of P-fertilizer was an increase of the gorse density (plants m^{-2}) and biomass. In the treatments with most fertilizer, the understorey was almost completely composed of gorse. The gorse plants were clearly stimulated by increasing doses of P-fertilizer (Figure 1). In the treatment with most fertilizer, mean total biomass reached 31.1 t ha^{-1} after six growing seasons.

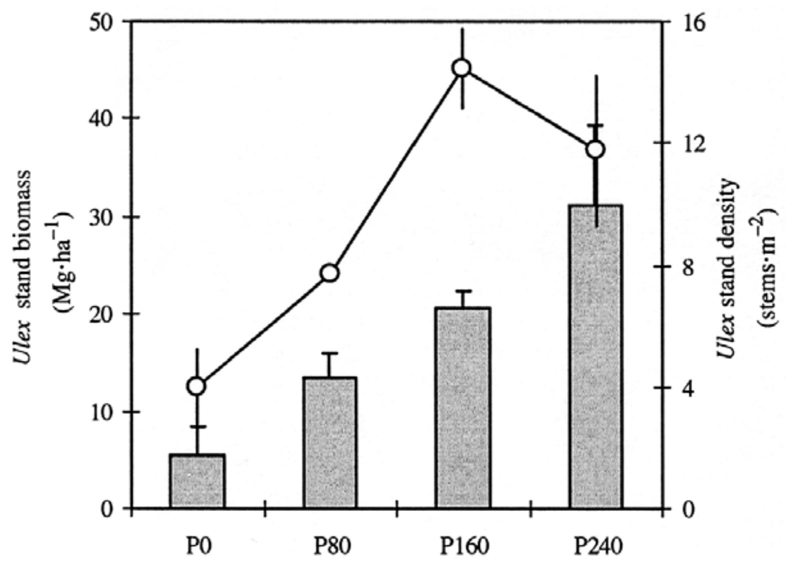


Figure 1. Effect of P fertilization on gorse biomass (bars) and density (line) (adapted from Augusto et al., 2005).

Table 3 gives the effect of P-fertilization on gorse characteristics in the same study. The nutrient (N and P) amounts accumulated in the biomass followed the same pattern as biomass. Also, fertilization significantly modified the N content of the green twigs of gorse. From Table 3, it is clear that the biomass, and consequently the amounts of N and P in the biomass, were well correlated with the dose of P-fertilizer.

Table 3: Effect of P-fertilization on gorse characteristics (adapted from Augusto et al., 2005)

Fertilization level ($kg\ P_2O_5\ ha^{-1}$)[a]	Biomass ($t\ ha^{-1}$)	Density ($stems\ m^{-2}$)	N amount ($kg\ N\ ha^{-1}$)	P amount ($kg\ P\ ha^{-1}$)	N content in green twigs ($mg\ g^{-1}$)
P240	31.1 + 8.3	11.8 + 2.5	360.5 + 97.7	19.7 + 5.8	17.85
P160	20.6 + 1.7	14.4 + 1.3	229.7 + 33.5	12.3 + 1.6	15.43
P80	13.3 + 2.6	7.8 + 0.3	130.5 + 15.1	5.2 + 0.6	14.89
P0	5.4 + 2.9	4.0 + 1.2	50.7 + 24.6	1.5 + 0.7	13.92

A: P80, P160 and P240 correspond to 35.2, 70.4, and 105.5 kg P ha^{-1}, respectively.

Most of the annual production of biomass, with its high N content, ends up in litter (Hackwell, 1980). Gorse produced more litter than other shrubs and shrub-tree stands at Taita (Egunjobi, 1969), and the litter mass and its N content increased with the age of the gorse stand (Table 4).

Table 4: Quantity of litter and its N content on the floor of gorse sites (adapted from Egunjobi, 1969).

Age of gorse (years)	Litter ($kg\ ha^{-1}$)	N content of litter (%)	N content of litter ($kg\ ha^{-1}$)
4	9130	1.50	137
7	8800	1.47	129
10	11810	1.93	228

In large gorse thickets large amounts of dead material can collect both in the branches and on the ground. Fagan (1999) compared the elevated gorse material (located in the branches of the gorse) with the ground layer material. Gorse material collected above the ground had a lower density and a more aerated state. It was brittle when touched, with an obvious drier feel than the ground litter, and dried faster than that on the ground.

Lee et al. (1986) recorded gorse densities of 60 000 stems ha^{-1}, and a mean litter depth of 55 mm in mature sites in New Zealand. Large amounts of litter produced by gorse can modify the substrate, and make it more acidic, drier, and coarser structured (Lee et al., 1986). Accumulation of such an acidic litter layer in gorse sites may impact soil health and could inhibit establishment of other species (Lee et al., 1986). Also, the litter produced by gorse is not easily decomposed (Egunjobi, 1971a,b).

LITTER DECOMPOSITION AND NITROGEN MINERALISATION

A large proportion of the net primary production in a typical terrestrial ecosystem is shed as litter and subsequently enters the decomposition pathway releasing a pool of plant-available nutrients. Decomposition is the catabolism of organic compounds in plant litter, and is mainly the result of microbial activity. Litter decomposition is an essential stage in the cycling of organic matter and mineral elements, which contributes to the productivity and the dynamics of ecosystems. The rate of this process depends on the chemical composition of the litter as well as on environmental parameters.

Several processes have been proposed to explain N accumulation in litter: input by leaching from the plant canopy, atmospheric N fixation within the litter by free living microbes, and soil fauna excrement. If external inputs and microbial neo-synthesis continue at a higher level than net mineralization, which is a N-releasing process, the overall balance will be a progressive enrichment in N during the first few years of decomposition (Ballini and Bonin, 1995). Since the N content of gorse plants is high, their litter is expected to be richer in N. In New Zealand, Egunjobi (1969) showed that the N concentrations are generally higher in gorse litter than in litter collected under shrubs and trees.

In an incubation study, O'Toole et al., (1984) observed that although there was a lengthy delay prior to onset of active N mineralisation in gorse litter, this material released significantly more mineral-N during 80 days' incubation than either senescent gorse or non-gorse litter. Cumulative mineralisation of N in these materials was 5.9, 1.2 and 2.3 mg N g^{-1} total-N, respectively. Ammonium-N comprised >90% of the N released by each material (O'Toole et al., 1984).

Despite many studies on litter decomposition, there is little information on decomposition and N mineralisation of litter and soil under gorse sites. O'Toole et al. (1984) observed that the patterns and quantities of N mineralisation differed markedly in "high" and "low" gorse soils. Release of soil N commenced without delay in the high-gorse soil and increased significantly up to c.96 days of incubation. In contrast, N mineralisation rates in the low-gorse soil remained very low throughout incubation and were very much inferior to rates in the high-gorse soil. Cumulative mineral-N production after 112 days' incubation comprised 3.3% of total-N in the high-gorse soil compared to only 0.4% in the low-gorse soil. Again, little nitrate-N was produced in either soil (O'Toole et al., 1984).

Egunjobi (1971a,b) reported that litter fall is nearly 50% of total annual dry matter production in gorse sites. As gorse sites can produce large amounts of litter material with a relatively high concentration of N (Egunjobi, 1969), it is important to investigate the fate of the gorse-derived N in the receiving environment and its ecological impact, particularly in a sensitive environment, such as catchments of Rotorua lakes. Studies on gorse litter quality and decomposition, and the mineralisation rate of N in litter and soil are essential to quantify the potential N input to the Rotorua lakes from gorse ecosystems.

NITROGEN CONTENT IN SOIL

During and after litter decomposition, N in plants is released to soil. Egunjobi (1969) reported that the N concentration was high in the soils under gorse sites because of its N-fixing ability and the large quantities of litter it produced. The gorse sites accumulated more N per unit area than older stands dominated by non-N fixing shrubs and trees. However, there is no particular study that reports the effect of gorse on soil N and more research is needed in this area. Table 5 gives the concentration and content of N in soils under gorse of different ages from a New Zealand study.

Table 5: Concentration and content of N in soils under gorse of 4-, 7-, and 10-year sites (adapted from Egunjobi, 1969).

Age of gorse (years)	Soil layer sampled (depth in cm)	N concentration (%)	N content	
			In soil layer sampled (kg ha^{-1})	In whole profile (kg ha^{-1})
4	0-7	0.34	1,873	5,272
	7-14	0.15	1,389	
	14-21	0.15	1,238	
	21-28	0.08	772	
7	0-7	0.28	1,632	4,983
	7-14	0.15	1,304	
	14-21	0.11	1,177	
	21-28	0.08	870	
10	0-7	0.23	1,778	4,409
	7-14	0.15	1,332	
	14-21	0.07	685	
	21-28	0.06	614	

From measurements of plant contents, litter-fall, and rain through-fall it has been estimated that over 65% of the N taken up by gorse is returned annually to the soil (Egunjobi, 1971a,b).

Table 6 gives the N concentration in the soil under gorse as reported internationally.

Table 6. Nitrogen concentration in the soil under gorse

Soil type	Soil depth	Mean N conc	Range	Reference
Silty loam	0 – 2 cm	3.05 (ug/g)	0.67 – 5.69	Grubb & Suter (1970)
Sand waste site	0 – 9 cm	0.023 %		Dancer et al. (1977)
Volcanic soil	0-10 cm	0.9 – 1.3%		Leary et al. (2005)

O'Toole et al. (1984) reported that the N content of the soil and the soil plus total vegetation tends to increase with increasing gorse cover. Real effects of gorse on N content of the soil during the comparatively short time span since invasion of the site by the legume (5 years) were difficult to detect against a large background of ≥ 2000 kg soil N ha^{-1}. In another study, to determine how gorse infestation influenced the volcanic soil environment in Hawaii, Leary et al. (2005) compared the soil nutritional contents of the gorse-infested epicentres and the adjacent uninfested peripheries. They found that the soils within the epicentres of the gorse infestation were significantly more acidic than the soils within the uninfested periphery, but there were no significant differences in the soil concentrations of N and P between the epicentre and peripheral zones.

Nitrogen in the soil may be subject to denitrification, volatilisation as ammonium, plant uptake, leaching, surface runoff and immobilisation into the organic matter. Typically more than 95% of N retained in soils is in organic form (Batjes, 1996). Most organic N in soils is covalently bonded to C, so the amount of N stored is dependent on the amount of organic C available for bonding and storage. Typically the C:N ratio of topsoils is approximately 10 (Batjes, 1996).

EXTENT OF N LEACHING UNDER GORSE

Important considerations in assessing the potential N leaching to groundwater are the amount and rate of N release from plant litter. Although research has shown that prunings of legume species can be an effective source of N for crop production little is known regarding factors that govern the N release patterns under different ecological conditions.

Dyck et al. (1983) studied nitrate losses from different undisturbed and disturbed (by crushing and burning) gorse and forest ecosystems. Soil water was periodically collected from 10 lysimeters in each treated area for up to 2 years after disturbance as well as in undisturbed controls, and analysed for nitrate N as an indicator of nutrient loss. They found that in undisturbed areas more nitrate was leached from sites under gorse than from sites under the tree species. For example, NO_3-N concentrations from the gorse area averaged 5.1 g m^{-3} whereas nitrate from radiata pine averaged 0.006 g m^{-3} (Table 1). In the same study, Dyck et al. (1983) suggested that decomposing gorse tissue released fairly large amounts of nitrate to groundwater.

Table 7. Average nitrate-N concentrations leaching from undisturbed control sites under various plant species (adapted from Dyck et al., 1983).

Plant species	Age (yr)	Stocking rate (stems ha^{-1})	Soil type	Monitoring period (yr)	Average NO_3-N conc. (g m^{-3})
Radiata pine	20	250	Kaingaroa silty sand	2	0.006
Douglas fir	56	200	Te Rere sand	2	0.272
E. saligna	18	100	Manawahe coarse sand	1	0.08
Gorse	20	Dense	Galatea sand	2	5.1

Nitrate levels in soil water under the control plot in the gorse area averaged 5.1 g m^{-3} and showed a winter peak the first year of monitoring and another peak the following autumn. Concentrations in the treated sites (crushed and burned) were high at the first collection 1 week after burning, and a maximum recorded value (23.3 g m^{-3}) occurred in week 10. Nitrate in soil water increased immediately in response to the second burn but not to spraying, and peaked at 22 g m^{-3}. Concentrations then rapidly declined to background levels in the control plots.

Egunjobi (1969) suggested that the level of soil N will decrease when the gorse phase is followed by non-N fixing species because of plant uptake, leaching, and run-off losses. The results of Dyck et al. (1983) suggest that decomposing gorse tissue releases fairly large amounts of nitrate to groundwater. According to Egunjobi (1969) this should continue and soil N content should decline as gorse is replaced by other species.

Throughfall is generally defined as that portion of the gross rainfall that reaches the soil directly through spaces in the canopy and as drip from leaves, twigs, and stems (Aldridge, 1968). Egunjobi (1967) measured throughfall under gorse using trough gauges over a 6-month period and reported that the monthly totals of throughfall were only 18%-30% of the monthly gross rainfall. Aldridge (1968) for the same period on a similar gorse site reported throughfall 20-30% of the gross rainfall reached the ground. So, care must be taken when estimating leaching losses under gorse because of low throughfall at gorse sites. This is because not all the rainfall is taking part in leaching nitrogen leaching.

Although the vast majority of soil N is relatively immobile, nitrate because of its negative charge, is repelled by cation exchange sites and is therefore readily leached when water drains through the soil. In most areas of New Zealand, nitrate leaching mainly occurs in late autumn, winter, and early spring, when there is an excess of rainfall over evapotranspiration and the soil is at or near field capacity (Magesan et al. 1996). At these times of the year, plant uptake of N is low and therefore nitrate may be present in significant quantities in the soil solution.

SUMMARY

Gorse was deliberately introduced to New Zealand over a century ago as a hedge plant and as a fodder crop for domestic stock. Now, gorse is regarded as an environmental weed because of its invasiveness, potential for spread, and economic and environmental impacts. Since its introduction gorse communities have colonised around 900 000 hectares or approximately 3.6% of New Zealand as a weed of forestry land, agricultural land, and in parks and reserves.

Gorse is capable of fixing up to 200 kg N ha^{-1} yr^{-1}. While fertilizer N supply can affect N fixation in gorse, some studies have shown that inputs of phosphorus enhance the growth of gorse and result in an increase of the biomass and the N-fixing activity of gorse.

The quantity of dry matter (above ground) produced in the first year was comparable to pasture production on the same soil type. For next 4 to 5 years, the mean annual accumulation was 15 t ha^{-1}. Between 7 and 10 years, the mean annual accumulation of dry matter declined to approximately 10 t ha^{-1}. The productivity would have been considerably greater than this as the annual litter fall for a 7- to 8-year stand was approximately 9 t ha^{-1}.

During the period of rapid dry-matter accumulation, N accumulated at a rate of 100 to 200 kg ha^{-1} $year^{-1}$ in gorse sites. Since the N content of gorse plants is high, their litter is expected to be richer in N. The N concentrations are generally higher in the gorse litter than in the litters collected under shrubs and trees. The litter on the soil at increasing-age gorse sites was found to have N concentration of 1.5% to 1.9%.

During and after litter decomposition, N is released to soil. Egunjobi (1969) reported that the N concentration was high in the soils under gorse sites because of its N-fixing ability and the large quantities of litter it produced.

The literature review shows that there has been no study of long-term inputs of N from gorse into receiving waters or groundwater. Also, there are no reviews of N balance and loss for gorse ecosystems over the long term.

REFERENCES

Aldridge, R. 1968. Throughfall under gorse (*Ulex europaeus*) at Taita, New Zealand. New Zealand Journal of Science, 11: 447-451.

Aldridge, R., Jackson, R.J. 1968. Interception of rainfall by Manuka (*Leptospermum scoparium*). New Zealand Journal of Science, 11: 301-317.

Augusto, L., Crampon, N., Saur, E., Bakker, M.R., Pellerin, S., de Lavaissière, C., Trichet, P. 2005. High rates of nitrogen fixation of *Ulex* species in the understorey of maritime pine stands and the potential effect of phosphorus fertilization. Canadian Journal of Forest Research, 35: 1183-1192.

Ballini, C., Bonin, G. 1995. Nutrient cycling in some *Ulex parviflorus* Pourr. scrubs in Provence (southeastern France). II. Nutrient release from decomposing litter. European Journal of Soil Biology, 31: 143-151.

Batjes, N.H. 1996. Total carbon and nitrogen in soils of the world. European Journal of Soil Science 47, 151–163.

Blaschke, P.M., Hunter, G.G., Eyles, G.O., van Berkel, P.R. 1981. Analysis of New Zealand's vegetation cover using land resource inventory data. New Zealand Journal of Ecology, 4: 1-19.

Brady, N.C. 1984. The Nature and Properties of Soils. MacMillan Publishing Company, New York.

Clements, D.R., Peterson, D., Prasad, R. 2001. The biology of Canadian weeds - 112 - *Ulex europaeus* L. Canadian Journal of Plant Science, 81: 325-337.

Dancer, W.S., Handley, J.F., Bradshaw, A.D. 1977. Nitrogen accumulation in Kaolin mining wastes in Cornwall. I. Natural communities. Plant and Soil, 48:153-167.

Dixon, R.O.D., Wheeler, C.T. 1983. Biochemical, physiological and environmental aspects of symbiotic nitrogen fixation. In: Gordon, J.C., Wheeler, C.T., Eds. Biological Nitrogen Fixation in Forest Ecosystems: Foundations and Applications. The Hague: Martinus Nijhoff/Dr W. Junk Publishers, 107-171.

Druce, A.P. 1957. Botanical survey of an experimental catchment, Taita, New Zealand. Department of Scientific and Industrial Research Bulletin, 124: 1-81.

Dyck, W.J., Gosz, J.R., Hodgkiss, P.D. 1983. Nitrate losses from disturbed ecosystems in New Zealand - A comparative analysis. New Zealand Journal of Forestry Science, 13(1): 14-24.

Egunjobi, K.J. 1967. A comparison of primary productivity and chemical element cycling in gorse (*Ulex europaeus*) and pasture ecosystems. Ph.D. thesis, Botany Department, Victoria University of Wellington.

Egunjobi, J.K. 1969. Dry matter and nitrogen accumulation in secondary successions involving gorse (*Ulex Europaeus* L.) and associated shrubs and trees. New Zealand Journal of Science, 12: 175-193.

Egunjobi, J.K. 1971a. Ecosystem processes in a stand of *Ulex Europaeus* L. I. Dry matter production, litter fall and efficiency of solar energy utilization. Journal of Ecology, 59: 31-38.

Egunjobi, J.K. 1971b. Ecosystem processes in a stand of *Ulex Europaeus* L. II. The cycling of chemical elements in the ecosystem. Journal of Ecology, 59: 669-678.

Gaynor, D.L., MacCarter, L.E. 1981. Biology, ecology, and control of gorse (*Ulex Europaeus* L.): a bibliography. New Zealand Journal of Agricultural Research, 24: 123-137.

Grubb, P.J., Suter, M.B. 1970. The mechanism of acidification of soil by Calluna and Ulex and the significance for conservation. In E. Duffy, A.S. Watt. Eds. The scientific management of animal and plant communities for conservation. The 11th Symposium of the British Ecological Society. Blackwell Scientific Publications, Oxford.

Hackwell, K. 1980. Gorse: a helpful nurse plant for regenerative native forests. Forest and Bird, 13(5): 25-28.

Healy, A.J. 1961. The interaction of native and adventive plant species in New Zealand. Proceedings of the New Zealand Ecological Society, 8: 39-43.

Hermann, R.K., Newton, M. 1968. Tree planting for control of gorse on the Oregon coast. School of Forestry, Research Paper 9, Oregon State University, Corvallis, OR. 12 p.

Hill, R.L. 1987. The biological control of gorse (*Ulex europaeus* L.) in New Zealand: an environmental impact assessment. Entomology Division, Department of Scientific and Industrial Res., Christchurch, New Zealand, 130 p.

Hill, R.L., Gourlay, A.H., Barker, R.J. 2001. Survival of *Ulex europaeus* seeds in the soil at three sites in New Zealand. New Zealand Journal of Botany, 39: 235-244.

Hoshovsky, M. 1986. Element Stewardship Abstract for *Ulex europaeus*. The Nature Conservancy, California Field Office, 785 Market Street, 3rd Floor, San Francisco, CA. 25 p. (http://tncweeds.ucdavis.edu/esadocs/ulexeuro.html).

Ivens, G.W. 1978. The influence of temperature on germination of gorse. Weed Research, 23: 207-216.

Knight, P.J. 1969. Influence of gorse on establishment of *Pinus radiata* seedlings. New Zealand Forest Service, Forest Research Institute Report 1968: 27-28.

Krause, M.A., Beck, A.C., Dent, J.B. 1988. Control of gorse in hill country: an economic assessment of chemical and biological methods. Agricultural Systems, 26: 35-49.

Lambert, M.G., Jung, G.A., Costall, D.A. 1989. Forage shrubs in North Island (New Zealand) hill country: 1. Forage Production. New Zealand Journal of Agricultural Research, 32: 477-483.

Leary, J.K., Hue, N.V., Singleton, P.W., Borthakur, D. 2005. The major features of an infestation by the invasive weed legume gorse (*Ulex europaeus*) on volcanic soils in Hawaii. Biology and Fertility of Soils,

Lee, W.G., Allen, R.B., Johnson, P.N. 1986. Succession and dynamics of gorse (*Ulex europaeus* L.) communities in the Dunedin Ecological District, South Island, New Zealand. New Zealand Journal of Botany, 24: 279-292.

MacCarter, L.E., Gaynor, D.L. 1980. Gorse: a subject for biological control in New Zealand. New Zealand Journal of Experimental Agriculture, 8: 321-330.

MacConnell, J.T., Bond, G. 1957. A comparison of the effect of combined nitrogen on nodulation in non-legumes and legumes. Plant and Soil, 8: 378-388.

Magesan, G.N. 2004. Land application of municipal wastewater and its influence on soil physical properties and nitrate leaching. Juhasz, Magesan & Naidu (eds.). *Waste Management*. Science Publishers, USA.

Magesan, G.N., McLay, C.D.A., Lal, V.V. 1998. Nitrate leaching from a free-draining volcanic soil irrigated with municipal sewage effluent in New Zealand. Agriculture, Ecosystems and Environment, 70: 181-187.

Magesan, G.N., White, R.E., Scotter, D.R. 1996. Nitrate leaching from a drained, sheep-grazed pasture. 1. Experimental results and environmental implications. Australian Journal of Soil Research, 34: 55-67.

Matthews, L.J. 1982. Pasture weeds of New Zealand. Pp. 387-393 in: Holzner, W., Numata, N., Eds. *Biology and Ecology of Weeds*. Junk Publishers, The Hague, The Netherlands,.

McCracken, I.J. 1993. Natural succession as a management strategy for gorse and broom covered land. Minimum interference management. Report prepared for the Canterbury Regional Council with the co-operation of New Zealand Forest Research Institute Ltd. 21 p.

McLaren, R.G., Cameron, K.C. 1990. Soil Science. Oxford University Press, Auckland.

Meeklah, A. 1979. Controlling gorse in Otago and Southland. New Zealand Journal of Experimental Agriculture, 139: 51-53.

Miller, D. 1970. Gorse (*Ulex europaeus* L.). Pp. 27-58 in: Miller, D. Biological Control of Weeds in New Zealand, 1927-48. New Zealand Department of Scientific and Industrial Research information series no. 74.

Moss, G.R. 1960. Gorse, a weed problem of thousands of acres of farm land. New Zealand Journal of Agriculture, 100: 561-567.

O'Toole, P., Dowds, J., Farrell, E.P. 1984. Nitrogen accumulation by *Ulex gallii* (Planch.) in a forest ecosystem. Irish Forestry, 41: 14-29.

O'Toole, P., Cahalane, D.G., Farrell, E.P. 1991. Effects of phosphate fertilizer on biomass production and $N_2(C_2H_2)$ fixation by pot-grown *Ulex gallii* Planchon in a forest soil. Biology and Fertility of Soils, 12: 177-181.

Parker, B.W. 1984. Gorse to grass. New Zealand Journal of Agriculture 108: 314-318.

Partridge, T.R. 1989. Soil seed banks of secondary vegetation on the Port Hill and Banks Peninsula, Canterbury, New Zealand, and their role in succession. New Zealand Journal of Botany, 27: 421-436.

Pate, J.S. 1961. Perennial nodules on native legumes in the British Isles. Nature, 192: 376-377.

Radcliffe, J.E. 1986. Gorse - A resource for goats? NZ Journal of Experimental Agriculture, 14: 399-410.

Reid, T.C. 1973. Nitrogen fixation by *Ulex europaeus* (gorse) and *Cytisus scoparius* (broom). PhD Thesis, University of Canterbury, pp. 139.

Richardson, B., Hill, R.L. 1998. The biology of Australian weeds. 34. *Ulex europaeus* L. Plant Protection Quarterly, 13: 46-58.

Richardson, B., Vanner, A., Ray, J., Davenhill, N., Coker, G. 1996. Mechanisms of *Pinus radiata* growth suppression by some common forest weed species. New Zealand Journal of Forestry Science, 26: 421-437.

Sandrey, R. 1985. Biological control of gorse: an ex-ante evaluation. Agricultural Economics Research Report No. 172. Lincoln College, Canterbury, New Zealand, pp 96.

Skeffington, R.A., Bradshaw, A.D. 1980. Nitrogen fixation by plants grown on reclaimed china clay wastes. Journal of Applied Ecology, 17: 469-477.

Thornton, B., Millard, P., Tyler, M.R. 1995. Effects of nitrogen supply on the seasonal re-mobilization of nitrogen in *Ulex europaeus*. New Phytologist. 130: 557-563.

Yamoah, C.F., Agboola, A.A., Wilson, G.F. 1986. Nutrient contribution and maize performance in alley cropping systems. Agroforestry Systems, 4: 247–254.

Zabkiewicz, J.A., Gaskin, R.E. 1978. Effect of fire on gorse seeds. Proceedings of the 31st New Zealand Weed and Pest Control Conference, 47-52.

Zielke, K., Boateng, J., Caldicott, N., Williams, H. 1992. Broom and Gorse: a Forestry Perspective Problem Analysis. British Columbia Ministry of Forests, Queen's Printer, Victoria, BC. 20 p.