Department of Agriculture, Food and the Marine
An Roinn Talmhaíochta, Bia agus Mara

CoFoRD

Final Report

'Green Novel Approach for Weevil Control (GNAW-Control)'

DAFM Project Reference No: 10/RD/GNAW/UCD/722

Start date: 01/12/2011

End Date: 31/05/2015

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Please place *one* "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental → Applied/Pre Commercial

			X			

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area(s)	**Priority Area I - Sustainable Food Production and Processing (including Forestry)** **Priority Area L - Manufacturing Competitiveness (Green sustainable technologies)**

Key words: *biogeochemistry, forest health and protection, integrated pest management, waste recycling*

1. Rationale for Undertaking the Research

This section should outline the rationale for carrying out the research and identify the need / problem to be addressed

The Large pine weevil (*Hylobius abietis*) is the most serious insect pest of plantation forests in north-western Europe. In Ireland, *H. abietis* is the only forestry pest that requires routine chemical insecticide applications to prevent total loss of newly planted coniferous stands. However, imminent restrictions on the use of chemical pesticides in EU forestry mean that alternative pest management options are urgently required. Various other control methods have been investigated, including the use of entomopathogenic nematodes, physical barriers, leaving restocking sites fallow for a number of years, collars, and external stem coatings including wax and glued sand grains to protect seedlings physically. Each of these methods has had varying degrees of success, but to-date no effective, affordable plant protection product has been developed that can be used on all sites and on bare-root stock, the preferred plant choice for Irish conditions. The rationale was to investigate an entirely novel, reliable, 'green' pest control approach that would be environmentally safe and highly cost effective and also easy to integrate into sustainable forestry management and planting operations. The approach uses a radically different, potential alternative to deterring feeding by *H. abietis* on seedlings based on the use of silicon (Si). Elevated Si plant tissue concentrations have been shown to be effective at deterring feeding by both vertebrate and invertebrate herbivores, most markedly in grasses. However, knowledge of the potential effect of Si in coniferous species is scarce, and it was not known if conifers (if provided with additional Si sources) accumulate sufficient amounts of Si in bark to deter weevil feeding. These knowledge gaps were addressed by the project.

2. Research Approach

Specify the research methodologies employed, emphasising novel techniques and also outline any modifications from the original approved project proposal

The research approach combined methods from soil science, geosciences, entomology and forestry research, under laboratory and field conditions. The research had to address four main knowledge gaps, namely 1) the status of soils and tree seedlings in Ireland in terms of Si availability and uptake; 2) the dynamics of Si release from a range of potential Si-rich materials that might be useful as Si amendments; 3) the uptake of additional Si by seedlings and the effects on weevil bark feeding under controlled conditions; 4) the effects of Si amendments provided to seedlings on the mortality and growth as well as weevil bark feeding damage on these seedlings when planted out in the field.

The first research task was a survey of Si in Irish plantation forests. Samples were taken from 10 replanted forest sites and 2 nurseries. Analytical methods were adopted and

optimised for routine measurement of the plant available Si in forest soils as well as total Si concentrations in seedling bark. Soil properties (that may explain Si levels) were also measured including soil organic matter and pH.

The second research task investigated the dynamics of Si release into soil solution and leachate, from 12 Si-rich sources that could potentially be used as Si amendments. This long-list of materials included peat ash, coal ash, wheat straw ash, rice husks, rice husk ash, ground granulated blastfurnace slag, diatomaceous earth, quartzite and K-feldspar, along with an unamended control and three "positive" controls (two levels of Sodium metasilicate, and a commercial Si booster product). Materials were mixed in forest soil and incubated outdoors, over 15 months, and measurements were taken fortnightly in the early phase or monthly in the later phase of the experiment. Soil temperature and moisture were monitored as they were likely useful explanatory environmental variables for the Si dynamics.

The third task assessed pine weevil feeding, under controlled conditions, on spruce seedlings grown for several months with and without a selection of Si rich amendments. Indoor experiments measured weevil feeding damage on whole, potted plants inside large mesh cages, under a scenario of food choice (seedlings from different treatments placed inside the same cage) or no-choice (weevils caged onto specific seedlings). Si concentrations in seedlings grown with different amendments were measured.

In the fourth tasks, about 1050 spruce seedlings were grown outdoors in pots for 11 months with a "short-list" of the most promising Si amendments (slag, coal ash, rice husk ash, peat ash, Sodium metasilicate, commercial Si product, unamended Control), and then planted out bare-root at two commercial forest sites. Seedlings were monitored on four occasions, over two years, in terms of mortality, growth, stem girdling and bark feeding damage. Si concentrations in seedlings grown with selected amendments were measured.

To address environmental proofing, ecotoxicological laboratory assays were conducted to assess the effects of varying levels of added Si (as Sodium metasilicate) on non-target species (earthworms).

There were no major modifications from the original approved project.

3. Research Achievements/Results

Outline main results achieved

The baseline survey of Si concentrations in soil and bark of Sitka spruce seedlings provides data for the first time on the Si status of spruce seedlings in Ireland. Data suggest that mineral soils are well supplied with Si and that Si concentrations in the bark of Spruce seedlings was relatively high compared to published data from other conifer species. However, the Si concentrations in bark of Sitka spruce seedlings was lowest on acidic, organic rich peat soils.

A major achievement of the project is the list generated, for the first time, of organic and inorganic materials (mostly "waste products" or residues) that were shown to release substantial quantities of plant-available Si into soil solution when incorporated into soil. Some of these amendments (rice husks, rice husk ash) were shown to be excellent, slow-release sources of plant available Si, releasing it in very high concentrations for more than 1 year. The Si uptake experiment provided data for the first time on the uptake of additional Si by spruce seedlings and deposition into bark. The data showed that, compared to the unamended control, none of the tested amendments resulted in spruce seedlings with consistently enriched Si bark concentrations, with the exception of the DYNA-GRO ProTekt® commercial product.

Overall, Si treatments did not have systematic, statistically significant effects on the feeding (reduction or increase) by weevils on spruce seedlings under controlled conditions. (There was a trend of larger occurrence of shallow bark feeding in the no-choice setting with some amendments.) Similarly, at the commercial forestry scale, none of the measures of tree growth or mortality, nor weevil feeding damage were systematically different between Si treatments or the unamended control. The field-site and between-year effects were larger than any treatment effects. Absolute feeding damage (area debarked) was positively correlated with seedling diameter. The Si treatments did not result in long-term higher bark Si concentrations, mirroring the earlier controlled experiment suggesting that spruce is not a Si accumulator. However, natural Si concentrations in the seedlings were already high, from their mineral nursery soil.

No ecotoxicological or detrimental effects were observed in laboratory assays for liquid Si amendments on non-target species (earthworms), even when applied at unrealistically high concentrations. A literature review suggested that the solid amendments investigated here – when applied at the concentrations envisaged for Si fertilisation rather than bulk waste disposal – would have no direct detrimental effects on other soil biota.

4. **Impact of the Research**

A summary of the impact of the research should be provided through the project outputs and outcomes however please provide a synopsis of the benefits / improvements the research has made to the area under investigation. Outline the benefits of the research to end users, e.g. industry, consumers, regulatory authorities, and scientific community etc

This basic information on Si levels in Irish forests gained from the field survey fills a knowledge gap. The information can be of use for end users such as nursery producers and foresters who consider applying commercially available Si booster products (such as DYNA-GRO ProTekt®) to their crops.

The research on the Si release dynamic from Si rich materials fills a major knowledge gap that can be of use to all various users (including farmers, horticulturists, recycling businesses) who consider applying Si-rich materials (or commercially available Si booster products) to their crops. This is not restricted to tree nursery producers and foresters,

but applicable very widely to all practitioners in the plant industry. Other end users are recycling businesses who could develop novel products from wastes or harvest residues that provide Si fortification to a wide range of crops.

Overall, it is concluded that providing additional plant-available Si through amendments did not confer protection of Sitka spruce seedlings against pine weevil feeding, under the conditions and with the soil used. Based on these detailed studies, it is concluded that providing Sitka spruce seedlings with Si-rich amendments in the manner and form it was done here did not significantly deter feeding by pine weevils. The first part of the "green" approach was successful (i.e. waste materials were shown to be a good Si source), but the second part of the original research question (i.e. Do seedlings take up additional Si and thus gain resistance against weevil feeding?) was not confirmed. Enriching seedlings with Si does not seem to be a useful protection strategy against the pine weevil.

Based on the ecotoxicological assessment results, users of existing liquid Si fertilisers (such as DYNA-GRO ProTekt®) can be reassured that these products are unlikely to have toxic effects on non-target soil organisms such as earthworms.

4(a) Summary of Research Outcomes

(i) Collaborative and Industry links developed during this research

- Research links with the Institute of Bioengineering and Agroecology, NUI Maynooth (Prof. Christine Griffin) who is specialised in biocontrol of Pine weevils by EPN nematodes and other natural enemies.
- Advisory input and seedling donation from Coillte Nursery, Ballintemple, Co. Carlow.
- Attended two conferences of INTERREG Project IMPACT: Open Science Meeting (24/01/2012) and Final project Conference "Protecting Current and Future Forests: Coping with Pests, Pathogens and Climate Change", Dublin (07/05/2013).
- Attended FAO and European Forest Institute workshop "Planted Forests Providing Ecosystem services and Landscape Restoration", Dublin Castle (16-18/05/2013).

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

A major outcome of the project is the shortlist of organic and inorganic materials (mostly "waste products" or residues) that have been shown to release substantial quantities of plant-available Si into soil solution when incorporated into soil. These materials are potentially ideal as slow release fertilizers for crop production. This research fills a major scientific knowledge gap that is of wide interest to various end users (including farmers, horticulturists, recycling businesses) who consider applying Si-rich materials to their crops.

Complementing and extending the present research, a successful proof-of-concept study (conducted by undergraduate students at no cost to this project)

demonstrated the controlled Si enrichment of wheat seedlings and subsequent reduction of foliar feeding by pest molluscs (published as Griffin et al., 2015, see under 4b above). This opens up a completely new avenue of research into crop protection against slugs and snails, especially cereal crops and other grasses that are known to be Si accumulators.

(iii) Outcomes with economic potential

The information on Si-rich products is applicable widely to practitioners in the plant industry. The Si-rich materials identified by the research are likely to offer much more economical Si sources than commercially available Si booster products. Potential end users in the economy are recycling businesses who could develop novel products from wastes or harvest residues (including rice husks, the largest crop residue globally) that provide Si fertilisation to a wide range of crops.

The lack of evidence for positive effects on spruce seedlings of the commercially available product DYNA-GRO ProTekt® (and similar products) could be of interest to end users who use this product or who consider using it in the future. The company does not specify the target plant groups for this product, but their focus appears to be on ornamentals (see http://dyna-gro.com/wp-content/uploads/2016/07/Pro-TeKt-Sheet.pdf).

(iv) Outcomes with national/ policy/social/environmental potential

None of the solid, liquid or commercial Si amendments tested in the project produced any systematic, significant effects for field-planted Spruce seedlings in terms of growth, survival or bark feeding by weevils. Overall, these (negative) findings are of current scientific interest, but they do not offer a new strategy to end users, including foresters, nursery operators and forest protection specialists searching for new protection strategies of spruce seedlings against pine weevil attack.

A surprising result was the low release of plant available Si from peat ash, coal ash and slag into soil solution and leachate. These materials are already on occasion being used as a soil amendment, but their low Si release cannot be used as an argument of a benefit when weighing up their environmental impacts in plant-soil ecosystems including potential toxic effects (e.g. through heavy metals).

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.

Griffin, M., Hogan, B., Schmidt, O. (2015). Silicon reduces slug feeding on wheat seedlings. Journal of Pest Science 88, 17-24.

Hogan, B., McDermott, F., Schmidt, O. (under review). Silicon concentrations in soils and bark in Irish spruce forests. Journal of Plant Nutrition and Soil Science [submitted 29/07/2016, revised version submitted 31/10/2017]

Hogan, B., McDermott, F., Schmidt, O. (under review). Effects of silicon-rich soil amendments on growth, mortality and bark feeding damage of Sitka spruce (Picea sitchensis) seedlings under field conditions. Scandinavian Journal of Forest Research [submitted 04/09/2017]

Hogan, B., McDermott, F., Schmidt, O. (in preparation). Release of plant-available silicon from various silicon-rich amendments into soil solution and leachate. Journal of Soils and Sediments

(ii) Popular non-scientific publications and abstracts including those presented at conferences

Hogan, B., McDermott, F., Schmidt, O. (2014) Weathering of silicon rich amendments and concentration of silicic acid in soil solution. ENVIRON2014 24th Irish Environmental Researchers' Colloquium,26-28/02/2014, Trinity College, Dublin [poster presentation]

Schmidt, O., Griffin, M., Hogan, B. (2013) Silicon reduces slug (Gastropoda) feeding on wheat seedlings. In: Slugs and Snails as Invasive Species. IOBC/WPRS Slugs and Snails Subgroup meeting, Bergen, Norway, 25-27/09/2013. Book of Abstracts p. 16 [Oral presentation]

(iii) National Report
n/a

(iv) Workshops/seminars at which results were presented
n/a

(v) Intellectual Property applications/licences/patents
n/a

(vi) Other
n/a

5. Scientists trained by Project

Total Number of PhD theses: __1*__

*Please note the PhD student was not funded by DAFM.

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

Hogan, B.: *Silicon in Irish Forestry*. PhD Thesis, University College Dublin. Date of original submission was 04/09/2015. [Outcome of viva voce examination was Revise and Resubmit. Anticipated date of submission of revised thesis is 31/12/2017.]

Total Number of Masters theses: __0__

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
University College Dublin	2	0.4
Total		

7. Researchers Funded by DAFM*

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	0	
PhD students	1	2.75
Masters students	0	
Temporary researchers	0	
Other	0	
Total	**0**	

*Please note the PhD student was not funded by DAFM.

8. Involvement in Agri Food Graduate Development Programme*

Name of Postgraduate / contract researcher	Names and Dates of modules attended
n/a	n/a
* Please note the student was obliged under the scholarship rules to complete 30 ECTS of course work provided by the Innovation Academy.	

9. Project Expenditure

Total expenditure of the project*: €119,803.65

Total Award by DAFM: €18,633.65

Other sources of funding including benefit in kind and/or cash contribution (specify): 1,500 seedlings (Coillte) €450

*Core funding for this research project (€101,170) was provided by a 4-year UCD Innovation Bursary.

Breakdown of Total Expenditure

Category	University College Dublin	Name Institution 2	Name Institution 3	Name Institution 4	Total
Contract staff	0				0
Temporary staff	0				0
Post doctorates	0				0
Post graduates	0				0
Consumables	€7,887.98				€7,887.98
Travel and subsistence	€5,956.67				€5,956.67
Sub total					
Durable equipment	0				0
Other (ext. assist.)	€635.60				€635.60
Overheads	4,153.40				4,153.40
Total	**18,633.65**				**18,633.65**

10. Leveraging

Summarise any additional resources'/funding leveraged by this award from other sources i.e. Additional Staff, National/EU funding secured, EI Commercialisation Fund

In January 2014 O. Schmidt became a Management Committee Member (MC) for Ireland in the COST Action FP1305: "Linking belowground biodiversity and ecosystem function in European forests".

11. Future Strategies

Outline development plans for the results of the research.

The proof-of-concept study published by Griffin et al. (2015, see 4b above), along with the list of suitable Si-rich amendments, opens up novel prospects for the application of Si releasing amendments in cereal crops and other grasses. Funding has already been sought for this completely new avenue of research into crop protection against slugs and snails. We now have the expertise and published track record in the area of Si analysis and Si-rich amendments for crops, which makes us competitive when seeking to leverage funding.

12. Consent to Publish Final Report on the DAFM Website and/or Through Other Dissemination channels

I consent to this report being made available to the public, through the Department's website and other dissemination channels. *

Yes X No ☐

13. Declaration

I declare that the information contained in this final report is complete and true to the best of my knowledge and belief.

Signed: _____  _____Project Coordinator

Date: _____3rd November 2017_____

*IPR sensitive information that the coordinator does not wish to make public should be highlighted in red font. All text in red font in this report will <u>not</u> be made publicly available by DAFM.