Institution: Aberystwyth University

Unit of Assessment: 6: Agriculture, Veterinary and Food Science

Title of case study: The breeding of highly persistent forage clover varieties has a positive impact on the sustainability of livestock farming.

Period when the underpinning research was undertaken: 2002- 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Leif Skøt	Principal Investigator; Reader; Head of Forage Plant Breeding	3 August 1987- 31 December 2020
Dr David Lloyd	Legume Breeder	1 October 2012- present
Professor Michael Abberton	Programme Leader; Professor	8 February 1993- 17 August 2012
Professor Athole Marshall	Principal Research Scientist; Principal Investigator; Leader Public Good Breeding; Chair	1 April 1994- 31 December 2017
Dr Rosemary Collins	Senior Research Scientist; Principal Investigator; Senior Lecturer	1 April 1996- 30 September 2019

Period when the claimed impact occurred: August 2013- July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Aberystwyth University (AU) research and breeding programmes have generated highly persistent clover varieties. Increasing the use of these varieties in grassland agriculture provides economic and environmental benefits. The rhizomatous trait (i.e. spreading via underground shoots) from Caucasian clover was introduced into white clover through interspecific hybridisation to improve persistence under grazing and drought. The first such commercial white clover variety is AberLasting with 40t of seed being produced in 2017, and the demand is rapidly increasing. Persistent red clover varieties have been developed, notably AberClaret, which produces high yields in the third and fourth harvest years. It accounts for 15% of red clover seed sales in the UK.

2. Underpinning research (indicative maximum 500 words)

Research and breeding of forage crops at Institute of Biological, Environmental & Rural Sciences (IBERS), AU is based on clear objectives and innovative routes to generate commercially successful forage crop varieties, supported by BBSRC, the Welsh Government and Innovate UK, and funded significantly by our strategic partner Germinal Holdings Ltd. (the largest UK owned forage seed wholesale company) [3.8- 3.11]. White and red clover are two of the most important forage legumes for temperate sustainable livestock production systems. They can fix, on average, 150kg N/ha/yr, reducing the need for industrial nitrogen fertilizer. They produce high yields of good quality forage with a crude protein (CP) content of 18-19% and improve soil structure and fertility. However, greater use in the UK has been limited by its lack of persistence in swards. Increasing persistency therefore, particularly in mixtures with grasses is

an important breeding target. AberLasting [3.1] and AberClaret [3.2] are white and red clover varieties, respectively, which have been developed at IBERS with this goal in mind.

AberLasting

Research at IBERS underpinned the breeding of novel white clover varieties derived from introgression of the rhizomatous trait from Caucasian clover (*T.ambiguum* M. Bieb) as a route to improving drought tolerance of white clover and persistence under grazing [3.3]. A programme of hybridisation and backcrossing to the white clover parent produced hybrids that are white clover-like in appearance, but which incorporate the rhizomatous growth habit. This research was carried out by Abberton, Marshall and Collins, and has delivered selection tools facilitating development of novel germplasm and its successful inclusion into the IBERS white clover breeding programme [3.4]. The first variety from the programme, AberLasting, was added to the UK National List in 2016, and is now in trials and commercial production.

Field experiments demonstrated that improved resilience to drought and frost compared to white clover was attained without compromising dry matter yield and forage quality, partly due to a greater root biomass at depth [3.5]. This genetic material is now included in the IBERS white clover breeding programme enabling the rhizomatous trait to be introduced into a range of recipient types to further improve grazing tolerance [3.6].

AberClaret

Under typical UK silage management, red clover tends to persist for 2-3 harvest years, after which yields decline. Therefore, increased persistence is a major breeding target to achieve high biomass yield beyond the third year. IBERS research had already established that morphological trait variation for crown diameter and growth habit influenced mortality rates of red clover, and subsequently IBERS initiated a breeding programme to improve persistency utilising recurrent selection starting with short-lived elite germplasm.

Persistent populations with high biomass yield continuing in the third and fourth harvest year led to the development of the AberClaret variety. AberClaret gave the highest dry matter yield in mixed swards in Year 4 (61%) in an experiment comparing 12 red clover varieties [3.7]. This resulted in greater CP yields on an area basis, highlighting the importance of red clover persistence to the feeding value of grass/red clover swards.

3. References to the research (indicative maximum of six references)

3.1 Lloyd, D.C., **Marshall, A.H.**, Lowe, M., Sizer Coverdale, E., **Abberton, M. T.**, Michaelson-Yates, T.P.T. and Meredith, M. (2016) AberLasting - *Trifolium repens* (white clover)/*Trifolium ambiguum* (caucasian clover) hybrid.

3.2 Michaelson-Yeates, T.P.T., **Collins, R.P., Marshall, A.H.** and **Abberton, M.T.** (2010) Aa4495 AberClaret, Red clover variety.

3.3 Abberton, M.T and **Marshall, A.H**. (2005) Progress in breeding perennial clovers for temperate agriculture. *J. Agric. Sci.* 143: 117-135. DOI: 10.1017/S0021859605005101

3.4 Abberton, M.T., Michaelson-Yeates, T.P.T, Bowen, C., Marshall, W. and Carlile, E. (2003). Bulked segregant AFLP analysis to identify markers for the introduction of the rhizomatous habit from *Trifolium ambiguum* into *T. repens* (white clover). *Euphytica* 134, 217-222. DOI: 10.1023/B:EUPH.0000003912.58022.e4

3.5 Marshall, A.H., Williams, A., **Abberton, M.T.,** Michaelson-Yeates, T.P.T and Powell, H.G. (2002). Dry matter production of white clover (*Trifolium repens* L.), Caucasian clover (*T. ambiguum* M. Bieb.) and their associated hybrids when grown with a grass companion over 3 harvest years. *Grass and Forage Science* 58, 63-69. DOI: 10.1046/j.1365-2494.2003.00354.x

3.6 Lloyd, D.C., Vale, J.E., Sizer-Coverdale, E.M. and **Marshall, A.H.** (2017). Interspecific hybridisation of white clover and Caucasian clover confers grazing tolerance. *Grassland Science in Europe* 22, 351-353 URL: hdl.handle.net/2160/45211

3.7 Marshall, A.H., Collins, R.P., Vale, and Lowe M. (2017). Improved persistence of red clover (*Trifolium pratense* L.) increases the protein supplied by red clover/grass swards grown over four harvest years. *European Journal of Agronomy* 89, 38-45. URL: www.cabdirect.org/cabdirect/FullTextPDF/2012/20123234019.pdf

Research grants

3.8 Marshall, A., Skøt, L. et al.; Breeding of improved forage varieties to increase protein supply and protein utilisation by ruminants; TSB-BBSRC project TS/J002895/1 (with Germinal Holdings and NIAB TAG); 2012-2017; GBP991,360

3.9 Marley, C., **Collins, R.,** Doonan, J., Hegarty, M., Humphreys, M., **Marshall, A**., Scollan, N., Yadav, R.; Roots for the Future - A systematic approach to root design [SUREROOT]; BBSRC LINK project BB/L009889/1 (with Germinal Holdings LTD, Waitrose Supply Chain, Stonegate, Rothamsted Research, Muller, Mole Valley Farmers, HCC, Gressingham Foods, Dovecote Parks, Dalehead Foods, Coombe Farms, BQP, BGS, AHDB; bbsrc.ukri.org/research/grants-search/AwardDetails/?FundingReference=BB%2FL009889%2F1; 2014-2019; GBP896,229

3.10 Marshall, A., Collins, R.P., **Lloyd, D.;** Application of innovative plant breeding and phenotyping technologies to reduce the nutrient requirement of forages and improve livestock production efficiency – APPLE; IUK-BBSRC (with Germinal Holdings) gtr.ukri.org/projects?ref=102532; 2016-2019; GBP264,816

3.11 Skøt, L., Marshall, A.; Improved resistance of red clover to soil borne pathogens for sustainable livestock production; WEFO SMARTExpertise 2017/COL/008 with Germinal Holdings Ltd and Hybu Cig Cymru; 2018-2021; GBP500,000.

4. Details of the impact (indicative maximum 750 words)

Economic and commercial impact

Seed of the IBERS bred clover varieties is marketed through a strategic alliance between IBERS and Germinal Holdings Ltd. 40t of seed of 'AberLasting' was produced in New Zealand in 2017, with a further 40t produced in 2019. Demand is increasing as the variety is very popular in New Zealand [5.1.1- 4], and seed is returned to the UK for inclusion in Germinal mixtures [5.1.5], such as AberSheep [5.1.6]. Germinal seed sales in tons are shown in Figure 1. [5.2.1] Trials are taking place in Japan, France and other countries. It is anticipated that in the future, seed of this and other varieties developed from this germplasm will be sold in many European countries.

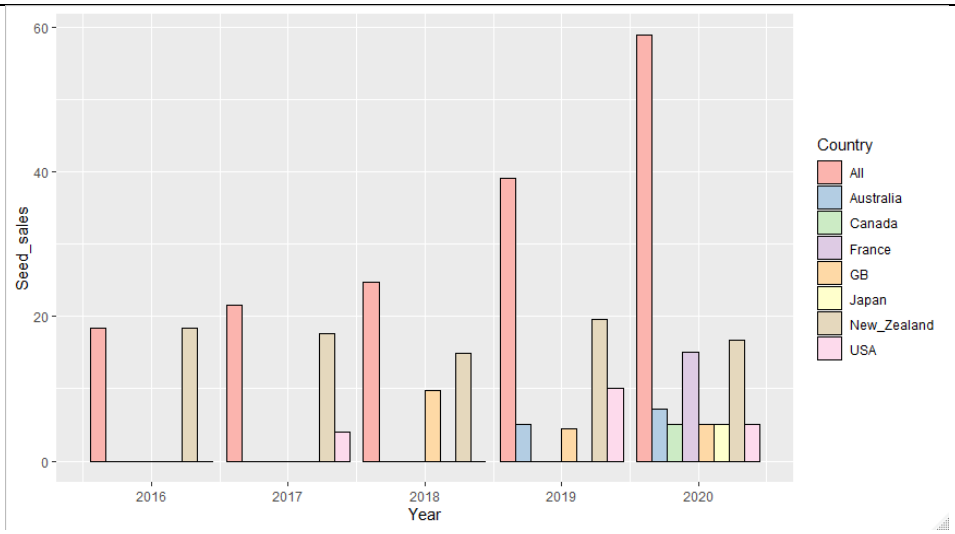

Figure 1: Annual Germinal seed sales by country [tons]

Germinal annual seed sales of AberClaret was 34.4t in the UK (approximately 15% of the UK market in 2017), 20t in Switzerland and further expansion into other overseas markets including New Zealand, Australia and Canada. The England and Wales Recommended List shows that among diploid varieties, AberClaret had the second highest yield in the second and third harvest years, with a score of 106% and 111%, respectively [5.2.2]. Its high biomass yield, even in the fourth year, translates to approximately 2t CP/ha/yr, increases the nutritional quality of the silage, and persistence for the duration of many medium-term leys [5.3]. At the farm level this equals a saving of GBP700 on imported soybean meal. Assuming a price of GBP350 per t, worth up to GBP7,000,000 for 10,000ha. Growth rates of 1.3kg/head/day (growing ration) and 1.5 kg/head/day (finishing) in beef cattle are being achieved, with no oil seed rape meal or soya required when red clover silage is available [5.4].

Societal and environmental benefit

White clover fixes approximately 150kg N/ha/yr some of which is utilised by the companion grass, providing an economic and environmental benefit to the farmer and society by reducing the need to apply mineral nitrogen fertiliser. White clover breeding programmes have focused on ensuring that the proportion of white clover in a sward is sufficiently persistent to be maintained at an optimal 30% in mixtures with grass. Such mixtures require 300 to 400kg N/ha/yr less N fertiliser compared to grass monocultures to achieve the same yield. This reduction in fertiliser application reduces CO_2 emissions by approximately 1t/ha/yr [5.5], and provide a saving of GBP70 per ha for the farmer, assuming a cost of approximately GBP200 per t N. Furthermore, application of nitrogenous fertilisers accounts for the majority of N_2O emissions. For every 100kg of fertiliser N added to the soil, on average 1kg of N is emitted as N_2O, which is equivalent to approximately 600kg of CO_2 [5.6].

Red clover contains high levels of the enzyme polyphenol oxidase which has beneficial effects on nitrogen utilisation in ruminants. It is also an excellent break crop allowing soil fertility to build up, and reducing weed problems, particularly blackgrass in cereal crops.

In addition to N-fixation, soil fertility and structure, clovers reduce the need for reseeding as they remain productive for 5 or 6 years, even under heavy abiotic stress. They continue to grow during drought periods in contrast to grass and provide more tangible benefits to the environment in terms of food and habitat for insect pollinators, thus maintaining the biodiversity in grasslands. [5.4]

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 Germinal webpage content

5.1.1. Germinal New Zealand AberLasting – "The first super clover is here" germinal.co.nz/wp-content/uploads/2019/04/AberLasting.pdf
5.1.2. Germinal New Zealand AberLasting product description germinal.co.nz/product/aberlasting-caucasian-x-white/
5.1.3. Germinal New Zealand Facebook posts: www.facebook.com/pg/GerminalNZ/posts/
5.1.4. Statements by New Zealand farmers using AberLasting:
a. germinal.co.nz/knowledge-hub/aberlasting-case-study-hamish-mackenzie/
b. germinal.co.nz/knowledge-hub/aberlasting-case-study-gavin-nichol/
c. germinal.co.nz/knowledge-hub/aberlasting-case-study-helen-andrews/
5.1.5. Statements by UK farmers in Germinal Forage Seed 2019 brochure: germinal.co.uk/wp-content/uploads/2019/04/GERMINAL_FORAGE-SEED_BROCHURE_2019_DIGITAL.pdf
5.1.6. AberSheep seed mixture: germinal.co.uk/product/abersheep/

5.2.1 Annual Germinal seed sales by country, Managing Director, Germinal GB
5.2.2 Recommended Grass and Clover Lists for England and Wales 2020-2021: ahdb.org.uk/knowledge-library/recommended-grass-and-clover-lists-2020-21

5.3 ProCam, specialist agronomy and crop production advisors (21-11-2018): www.procam.co.uk/red-clover-offers-potential-to-boost-production-from-forage/
5.4 Forager magazine (Winter 2019) "Clovers key to low carbon beef" (p.13)
5.5 Environmental impact of ammonia production: ammoniaindustry.com/ammonia-production-causes-1-percent-of-total-global-ghg-emissions/
5.6 IPCC Guidelines for National Greenhouse Gas Inventories (2006): www.ipcc-nggip.iges.or.jp/support/Primer_2006GLs.pdf