Institution: Aberystwyth and Bangor Universities - Biosciences, Environment and Agriculture Alliance (BEAA)

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

Title of case study: The breeding of high sugar grasses (HSG) has had a positive effect on UK greenhouse gas mitigation and on livestock production

1. Summary of the impact

BEAA research on high sugar grasses (HSG's) led to the breeding of HSG varieties that have had a significant impact on the contribution of grassland to livestock feeding across the UK. Their impact on the economy, commerce and the production of livestock products has been significant in the UK and increasingly in other countries. HSG varieties currently account for over 28% of the perennial ryegrass seed sales in the UK, with over 150,000 ha sown in the UK alone of these varieties since 2008, as their positive benefit on the economics of livestock production from grass and environmental benefit through reduced N pollution from livestock production is recognised.

2. Underpinning research

Research within BEAA has both directed the course of, as well as been driven by the outputs of the forage grass breeding programmes. Humphreys (Aberyswyth,1977-2008) and other researchers within BEAA hypothesised that increasing the water soluble carbohydrate (WSC) fraction of grasses would lead to improved ruminant utilisation. Since this time underpinning research on the biochemistry, metabolism, enzymology and genetics of WSC (fructan) metabolism in perennial ryegrass has been carried out by Thomas (Aberystwyth, 1972-2007), Cairns (Aberystwyth, 1986-2010), Lovatt (Aberystwyth, 1974-present) and Armstead (Aberystwyth, 1991-present) [3.1, 3.2]. Similarly an understanding of the microbial utilisation of protein and carbohydrate in the rumen (Kim: Aberystwyth, 2001-2011, Lee: Aberystwyth, 2001-2013, Moorby: Aberystwyth, 1993- present & Scollan: Aberystwyth, 1993- present) was built up and established the rationale for high WSC as a key breeding target [3.3-3.6]. The BEAA diploid ryegrass breeding program, has exploited this research to breed HSG varieties, utilising a mixture of spaced plant assessment and half-sibling plot performance as a basis for half-sibling recurrent selection over many generations. The impact of HSG on the livestock sector has been significant and in recognition of this, the HSG perennial ryegrass variety AberDart was awarded the NIAB Cup in 2003, the first forage grass to receive this award [3.7], and has remained on the UK National (NL) and Recommended Lists (RL) [3.7].

The intermediate heading date breeding programme is now entering the 14th generation of selection, while the late heading breeding programme is now in the 5th generation of selection. These diploid varieties are chromosome doubled to form the cornerstone of the tetraploid and hybrid ryegrass breeding schemes [3.1]. Varieties, diploid, tetraploid and hybrid, have been assessed in vitro and in vivo experiments to qualify and quantify the effect of high WSC on rumen microflora and digestion, milk and meat production and the effect they have upon protein utilisation, including the reduction in ruminant greenhouse gas emissions [3.3-3.6,3.8]. We also showed that higher WSC in HSG varieties provides additional energy that improves the efficiency of plant protein conversion in ruminants [3.4]. Mapping populations have also been created from HSG varieties to investigate the genetics of the trait [3.2]. Experimental observations and conclusions have been used to feed back into the breeding programmes to further improve new varieties for this trait.

HSG perennial ryegrass varieties, bred within BEAA have been shown to increase milk production by up to 6% per cow over the grazing season, increase dry matter intake by up to 2 kg per head per day and a 3% improvement in diet digestibility [3.5]. Research on beef showed that HSG varieties increased forage intake by around 25%, contributing to 18-35% higher daily live weight gain and therefore enabling slaughter weights to be reached more quickly [3.4]. In the lamb sector, HSG's have led to a 10-15% higher daily live weight gains with a 20% higher carrying capacity of

swards containing the HSG varieties [3.6].

The positive environmental effects of HSG in livestock production can be estimated. Livestock account for approximately 37% of all emissions of methane (CH_4), which has 20-25 times the global warming potential of CO_2. Studies undertaken within BEAA has demonstrated that on average a lamb fed with the HSG variety released 20% less CH_4 than a lamb fed with the control variety [3.8]. Livestock account for approximately 85% ammonia emissions, whose breakdown products include nitrous oxide (N_2O), which has ~250-310 times the global warming potential of CO_2. In three zero-grazing trials undertaken within BEAA, the amount of feed nitrogen (N) lost in the urine was reduced by up to 24% [3.3-3.5].

3. References to the research

3.1. Wilkins, P.W. and Lovatt, J.A. 2003. Progress in improving the ratio of water-soluble carbohydrate to crude protein in perennial ryegrass. Aspects of Applied Biology 70:31-35.

3.2. Turner, L. B., Cairns, A. J., Armstead, I. P., Thomas, H., Humphreys, M. W., Humphreys, M. O. (2008). Does fructan have a functional role in physiological traits? Investigation by quantative trait locus mapping. New Phytologist, 179, (3), 765-775 DOI: 10.1111/j.1469-8137.2008.02495.x

3.3. Kim, E.J., N.D. Scollan, and J.V. Nolan. 2007. Effect of water-soluble carbohydrate on rumen nitrogen kinetics of steers given perennial ryegrass silage measured by N-15-tracer methodology. Energy and Protein Metabolism and Nutrition 124:427-428.

3.4. Lee, M.R.F., L.J. Harris, J.M. Moorby, M.O. Humphreys, M.K. Theodorou, J.C. MacRae, and N.D. Scollan. 2002. Rumen metabolism and nitrogen flow to the small intestine in steers offered Lolium perenne containing different levels of water-soluble carbohydrate. Animal Science 74:587–596.

3.5. Moorby, J.M., Evans, R.T., Scollan, N.D., MacRae, J.C. and Theodorou, M.K. 2006. Increased concentration of water-soluble carbohydrate in perennial ryegrass (Lolium perenne L.). Evaluation in dairy cows in early lactation. Grass and Forage Science 61:52-59. DOI: 10.1111/j.1365-2494.2006.00507.x

3.6. Marley, C.L., Fraser, M.D., Fisher, W.J., Forbes, A.B., Ones, R., Moorby, J.M., MacRae, J.C. and Theodorou, M.K. 2007. Effects of continuous or rotational grazing of two perennial ryegrass varieties on the chemical composition of the herbage and the performance of finishing lambs. Grass and Forage Science 62:255-264. DOI: 10.1111/j.1365-2494.2007.00582.x

3.7. AberDart. High Sugar Perennial Ryegrass. England and Wales Recommended List for Grasses and Clovers 2013. This provides details of the varieties of grasses and legumes recommended for use in England and Wales. The list is drawn up after rigorous and independent testing for attributes such as yield, feed quality, disease, persistence and seasonal growth patterns. Awarded NIAB Cup in 2003.

3.8. DEFRA Report Ruminant Nutrition Regimes to Reduce Methane & Nitrogen Emissions http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14952

4. Details of the impact

Impact on the economy

The BEAA forage grass breeding programme generates economically important varieties that contribute to the improved efficiency of livestock production. The HSG varieties bred within BEAA are marketed by Germinal Holdings in the UK and overseas. In 2012, the BEAA bred HSG perennial ryegrasses accounted for 28% of UK perennial ryegrass seed sales [5.1] and there are currently 12 HSG's on the England and Wales Recommended List [5.2] within the different heading date categories of diploids and tetraploids. HSG varieties are also on the Recommended List in

Scotland [5.3], Northern Ireland [5.4] and the Republic of Ireland [5.5] and marketed in many other countries around the world. The direct value of seed sales alone are estimated at £5.5million by Germinal Holdings [5.6]. The HSG varieties also have growing markets in Europe and the Southern Hemisphere with approximately 5,000 tonnes of HSG varieties sold overseas since 2003 [5.6]. The Institute of Biological, Environmental and Rural Sciences (IBERS) was awarded the British Grassland Society Innovation Award in 2011 in recognition of the beneficial impact of HSG on livestock production. HSG also formed part of the award of the Queens Anniversary Prize for 2009 that was awarded to Aberystwyth University [5.7] for "successfully producing improved plant varieties that combine high yield with reduced greenhouse gas emissions". The award was also in recognition of combining fundamental research on plant genetics with plant breeding techniques to develop new commercially viable plant varieties that are designed to tackle some of the pressing issues faced by communities across the world, those of food, water and energy security.

Impact on commerce

BEAA has been at the forefront of the breeding of HSG perennial ryegrass varieties that are now on the National (NL) and Recommended Lists (RL) of a number of countries. The Irish NL and RL system record water-soluble carbohydrate (WSC) content and thus provides independent verification of the levels of WSC within the HSG varieties. BEAA have four HSG ryegrass varieties on the Irish RL for 2013 [5.5]. The intermediate heading variety AberMagic has a WSC of 123% of the trial average, while the highest competitor's variety, Premium scored 96%. BEAA's later heading variety AberChoice scored 128%, with the highest competitor 112%. The tetraploid late variety AberGain scored 123% with Twymax the highest competitor at 112%. For hybrid ryegrass, the variety AberEcho scored 129%, with the highest competitor, Alliance scoring 107%.

Impact on production

The impact of high sugar grasses on the livestock sector has been significant. Approximately 6000 MT of HSG [5.3] has been sown in the UK since 2005, covering an area of 175 000 ha, with some 150,000ha sown since 2008. The benefits to the dairy sector over 5 years have been estimated at up to £78.2 million [5.8]. The environmental and economic value of HSG varieties has been recognised by a number of supermarket chains (Asda and Sainsbury), who are encouraging farmers in their supply chain to include HSG varieties in their swards. Asda have suggested that the use of HSG's on farms has the equivalent impact of cutting emissions by an estimated 186,000 tonnes of CO_2 per year, while also seeing farmer profitability increased by over £10m in the first year alone [5.9].

Impact on the environment

Ruminants contribute to agricultural losses of N through their excreta generating ammonia and nitrous oxide, as well as leaching nitrate into groundwater. The improved efficiency of plant protein conversion that depends on HSG varieties provides an economic benefit to farmers through improved feed conversion and an environmental benefit through reduced N pollution [see section 2]. This environmental impact of HSG formed part of the award of the Queens's Anniversary Prize to IBERS in 2009. Independent analysis of the benefits of higher water soluble carbohydrates and hence HSG varieties on animal production have confirmed a consistent response of improved N utilisation across a number of studies. Although substantial variation in livestock production responses was noted, the effect of HSG was often positive and no negative effect was recorded. They also concluded that in trials where an elevated WSC:CP (water soluble carbohydrate: crude protein) ratio was noted, a significant positive enhancement in animal production response was recorded.

5. Sources to corroborate the impact

5.1 England and Wales Recommended List for Grasses and Clovers 2013. This provides details of the varieties of grasses and legumes recommended for use in England and Wales. The list is drawn up after rigorous and independent testing for attributes such as yield, feed quality, disease, persistence and seasonal growth patterns.

5.2 NIAB TAG Seed handbook for agronomists 2012/13. This provides comprehensive coverage of

the relative merits of the major arable and livestock crops grown in the UK.

5.3 Scottish Recommended List, 2012-2013

5.4 DARD NI, 2012-2013 Grass and Clover Recommended Varieties for Northern Ireland

5.5 Grass and Clover Recommended List Varieties for Ireland 2013 This provides details of the varieties of grasses and legumes recommended for use in Ireland. The list is drawn up after rigorous and independent testing for a range of agronomic attributes. .

5.6 Letter from Managing Director, Germinal Holdings – Germinal Holdings market the BEAA bred HSG varieties in the UK and overseas.

5.7 Queen's Anniversary Prize for Higher and Further Education 2010 The Award acknowledges the work of scientists at IBERS who have successfully combined fundamental research on plant genetics with plant breeding techniques to develop new commercially viable plant varieties that are designed to tackle some of the pressing issues faced by communities across the world, those of food, water and energy security.

5.8 Biosciences KTN leaflet on the value of High Sugar grasses to the livestock sector.

5.9 http://your.asda.com/archives/press-centre/10/2011 ASDA press release detailing the benefits of HSG varieties