Institution: University of Nottingham

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

Title of case study: Improving wheat yield and quality by optimising crop management strategies

1. Summary of the impact

University of Nottingham (UoN) research into optimum plant populations and lodging in wheat has led to advances in agronomic practices for winter wheat in the UK, in particular changes in the way that seed rates are calculated (by number, rather than weight) to establish optimum plant populations. Most significantly, growers and agronomists now have an improved understanding of the crop characteristics that affect wheat lodging risk and have made changes to crop management to minimise the problem. This has led to reduced incidence of lodging in the UK, thereby protecting yield and quality of UK's most important arable crop.

2. Underpinning research

Key researchers:

Professor Keith Scott: Professor of Agriculture (UoN; deceased, April 2000)

Dr Debbie Sparkes: Associate Professor in Agronomy (UoN;1995-present)

Dr John Foulkes: Associate Professor (UoN;1993-present)

Professor Chris Baker: Professor of Civil Engineering (UoN;1980 - 1998)

Lodging is the permanent displacement of plants from their vertical position. In wheat, loss of productivity due to lodging is through a combination of reduction in yield, reduction in grain quality, increased drying costs and delayed harvest **[1]**. Yield reductions of up to 80% have been recorded in wheat with an average loss of 2.5 t ha^{-1} **[1]**. At the start of this research programme, it was estimated that severe lodging occurred approximately once every four years with costs incurred to UK wheat growers of approximately £130 million (50% attributable to losses in yield and quality and 50% resulting from increased drying and cleaning costs **[1]**). The price of wheat has increased markedly in recent years (from £80/tonne to £200/tonne) so potential economic losses associated with lodging are now much larger.

In response to this problem, UoN researchers carried out four interrelated research projects (three supported by HGCA, one by BBSRC) **[a-d]** with the aim of improving management of winter wheat in the UK. All projects were in collaboration with the agricultural and environmental consultancy ADAS, which has a network of experimental sites across the country, hence providing an excellent resource for field experiments. The first project on plant population in winter wheat **[b]** aimed to understand the response of wheat to changes in plant density and to identify optimum plant populations for winter wheat sown on different dates. The second project **[d]** expanded this work to consider the impact of latitude and nitrogen application on optimum plant density.

The initial lodging project **[a]**, a collaboration between UoN and ADAS, aimed to understand which crops were most prone to lodging and how this could be avoided through crop management (plant population, nitrogen application and sowing date). This led to greater understanding of crop characteristics that determined lodging risk and to the development of a model to predict the wind speed at which lodging would occur, based on these crop characteristics. The second lodging project **[c]** was funded by BBSRC to validate and further improve the lodging model. ADAS were again key collaborators on this project, along with Professor Chris Baker (who had moved to University of Birmingham from UoN in 1998).

Key research findings were:

- Through detailed monitoring of crop growth and development (shoot production, light interception, biomass production and yield formation), the physiological response of wheat to plant population density and how this is affected by sowing date, was elucidated **[2,3]**.
- Data from field experiments was combined with input costs (seed) and output prices (grain) to identify optimum plant population densities for wheat sown on a given date **[3]**.
- Through collaboration with civil engineers, a model was produced which identified key crop

characteristics that determine the risk of lodging. These were classified as *leverage traits*: centre of gravity, natural frequency, number of shoots per plant; *stem strength traits*: stem diameter, stem wall width, breaking strength; and *anchorage traits*: root plate spread and root plate depth **[1]**. This model was then calibrated against measurements from field experiments **[4]**.

- The impact of crop management on lodging risk was elucidated using the model. For example, high plant population leads to a small root plate spread and hence reduced anchorage strength, thereby increasing lodging risk (reducing stem failure wind speed) **[5]**.

The UoN projects led to a greater understanding of the factors affecting lodging and provided the basis recommendations for growers in how to prevent it happening.

3. References to the research

1. **Baker, C.J.**, Berry, P.M., Spink, J.H., Sylvester-Bradley, R., Griffin, J., **Scott, R.K.** and Clare, R. (1998) A method for the assessment of the risk of wheat lodging. *Journal of Theoretical Biology*, **194**, 587–603. DOI: 10.1006/jtbi.1998.0778
2. Whaley, J.M., **Sparkes, D.L.**, **Foulkes, M.J.**, Spink, J.H., Semere, T. and **Scott, R.K** (2000) The physiological response of winter wheat to reductions in plant density. *Annals of Applied Biology* 137: 165-177**.** DOI: 10.1111/j.1744-7348.2000.tb00048.x
3. Spink, J.H., Semere, T., **Sparkes, D.L.**, Whaley, J.M., **Foulkes, M.J.**, Clare, R.W. and **Scott, R.K.** (2000) Effect of sowing date on the economic optimum plant density of winter wheat. *Annals of Applied Biology* **137:** 179-188. DOI: 10.1111/j.1744-7348.2000.tb00049.x
4. Berry, P.M., Sterling, M., **Baker, C.J.**, Spink, J. and **Sparkes, D.L** (2003) A calibrated model of wheat lodging compared with field measurements. *Agricultural and Forest Meteorology* **119:** 167-180. DOI: 10.1016/S0168-1923(03)00139-4
5. Berry, P.M., Griffin, J.M., Sylvester-Bradley, R., **Scott, R.K.**, Spink, J.H., **Baker, C.J.**, Clare, R.W. (2000) Controlling plant form through husbandry to minimise lodging in wheat. *Field Crops Research*, **67**, 59–81. DOI: 10.1016/S0378-4290(00)00084-8

The research is published in the leading international agricultural journals. Agricultural and Forest Meteorology (3.421) and Field Crops Research (2.474) are ranked 5th and 11th out of 78 respectively in the subject category Agronomy. Annals of Applied Biology (2.147) is ranked 5/57 in Agriculture, Multidisciplinary with an impact factor of 2.179 while Journal of Theoretical Biology (2.351) is ranked 22/83 in the subject area of Biology.

Underpinning research projects:

a. 1992-97: Assessing risks and avoiding lodging in wheat. PI Prof RK Scott. Funder HGCA £ 353,000

b. 1996-99: Prediction of seed rate in winter wheat. PI Prof RK Scott, Cols, Dr DL Sparkes and Dr MJ Foulkes. Funder HGCA, £236,000

c. 1999-02: The validation and development of a model for predicting lodging risk in cereals. PI Prof RK Scott, Col Dr DL Sparkes. Funder BBSRC, £204,000

d. 2000-03: Prediction of seed rate in winter wheat – phase 2. PI Prof RK Scott, Cols, Dr DL Sparkes and Dr MJ Foulkes. Funder HGCA £250,000

4. Details of the impact

Wheat is the most important arable crop grown in the UK, with nearly 2 million hectares under cultivation each year. The value of the wheat harvest to the UK economy is over £1.6 billion. Successful plant breeding and improved crop management has increased the average yield of wheat in the UK from c. 2 tonnes ha^{-1} in 1940s to 8 tonnes ha^{-1} in 2012. However, this has resulted in crops being more 'top heavy' and susceptible to lodging (when the plant falls over either due to anchorage failure, or the stem breaking). Plants that are initially resistant to lodging may stand erect during favourable conditions but may fall down when exceptionally bad weather, such as heavy rain or wind prevails, or in wet ground. Plant growth regulators are used routinely to shorten the stem of wheat, which reduces lodging risk but does not eliminate it.

The results of the first UoN seed rate project **[a]** identified the optimum plant population for winter wheat and demonstrated a strong relationship with sowing date (the later the sowing, the higher the optimum plant population). This has been adopted by growers, leading to a saving in input costs (seed) particularly for early sowings. The outcome of the research on optimum plant population was first published by the Home Grown Cereals Authority (HGCA) in 2000, with revised recommendations for growers regarding optimum plant populations. Continued work from UoN informed the release of further guidelines within HGCA's Wheat Growth Guide, published in 2008. **(Source 1)**. In the new guide, target plant populations for crops sown on given dates are provided and growers are advised to only consider re-drilling wheat if fewer than 30 plants ha-1 are established. Prior to this project, most growers sowed a 'weight' of seed – e.g. 180kg ha^{-1}, but UoN demonstrated that, as seed weight can vary two fold, the same weight of seed could mean twice as many seeds in one year as the next. Now the majority of growers calculate their 'seed rate' in terms of number of seeds, rather than weight. HGCA provide a seed rate calculator on their website to help growers with this calculation **(Source 2)**. The benefit to growers is through savings in input cost and avoiding excessively large crops which are prone to lodging (and hence have lower yields). It is impossible to quantify the number of farms that make use of the research findings relating to optimum plant populations, but for those that do, the financial savings would be significant. Using figures from the Farm Business Survey (2010/11) it is calculated that if a grower was previously sowing 180 kg ha^{-1}, at £400 t^{-1}, this would cost £72 ha^{-1}. Moving to a calculated seed rate of 150 seeds m^{-2} would cost £27 ha^{-1}, at a thousand seed weight of 45g; a saving of £45 ha^{-1}. Exact savings will be farm-specific as they depend on baseline seed rates and the adopted seed strategy. Approximately 2 million hectares of wheat is grown in the UK, so even if these changes were adopted on only 10% of the area, this would equate to a saving of £9 million per year to the industry.

In a statement (2013), a farmer from Loughborough reported, "*Following Nottingham/ADAS research on seed rates, we have reduced our winter wheat seed rates. Back in the late 90's our standard seed rate would have been 400 seeds per square metre, but now we start to sow around 10th September at 225 seeds per square metre and then increase throughout the sowing period to allow for poorer establishment. Decisions are taken on a field by field basis. As on most local farms, our soil type is variable within fields so we aim to vary seed rate according to soil type within a field. We estimate that reducing seed rates in this way leads to savings of £28 per hectare for our business at current seed prices*" **(Source 3)**.

The lower plant populations are being actively used and winter wheat crops are less likely to lodge, leading to greater returns for the grower. The lodging model developed by Nottingham, led to greater understanding of how growers can influence lodging risk through crop management and to new guidelines for growers. These have since been updated and are actively used by growers **(Source 1)**. The lodging guidelines refer to a number of HGCA project reports co-authored by Nottingham **(Source 1)**. An agronomist from Hurren Agronomy Limited stated (2013) that "*The Nottingham/ADAS work on canopy management and lodging has provided greater understanding of how sowing date, seed rate and nitrogen availability affect lodging risk within the wheat*" **(Source 4)**.

BASIS is an independent organisation set up to establish and assess standards in the pesticide industry relating to storage, transport and competence of staff. The BASIS Certificate in Crop Protection is the 'Certificate to Practice' for agronomists making pesticide recommendations on farm. The lodging guidelines are also studied by those whilst working towards the BASIS Certificate in Crop Protection, which is an essential award for anyone giving advice to growers on crop management practices. The impact of the research found in the HGCA guidelines document was summarised by a BASIS trainer who stated, "*The HGCA document* (2008) *is a publication I find very useful, both on the BASIS Certificate in Crop Protection and Advanced BASIS Cereals courses. It helps to increase students' understanding of the causes of lodging, integrated lodging control, lodging risk assessment and the role of plant growth regulators*" (**Source 5**).

Since UoN began this programme of research and dissemination to farmers the frequency of severe lodging events has reduced. This is due to improved understanding of the factors affecting lodging elucidated by this research and the guidelines available on how to reduce the incidence of lodging. For example, avoiding early applications of nitrogen fertiliser to maximise stem strength

and reducing plant population to increase anchorage strength. This has resulted in significant savings through avoiding losses of yield and quality caused by lodging (especially in light of increased wheat price and drying costs). Through avoiding those losses in yield and quality, food processors benefit by being able to source high quality grain that is suitable for their products and consumers benefit from price stability. In 2013, the Principal Research Scientist at ADAS (the UK's leading expert on lodging) confirmed the benefits of following the guidelines. "*Between 1980 and the early 2000s the average frequency of severe lodging years in the UK was approximately one in year in four. Severe lodging years often coincided with growing seasons with rapid autumn growth and wet summers. The 2011/12 season was typified by a very mild autumn (hence rapid growth) and the wettest summer for 100 years. Despite the very favourable conditions for lodging there was in fact only a moderate amount of lodging in cereals during this season. A large part of this good lodging control is likely to be caused by good management of lodging risk through the use of low seed rates, delaying N fertiliser to forward crops and targeting robust PGR programmes to the crops with the greatest lodging risk. This better understanding about how to manage lodging risk has been developed by research at the University of Nottingham, ADAS UK Ltd and the University of Birmingham*' (**Source 6**).

The reach of the UoN research into lodging is currently being extended internationally. Uptake of the Nottingham work by Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has been informing research direction and assisting in grower extension activities. The Grains Research and Development Corporation (GRDC) is a statutory corporation reporting to the Australian Government Department for Agriculture, Fisheries and Forestry. GDRC delivers improvements in production, sustainability and profitability across the Australian grains industry. A research agronomist who has been leading GRDC funded projects since 2008 to improve the yield of irrigated wheat in north-eastern Australia stated, "*The work of Debbie Sparkes and her colleagues at The University of Nottingham has been invaluable in understanding the causes of lodging, and helping us to improve agronomic methods to control lodging while achieving high yields. A grower recently used some of these improved techniques to achieve 8.2 t ha^{-1}, which we believe is a record wheat yield for the State of Queensland*" (**Source 7**, 2013).

5. Sources to corroborate the impact

1. The Wheat Growth Guide. *Provides corroboration for publication and dissemination of research by HGCA with recommendations on optimum plant populations for growers* (http://www.hgca.com/cms_publications.output/2/2/Publications/On-farm%20information/The%20Wheat%20Growth%20Guide.mspx?fn=show&pubcon=4444) 2008.
2. Home Grown Cereals Authority seed rate calculator: (http://www.hgca.com/tools.output/114/114/Tools/Agronomy%20Calculators/Seed%20Rate%20Conversion.mspx?fn=seedRate)
3. Farmer from Woodlands Farm, Hallamford Road, Shepshed, Loughborough. *Provides corroboration for the use of research information in HGCA guidelines to reduce their wheat seed rates.* 2013.
4. Agronomist from Hurren Agronomy Limited, Suffolk. *Provides corroboration for the influence of research on understanding of canopy management and lodging*.
5. Statement by BASIS Trainer. *Provides corroboration for the use of lodging guidelines within BASIS training*. 2012.
6. Principal Research Scientist, ADAS. Will p*rovide corroboration for the reduction in lodging incidence following uptake of UoN research.*
7. Research Projects Officer, CSIRO. *Provides corroboration regarding the use of UoN research by CSIRO/GRDC in Australia both to inform their own research and provide advice for growers, increasing wheat yields.* 2013