Project number: 5658
Funding source: IRCSET
Date: November, 2010
Project dates: Dec 2006 – Sep 2009

Novel experimental designs and models for measuring agronomic effects of multi-species grassland swards

Key external stakeholders:

Researchers in sustainable agriculture, grassland agronomy and ecology, grassland farmers.

Practical implications for stakeholders:

- The outcome is that modest increases in sward diversity to four-species mixtures can increase yield and reduce weed invasion, compared to monocultures. These results are applicable at least up to fertiliser applications of 150 kg ha^{-1} of nitrogen per annum.

Main results:

- Applying our methodology to data from a common experiment across 34 European sites, we show that the above-ground biomass of four-species mixtures (two legumes and two grasses) in intensive grassland systems was consistently greater than that expected from monoculture performance, even at high productivity levels. The magnitude of this effect generally resulted in the performance of mixtures exceeding that of the best-performing monoculture. Mixtures very strongly reduced the incidence of weeds in the sward.

- A combined analysis (across all sites) of first-year results on aboveground biomass across sites showed that the additional performance of mixtures was strongly related to the evenness of the community.

- The effect of the mixtures on yield was consistent over a wide range of European environmental conditions, thus adding generality to our findings. It persisted over at least three harvest years and under relatively intensive management (>150 kg ha^{-1} of nitrogen fertiliser).

Opportunity / Benefit:

The use of simple agronomic mixtures with legumes offers potential further investigation of their contribution to ecosystem services from agricultural ecosystems, such as soil carbon sequestration, and mitigation of greenhouse gas emissions through the ability of legumes to fix atmospheric nitrogen.

Collaborating Institutions:

UCD

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External Collaborators: Prof. John Connolly, UCD

1. Project background:

Recent ecological research provides evidence that an increased number of plant species in semi-natural grasslands is strongly associated with increased biomass productivity, and provides a wide range of other ecosystem benefits. This suggests that increases in species diversity in agricultural ecosystems may similarly lead to increased benefits.

Traditionally, agronomic science suggests that, compared to more species-rich mixtures, species-poor mixtures or even monocultures of high-yielding species will maximise yield under productive and highly fertilised conditions. Although the maximisation of yield is often the dominant reason for use of monocultures, other advantages of agricultural monoculture systems include the synchronisation of farm management and the simplified harvesting associated with a single crop type. The increasing cost of nitrogen fertiliser, agri-environmental legislation and efforts to reduce greenhouse gas emissions are all contributing to a re-evaluation of the use of fertiliser nitrogen on farms and a search for lower-cost and environmentally compliant alternatives. Forage legumes offer the potential to lower fertiliser costs on farms and may offer a more sustainable option for pasture-based production, not just economically but also in terms of other environmental impacts. Whether increased crop diversity in species-poor agronomic systems could improve the provision of ecosystem services remains largely untested due to the rarity of multi-species agronomic experiments that use more than two species.

Controversy has surrounded the statistical design and analysis of mixture experiments and the extent to which mechanistic explanations of relationships can be inferred from their results. We developed and implemented a new statistical approaches to better measure the benefits of multi-species mixtures. This work was based on data from the COST 852 Agrodiversity experiment, which was conducted at 34 sites across Europe.

The work was conducted following an IRCSET Postdoctoral Fellowship award to Laura Kirwan.

2. Questions addressed by the project:

- How to develop statistical models that describe ecological interactions in multi-species swards?
- How to quantify the general effect of sward diversity on agronomic outputs (e.g. yield) across multiple experimental sites?

3. The experimental studies:

We developed a modeling framework that explicitly quantifies and separates the effects of individual species from the synergistic benefits that occur when species are mixed. This new approach allowed us to test between alternative descriptions of how synergistic benefits occur i.e. do all species interact equally? do some species interact more strongly than others? and, if so, are benefits related to specific traits? As well as being applicable to agronomic experiments, this approach can be applied to a variety of ecosystem functions and organisms.

We tested hypotheses about species mixtures using data from a collaborative European multi-site agricultural experiment (n= 34 sites) that established gradients of agronomic forage diversity (from monoculture to mixtures that systematically varied the proportions of four species) at each site for at least 3 years (time factor) across a wide variety of European climatic conditions (climate factor). At each experimental site, adapted cultivars of two legume and two grass species were chosen such that one of the grass and one of the legume species was fast establishing and the other was slow establishing. Five species-groups were selected depending on the geographical region of the experimental site: north European, mid-European, dry Mediterranean, moist Mediterranean and a fifth group consisted of sites, each with its own group of species but all with the same four functional groups. The experimental layout followed a simplex design with four monocultures and eleven mixtures of the four species sown at two levels of overall sowing density (low being 60% of high). The eleven mixtures consisted of four mixtures dominated in turn by each species (sown proportions of 70% of dominant and 10% of each other species), six mixtures dominated in turn by pairs of species (40% of each of two species and 10% of the other two) and the centroid

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community (25% of each species). Species proportions at sowing were based on proportions of seed mass considered appropriate for monocultures for each species at a site.

4. Main results:

We successfully developed a range of models that are relevant both to the design and analysis of yield from multi-species grassland experiments, but are also appropriate to address other functional effects e.g. yield stability, weed suppression, nitrate leaching, and nutrient dynamics.

Applying our methodology to data from a common experiment across 34 European sites, we show that the above-ground biomass of four-species mixtures (two legumes and two grasses) in intensive grassland systems was consistently greater than that expected from monoculture performance, even at high productivity levels. The magnitude of this effect generally resulted in the performance of mixtures significantly exceeding that of the best-performing monoculture (Fig. 1). A combined analysis (across all sites) of first-year results on aboveground biomass across sites showed that the additional performance of mixtures was greatest when the mixtures consisted of equal proportions of each of the four species. Mixtures very strongly reduced the incidence of weeds in the sward (Fig. 1). The effect of the mixtures on yield was consistent over a huge range of environmental conditions, thus adding generality to our findings. It persisted over at least three harvest years (in eleven sites that were analysed) and under relatively intensive management (~150 kg ha^{-1} per annum of nitrogen fertiliser).

Similar results were obtained for Irish sites that participated in this experiment, and virtually every mixture had a higher yield, and suppressed unsown species better, than monocultures of perennial ryegrass.

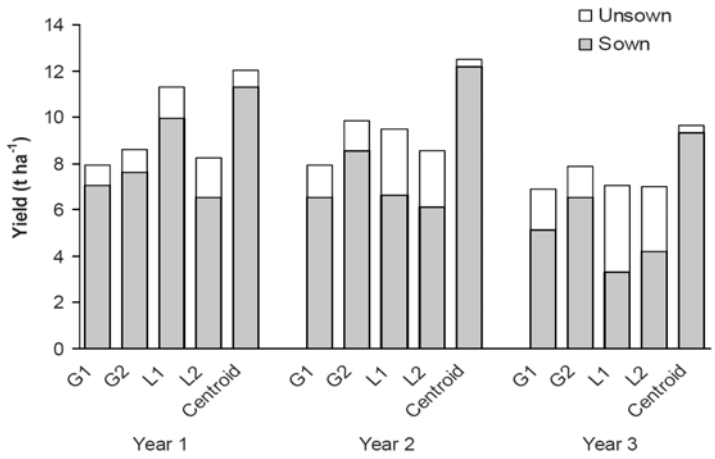

Figure 1 Predicted sown and unsown yield (t ha^{-1} of dry matter) for each monoculture and the centroid mixture for each year from the combined analysis across the 12 mid-European sites. The unsown yields in this diagram were calculated as the difference between estimated means of total yield and sown species yields. G1= *Lolium perenne (perennial ryegrass)*, G2= *Dactylis glomerata (Cocksfoot)*, L1= *Trifolium pratense (red clover)*, L2= *Trifolium repens (white clover)*. (From Helgadóttir *et al*. 2008.)

5. Opportunity/Benefit:

These multi-site results offer potential further investigation of the contribution of simple agronomic mixtures to soil carbon sequestration, and mitigation of greenhouse gas emissions through the ability of legumes to fix atmospheric nitrogen.

6. Dissemination:

Main publications:

Kirwan, L., Connolly, J., Finn, J.A., Brophy, C., Lüscher, A., Nyfeler, D. and Sebastià, M.T. (2009) 'Diversity-Interaction Modelling- Estimating Contributions of Species Identities and Interactions To Ecosystem Function.' *Ecology* 90: 2032 - 2038.

Connolly J., Finn J.A., Black, A.D., Kirwan L., Brophy C. and Lüscher A. (2009) 'Effects of Multi-Species

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Swards on Biomass Production and Weed Invasion at Three Irish Sites.' *Journal of Agricultural and Food Research* 48: 243 - 260.

Lüscher, A., Finn, J.A., Connolly, J., Sebastià, M.T., Collins, R., Fothergill, M., Porqueddu, C., Brophy, C., Huguenin-Elie, O., Kirwan, L., Nyfeler, D. and Helgadóttir, A. (2008) 'Benefits of Sward Diversity for Cultivated Fertile Grasslands' *Biodiversity* 9: 29 - 32.

Popular publications:

Kirwan, L., Finn, J.A., Brophy, C. and Connolly, J. (2007) 'Sward diversity in intensive grasslands – increased yield and reduced weeds' *TResearch* **2**: 30 - 31.

Carnus, T., Finn, J.A., Kirwan, L. and Connolly, J. (2007) 'Does Plant Diversity Stabilise Ecosystem Function?' In: *Ireland's Rural Environment: Research Highlights from Johnstown Castle* by Finn, J.A., Richards, K. and Shortle, G. (Eds.).Teagasc IE 45 - 46. ISSN 18 4170 4776

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