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PASTURE SCIENCE INFORMS SEED MIXTURE DECISIONS FOR SIMPLE AND MULTI-SPECIES SWARDS

This article describes a series of pasture mixture experiments, and how they can help farmers make informed decisions about which and how many species to include in a new pasture sowing.

Improving pasture production and resilience

In pastoral farming a seed mixture decision is a necessary first step towards improving pasture production and resilience. Conventional agriculture has promoted monocultures, simple mixtures and multi-species pastures to improve soil, plant and animal components in farm systems. Which species to grow, and how many species to grow where, have depended on the growing conditions and purpose of the pasture. Similarly, advocates of regenerative agriculture propose multi-species swards to maintain productivity and other ecosystem services with minimal inputs such as fertiliser.

The challenge of pasture scientists is to provide pasture seed mixture formulations to meet different farming needs as sustainably as possible. This requires knowledge of the role of each individual plant species and how they interact with other species to utilise natural resources as a plant community. Recent work in Europe and at Lincoln University has examined these complex species identity and interaction effects operating in pastures. Some key findings are summarised in this article.

Most pastures are mixtures

The vast majority of New Zealand's pastures are formed by mixing together two or more forage species. Some examples of the many and varied blends we use are:

- Dairy pastures consisting of perennial ryegrass *(Lolium perenne)*, white clover *(Trifolium repens)* and plantain *(Plantago lanceolata)*
- Herb pastures made by blending plantain, chicory *(Cichorium intybus)*, white clover and red clover *(Trifolium pratense)*
- Dryland pastures with cocksfoot *(Dactylis glomerata)* and mid- and late-flowering cultivars of subterranean clover *(Trifolium subterraneum)*
- Tall fescue *(Schedonorus arundinaceus)*-based pastures with cocksfoot, timothy *(Phleum pratense)*, white clover and red clover
- Short-term pastures using Italian ryegrass *(Lolium multiflorum)*, red clover and balansa clover *(Trifolium michelianum)*
- Horse pastures consisting of pasture brome *(Bromus valdivianus)*, cocksfoot, timothy, browntop *(Agrostis capillaris)* and Yorkshire fog *(Holcus lanatus)*.

Mixture experiment with Italian ryegrass red and balansa clovers

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In each example, one or more functions of the pasture are generally of interest to the farmer, agronomist or experimenter who is responsible for mixing the ingredients. Such functions are animal production, annual and seasonal dry matter (DM) yield, nutritional composition, resistance to pests and diseases, including weeds, rainfall penetration and resilience to seasonal drought. In every case, the measured response of the pasture depends on the percentages or proportions of the individual plant species that are present in the formulation.

The individual species and cultivars in the mixture are chosen based on their suitability to the abiotic (water, temperature and nutrient status) and biotic (grazing regime, pest and disease) conditions and animal feed requirements of the particular farm system (i.e. the purpose of the pasture). Most pastures exploit the advantage legumes have over most grasses and herbs in their ability to utilise soil inorganic nitrogen (N) – nitrate (NO_3–) and ammonium (NH_4+), as well as fix atmospheric N (N_2) via symbiotic bacteria (rhizobia) in root nodules.

Pastures usually end up with some weeds in them as well, such as 'low fertility' grasses like browntop, crested dogstail (*Cynosurus cristatus*) and meadow grass (*Poa trivialis*), and broadleaf weeds, including volunteer white clover and plantain, which divert scarce resources (light, water, nutrients and labour).

Historical wisdom

An important point to make here is that New Zealand has a rich history of grassland research spanning more than 80 years. However, much of that information is at risk of being forgotten unless we refer back to it now and again. Many articles are freely available at the New Zealand Grassland Association website: www.grassland.org.nz

The literature shows that improved pasture production through the optimal formulation of species mixtures is a recurring theme of dairy, and sheep and beef research in New Zealand. The work done by Cockayne and Levy in the 1910s to 1930s, the seminal papers by Brougham and Harris in the 1950s and 1960s, and the more recent studies by Fraser, Stevens, Nobilly, Woodward and others have all contributed to the scientific basis that underpins our seed mixture decisions for new pastures.

A very useful example of mixing together cultivars in mixture experiments was that described by Harris in an article in the 1968 *Proceedings of the New Zealand Grassland Association*. In the discussion part of the article, it says:

Asked about models to describe competition in mixtures of more than two species, Harris replied that at this stage these were not precise. It was stated that results from a series of two-species mixtures could be used to explain the complex competitive interactions involved in a multispecies sward.

Since this article, the design and analysis of mixture experiments, and their application in agricultural systems, have evolved considerably. The model analyses now allow the experimenter to disentangle the complex inter-species interactions operating in multi-species swards, to predict the response of any mixture of ingredient species, and to identify the optimal mixture should it not be one of the blends included in the experiment design.

Mixtures with Caucasian clover

Caucasian clover (*Trifolium ambiguum*) is well known for its slow and difficult establishment, but once established it can increase the legume content of permanent pastures. A mixture experiment was set up at Lincoln University to study the blending properties of Caucasian clover with perennial ryegrass and white clover. The three species were drilled as monocultures and four mixtures in November 1999 and grown with and without irrigation for five years. Figure 1 shows the average annual yields.

The three species differed in their monoculture yields, with Caucasian clover out-performing white clover in the long term. The monoculture performance of a species is a measure of its potential effect on pasture function, which grassland ecologists call the 'identity effect'. Therefore, Caucasian clover demonstrated a strong potential to contribute to pasture yield and weed suppression. In the mixtures the species interacted to produce 'diversity effects', which are defined as the excess mixture performances over that expected from the component species' monoculture performances. Diversity effects can increase yield and reduce the need for weed control and N fertiliser.

The strength of the diversity effects depended on the species. There was no interaction effect between Caucasian and white clovers, but both clovers interacted strongly with perennial ryegrass to increase annual yield. There was no complex three-way interaction effect among all three species and therefore the three-species mixture yielded the same as the two clover-ryegrass mixtures.

The interactions operating among forage species in pastures include niche partitioning and facilitation. Niche partitioning (differences in resource use among species) can allow for a more complete use of resources. For example, legumes can fix atmospheric N via rhizobia and utilise soil inorganic N when available, whereas most non-legumes can only utilise soil inorganic N. Facilitation occurs when species help other species to grow by changing the environment, such as legumes that help non-legumes by increasing soil inorganic N.

The irrigation treatment represents a process variable that is sometimes included in a mixture experiment when the researcher suspects the process condition will affect the blending properties of the mixture ingredients. In the Caucasian clover experiment, the effects of soil moisture availability on the species identity and interaction effects were studied. The identity and interaction effects were robust across the dryland and irrigated conditions (Figure 1).

There was considerable variation in the species identity effects over time. This reflected the slow establishment and temporal persistence of Caucasian clover, which started to out-perform white clover in the second year. These changes resulted in major shifts in species' relative abundances in the mixtures over seasons and years, but the diversity effects persisted.

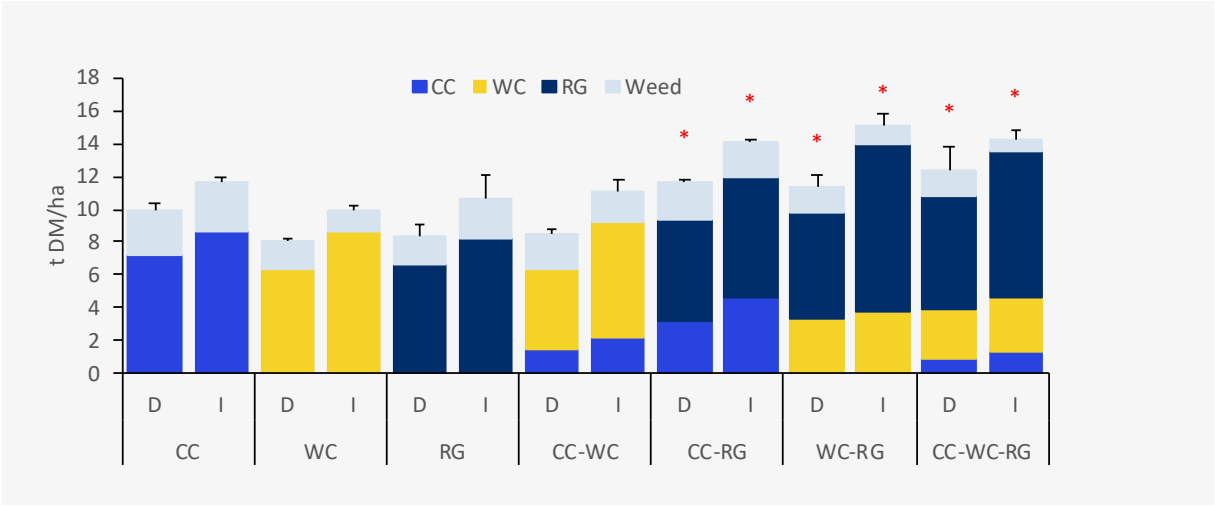

Figure 1: Annual dry matter (DM) yield response to monocultures and mixtures of Caucasian clover (CC), white clover (WC) and perennial ryegrass (RG) grown in dryland (D) and irrigated (I) conditions averaged over five years at Lincoln University. Asterisks indicate over-yielding by mixtures

Multi-site agro-diversity experiment

My own research has included a grassland scientist position with Teagasc at its Grange Beef Research Centre in County Meath, Ireland in the early 2000s. Work was carried out on a multi-site agro-diversity experiment that examined the blending properties of several different forage species in intensively managed grasslands across a wide range of environments throughout Europe (and one site in Canada).

A common experimental design and protocol allowed the grassland scientists involved to examine the blending properties of four species adapted to their own local environment, within functional groups of two grasses and two legumes. At each site, there were four monocultures and 11 mixtures that varied widely in sown relative abundances of the chosen species, each repeated at two levels of overall initial abundance, or total seeding rate. The plots were managed by cutting.

There was also the option to include a management or environmental factor in the experiment design and many participants examined the effects of applied N and genetic diversity within species (e.g. narrow vs broad genetic base). The effects of perennial ryegrass, timothy, white clover and Caucasian clover with two levels of applied N (75-100 and 150-200 kg N/ha p.a.) were examined at three Irish sites: Grange (east), Athenry (west) and Moorepark (south). However, at Grange the swards were overcome by chickweed and failed to establish.

Overall, the agro-diversity experiment found that the different mixtures of two grasses and two legumes provided greater annual yields and better weed suppression than the average monocultures ('over-yielding') and sometimes the best-performing monoculture ('transgressive over-yielding'). At low levels of applied N, the diversity effects persisted across sites and years alongside major changes in botanical composition, albeit at reduced strength as legumes declined. At high N levels the diversity effects were reduced and even declined in the third year. The diversity effects on yield were not accompanied by reductions in nutritive value. At the Moorepark site, earthworms favoured swards dominated by perennial ryegrass with low rather than high N inputs.

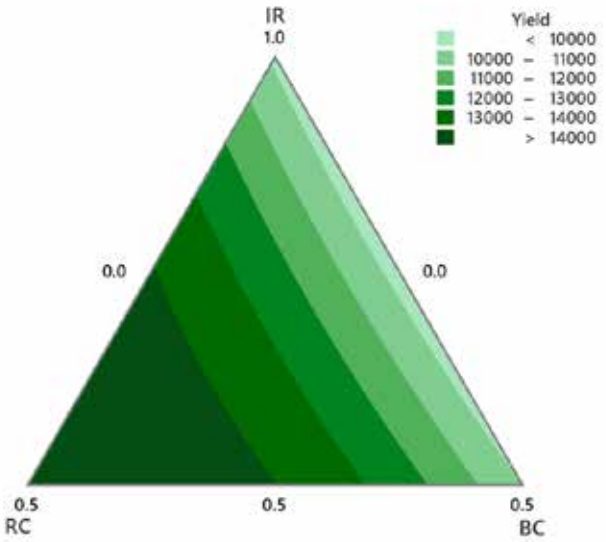

Figure 2: Contour plot of the relationship of accumulated total yield (kg DM/ha) with sown proportions of Italian ryegrass (IR), red clover (RC) and balansa clover (BC) in a short-term dryland pasture 12 months after a March sowing at Lincoln University

Italian ryegrass-clover blends for short-term pasture

At Lincoln University, four mixture experiments were run in predominantly grazed situations on university farmland from 2011 to 2021. Looking at short-term pasture options for dryland systems, the next experiment that followed in 2011 examined if mixtures of Italian ryegrass, red clover and balansa clover (a top-flowering annual) can yield more forage and suppress weeds better than Italian ryegrass alone.

Thirteen blends of the three species were drilled at 20 and 30 kg/ha in March 2011. The minimum proportion of Italian ryegrass in the seed mixtures was constrained to 50% because dryland systems need good cool season growth and this is a feature of Italian ryegrass. Plots were harvested six times over 12 months and were neither irrigated nor fertilised with N.

The inclusion of red clover increased annual yield by 41% compared with Italian ryegrass sown alone (13.79 vs 9.75 t DM/ha; Figure 2), and provided effective weed suppression (<5% of total yield) and high quality forage (crude protein 17.5% and metabolisable energy (ME) 11.3 MJ/kg DM). No benefits to yield and quality were gained from adding the balansa clover. The optimum seed mixture was 12 kg/ha Italian ryegrass, 8 kg/ha red clover and no balansa clover.

Four-species mixtures with species drilled in alternate rows

In addition to studying the blending properties of pasture species, recent work has also studied the effect of separating species in alternate drill rows to improve species evenness in swards. At Lincoln University four pasture species – perennial ryegrass, plantain, white clover and red clover – were used to create four monocultures and 15 mixtures varying widely in species richness and relative abundance. The effect of species separation was examined by replicating four mixtures of perennial ryegrass, plantain and white clover with the species separated in alternate drill rows. Red clover was not included in this test because the precision drill separated up to three species.

The plots were drilled in March 2015, grazed by sheep eight times annually, irrigated and did not receive any N fertiliser for six years. Over these years, sowing method did not influence the identity and interaction effects. Yield, weed suppression and quality were driven by identity effects

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and strong pairwise interactions between the legumes and non-legumes. The identity effects differed among species and varied over time, reflecting the different establishment, seasonal growth and persistence traits of the four species. Perennial ryegrass and white clover out-performed plantain and red clover in the long term. There were major changes in the botanical composition of the swards over time (Figure 3).

The two legumes interacted strongly with both perennial ryegrass and plantain to produce diversity effects of increased pasture yield and weed suppression. The pairwise interactions depended on the relative abundances of the species involved so they weakened as plantain and red clover declined.

More complex, multi-species interactions involving three or four species were rare and weak so they did not contribute much more to the diversity effect. Therefore, the simple blends of one legume with one non-legume species, such as white clover with perennial ryegrass, performed just as well and sometimes better than the mixtures with three or four species.

Pasture mixtures under N loss and application restrictions

New regulations about the use of N fertiliser will impact future seed mixture decisions. To help inform these decisions, the effects of applied N on identity and interaction effects were further examined at Lincoln University.

Three monocultures and seven mixtures of perennial ryegrass, white clover and plantain were drilled at two overall sowing rates in March 2017 and grown ±N fertiliser. The +N level was reduced from 275 kg/ha in Year 1 to 200 kg N/ha p.a. in anticipation of a restriction on the application of N fertiliser on grazed pasture. Plots were grazed by sheep eight times annually and irrigated. Over four years, the applied N affected the relationships of average pasture yield and quality with species relative proportions in the seed blend (shown for yield in Figure 4).

An equi-proportional mixture of perennial ryegrass and white clover (based on seed count) optimised annual yield, weed suppression, ME and crude protein regardless of N level. The optimal sowing rate was 12 kg/ha perennial ryegrass and 7 kg/ha white clover. The average annual yield of the optimal blend was 20.5 t DM/ha with 4% weed, 11 MJ/kg DM ME and 21% protein. Pasture yield and quality responded to changes in species proportions away from the optimal mixture, including the addition of plantain. The magnitude of the yield and quality responses was larger with than without applied N because the identity effects of perennial ryegrass and plantain, and the way all three species interacted, depended on N level.

Multi-species swards

A pasture mixture of multiple forage species (five or more) is at times promoted as the key to the improvement of pasture production. However, a simpler mixture of two,

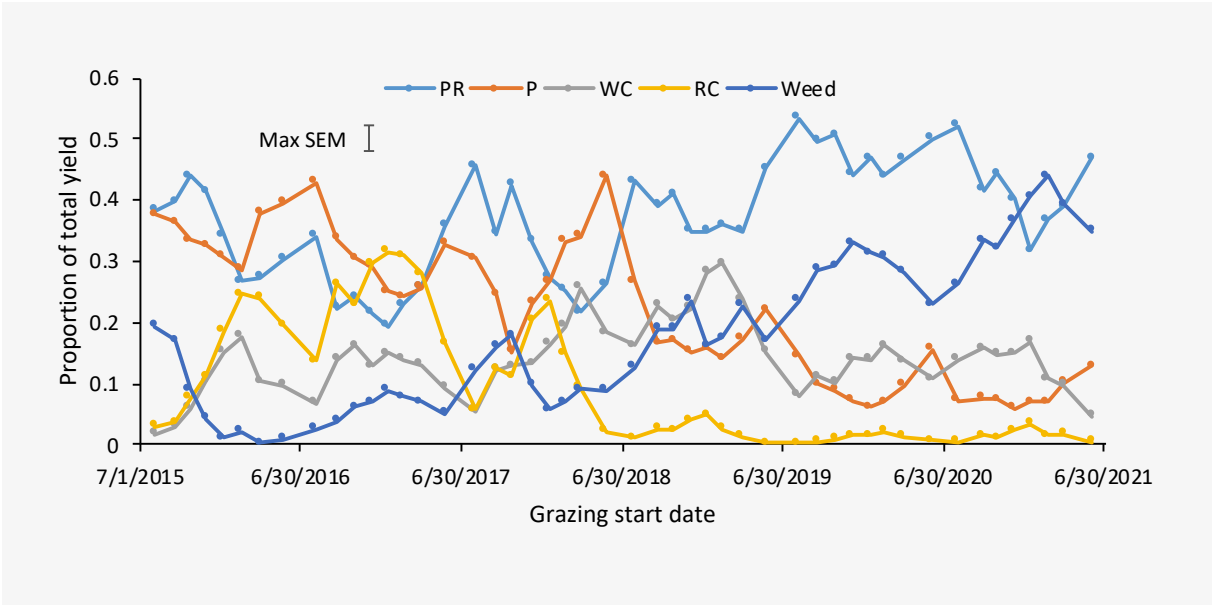

Figure 3: Pre-grazing pasture botanical composition of perennial ryegrass (PR), plantain (P), white clover (WC), red clover (RC) and unsown species (weed) averaged across monocultures and mixtures over six years at Lincoln University

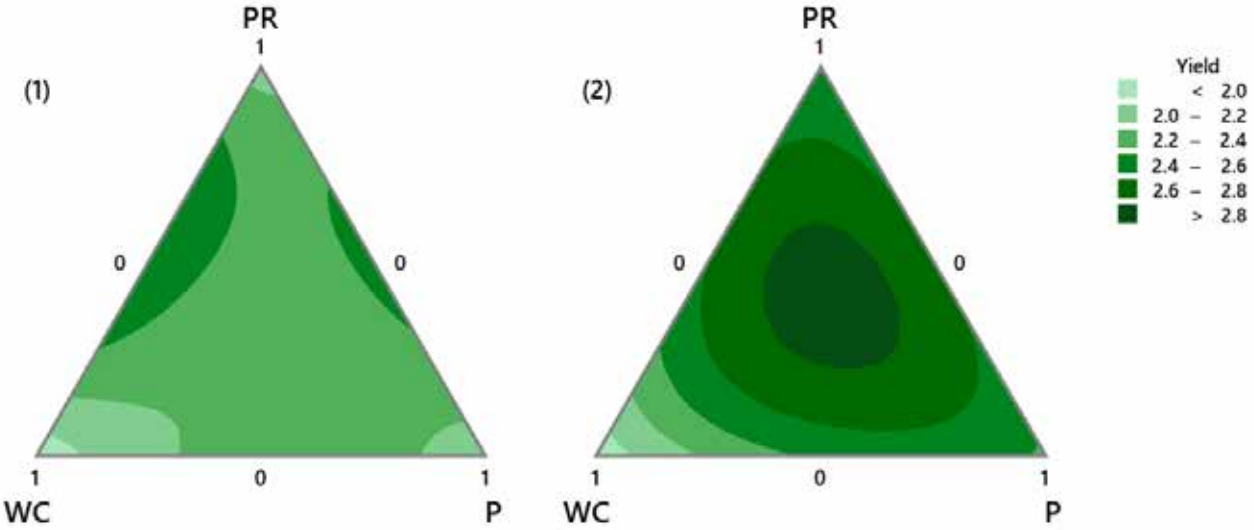

Figure 4: Contour plots of the relationship of pre-grazing pasture yield (t DM/ha) with sown proportions of perennial ryegrass (PR), white clover (WC) and plantain (P) without (1) and with (2) N fertiliser, averaged across 32 grazings over four years at Lincoln University

As a country, we need to accomplish significant reductions in nitrogen loading in over-allocated waterbodies in accordance with resource use limits set by regional councils.

three or four species can produce similar diversity effects and perform just as well.

The impact of multi-species swards on forage yield, weed suppression and quality was examined under sheep grazing and irrigation at Lincoln University. Sixty-nine mixtures of perennial ryegrass, cocksfoot, plantain, white clover, red clover and subterranean clover were sown in April 2018. After three years, the biomass-species richness relationships revealed that average pre-grazing pasture yield increased by 0.39 t DM/ha (3 t DM/ha/year), average weed yield decreased by 0.50 t DM/ha (from 44% to 7% of total yield), and average ME and crude protein did not change (10.9 MJ/kg DM and 21% of DM, respectively) with increased richness from one to six species.

However, there was substantial variation in each response between swards of equal richness, with several mixtures providing above-average total yield, ME and crude protein and below-average weed yield at two to four sown species. These highly productive swards included simple mixtures of perennial ryegrass and either white clover or red clover.

Conclusion

Sowing two to four legume and non-legume species together can increase pasture production compared with the production expected from the individual species. Any further increase in species number changes the botanical composition, but not the yield and quality of the pasture.

This diversity-production relationship is the result of pairwise interactions among legume and non-legume species. The strength of the interactions depends on the relative abundances of the species involved. If the species are not present in large enough abundance, the expression of the interaction is generally not strong enough to detect. Species relative abundances change substantially over time, with two or three species eventually dominating multi-species swards.

Acknowledgements

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Further reading

Black A.D. and Lucas R.J. 2018. Dry Matter Yield of Dryland and Irrigated Mixtures of Caucasian Clover, White Clover and Perennial Ryegrass Over 5 Years at Lincoln University. *Journal of New Zealand Grasslands*, 80: 73–80.

Harris W. 1968. Pasture Seed Mixtures, Competition and Productivity. *Proceedings of the New Zealand Grassland Association*, 30: 143–153.

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