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Plant diversity in agricultural grasslands – a sustainable adaptation option to climate change?

Key external stakeholders:

Grassland farmers, grassland breeders, grassland research community, policymakers

Practical implications for stakeholders:

Drought conditions are predicted to occur more frequently in future climate change scenarios, and the stability of grassland production will be dependent on how grasslands respond to weather volatility.

- Experimental drought over a 9-week period reduced yields by 50-75%.
- This field experiment showed that the yield benefit of four-species grassland mixtures was about 40-50% greater than that of the average yield of monocultures.
- Although there was a reduction of yield across all communities due to drought, this relative benefit of the mixtures was maintained under drought conditions. This yield benefit of mixtures was sufficiently large that drought-stressed mixtures at least attained the same yield as the average of the rain-fed monocultures in control conditions.
- Multi-species mixtures offer significant potential as an adaptation option to climate change.
- We gained new insights into the mechanisms behind this diversity effect, and showed that different species relied on different soil depths for their water and nutrient uptake.

Main results:

- Higher productivity of grassland mixtures compared to monocultures was maintained under drought conditions, as predicted in future climate change scenarios. Mixtures consistently yielded more than the average monoculture, and more than the *Lolium perenne* monoculture. This yield of mixtures was sufficiently large that drought-stressed mixtures at least matched the average yield of the rain-fed monocultures in control conditions.
- This increased productivity could be attributed to the relative increase in symbiotic nitrogen fixation and soil nitrogen utilisation in mixtures of legumes and non-legumes.
- Different species relied on different soil depths for their water and nutrient uptake; however, this could not be related to increased resource uptake in mixtures compared to monocultures.

Opportunity / Benefit:

Results and insights gained from this project may inform the design of more sustainable grassland production systems that are better able to withstand or recover from extreme weather events.

Collaborating Institutions:

Agroscope, Institute for Sustainability Sciences, Switzerland

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1. Project background:

Future scenarios of climate change predict an increase in weather volatility (extreme events such as drought and excessive rainfall). These changes are already underway, and pose serious challenges to Irish grassland production systems as they significantly impact yield and yield stability (resistance to and recovery from stress). There is increasing evidence for the benefit of grassland mixtures compared to monocultures both in terms of biomass production and increased stability in response to stress. Additionally, the inclusion of legumes has the potential for reducing fertiliser inputs and hence increasing sustainability. However, significant knowledge gaps remain in the understanding of the mechanisms that underpin the observed effects and the applicability of these systems under the predicted change scenario.

2. Questions addressed by the project:

- Does increased species diversity in grassland result in higher productivity under ambient and drought conditions?
- If so, can we explain this effect of plant diversity through utilization of soil water and nutrients?

3. The experimental studies:

We conducted two experiments in Switzerland in which we compared the productivity of four grassland species grown in monoculture or mixture. The four species were selected based on their ability for symbiotic N_2 fixation (legumes or non-legumes) and rooting depth (shallow-rooting or deep-rooting). During the summer, half of the plots were covered by drought shelters for ten weeks, to simulate moderate summer drought conditions.
We developed and applied a number of tracer methods using trace elements (rubidium) and stable isotopes (^{15}N, ^{18}O, ^{13}C) to investigate: the processes resulting in over-yielding in mixtures compared to monocultures; the contribution of symbiotically fixed nitrogen to total nitrogen uptake, and; whether there is increased water and nutrient utilization by combining deep and shallow-rooting species in mixtures.

4. Main results:

On average, mixture yields were 40-50% higher than monoculture yields, and the advantage was maintained under drought conditions. This benefit of mixtures was sufficiently large that drought-stressed mixtures at least attained the same yield as the average of the rain-fed monocultures in control conditions.
Our tracer methods showed that

1) Total biomass and nitrogen yields were higher in mixtures compared to monocultures. Legumes increased their N fixation activity when the availability of N in the soil was lower (i.e. under drought conditions and when grown in mixtures) and this resulted in a higher soil N availability for the non-legumes.
2) The different species relied on different soil depths for their water and nutrient uptake, however, this did not result in increased nutrient uptake in mixtures compared to monocultures.

5. Opportunity/Benefit:

Drought conditions are predicted to occur more frequently in future climate change scenarios. This research showed that the yield benefit (40-50%) of growing grassland mixtures compared to monocultures is maintained under drought conditions. The ability of drought-stressed mixtures to at least match the yield of the average of the rain-fed monocultures in control conditions indicates the adaptation potential of multi-species mixtures to changing weather conditions due to climate change.We gained new insights into the mechanisms behind this diversity effect, which can inform and improve the design and composition of grassland mixtures as an option for adaptation to climate change.

6. Dissemination:

Main publications:

Hofer, D., Suter, M., Haughey, E., Eickhoff, B., Finn, J.A., Hoekstra, N.J., Buchmann N, Lüscher A. Yield of forage species of intensively managed temperate grassland is either largely resistant or resilient to experimental summer drought. *Journal of Applied Ecology* (in review).

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Hoekstra, N.J., Finn, J.A., Buchmann, N., Gockele, A., Landert, L., Prill, N., Scherer-Lorenzen, M., Lüscher, A. (2014) 'Methodological tests of the use of trace elements as tracers to assess root activity' *Plant and Soil* 380:265-283.

Hoekstra, N.J., Suter, M., Finn, J.A, Husse, S. and Lüscher, A. (2015) 'Do belowground vertical niche differences between deep and shallow-rooted species enhance resource uptake and drought resistance in grassland mixtures?' *Plant and Soil*, accepted.

Hoekstra, N.J., Finn, J., Lüscher, A. 2014. 'The effect of drought and interspecific interactions on the depth of water uptake in deep- and shallow-rooting grassland species as determined by δ18O natural abundance.' *Biogeosciences*, 11 (16), 4493-4506.

Hoekstra, N., Finn, J.A. and Lüscher, A. (2013) 'Nutrient uptake in soil niches affected by plant species and drought stress' In: Agricultural Research Forum 2013, 11th March 2013, pp. 1.

Popular publications:

Hoekstra, N., Finn, J.A. and Lüscher, A. (2013) 'Effects of drought on nutrient dynamics in multi-species mixtures' In: Ireland's Rural Environment: Research Highlights from Johnstown Castle, pp. 68.

7. Compiled by: Nyncke Hoekstra and John Finn

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