

AGROECOLOGY

Agroecosystem diversification

The diversity of agricultural systems has been minimized in order to maximize yields under favourable conditions. Diversification of agroecosystems may be required to maintain and stabilize yields in an increasingly unpredictable climate.

Forest Isbell

Highly diverse grasslands, forests and aquatic ecosystems are more productive and stable than the sum of their constituent species, due to the complementary traits and interactions of different species. Ecologists have primarily focused on the negative implications of this phenomenon: plant species loss will lead to a reduction in the function and stability of natural ecosystems. Writing in *Nature Plants*, Prieto and colleagues¹ illustrate the positive implications of this relationship for agricultural systems, by showing that the addition of complementary plant species can promote forage crop yields in managed grasslands, and that further addition of genotypes within species can promote the stability of forage yield across harvests.

Many of Earth's grasslands, savannahs and forests have been converted to agricultural land. Worldwide, pastures and rangelands cover an area larger than Africa, and croplands cover an area nearly as large as South America. These land-use changes have delivered benefits, namely an increase in food production. But they have also come at a cost to the environment, due to concomitant increases in carbon emissions and reductions in water and air quality. Some of the costs of land conversion are the direct result of biodiversity loss; diversity is kept to a minimum in most agricultural systems, rendering them leaky — that is, less able to capture and retain carbon and nutrients.

In natural and extensively managed grasslands, productivity depends on plant diversity^{2–4}. Adding back some of the plant diversity lost during land conversion could therefore reduce the environmental costs and increase the benefits of agriculture. The idea of diversifying agricultural systems to enhance yields is not new. More than a century ago Darwin wrote⁵ “It has been experimentally proved that if a plot of ground be sown with one species of grass, and a similar plot be sown with several distinct genera of grasses, a greater number of plants and a greater weight of dry herbage can thus be raised.” But this understanding was temporarily lost during

the twentieth century, due to inadequately designed forage diversity experiments⁶ that confounded changes in species diversity with changes in species composition and biased data analyses².

Some combinations of species and genotypes are more complementary, and thus valuable, than others. Plants

can negatively impact one another by reducing the abundance of shared resources, such as water and nutrients, or by increasing the abundance of shared natural enemies, such as herbivores and pathogens. Species or genotypes can coexist in a complementary manner when they consume different resources and have specialized natural enemies, or when there is temporal and/or spatial variability in the abundances of resources or enemies (Fig. 1). The identification of complementary combinations of species remains challenging.

Prieto and colleagues¹ show that it's not just the diversity of species that affects forage yield, but also the number of genotypes per species. They varied the number of forage crop species and the number of genotypes per species present in experimental grassland communities, and monitored forage production over multiple harvests during the course of a year. The experiments were carried out in the presence and absence of a drought treatment. Forage yields rose with the number of species present in the drought-treated plots, due to the complementary use of resources, avoidance of specialist herbivores or pathogens, and/or beneficial interactions between species in diverse communities. In contrast, the stability of yields across harvests rose with the number of genotypes per species in both drought and non-drought treated plots that included many species.

It is surprising that Prieto and colleagues¹ found such complementarity among forage crop species in a short-term local-scale experiment. In natural ecosystems, the identity of the most productive plant species varies substantially across years, places, and environmental conditions⁷. Furthermore, species interactions limit the similarity between species and reinforce differences. As such, it's no surprise that diversity promotes productivity in these systems. In sharp contrast to native plants, however, crops have been developed to thrive in monocultures where conditions are kept as favourable and constant as possible. Over time, any initial complementary differences between crops



© BOB GIBBONS / ALAMY

Figure 1 | A diverse hay meadow. In order to increase yields in agricultural systems, diversity has typically been minimized and inputs maximized. This agricultural simplification strategy fails to promote yields when environmental variability across space or time cannot be controlled or anticipated. Prieto and colleagues¹ show that in managed grasslands diverse mixtures of complementary forage species are more productive than monocultures, especially under drought conditions, and that further increasing the number of genotypes per species stabilizes forage yield across harvests. Their findings suggest that the diversification of agroecosystems systems could enhance the productivity and stability of these systems.

are likely to be eroded by lack of both species interactions and spatiotemporal variability in limiting factors. It is therefore impressive that crop species can be strategically combined to complement one another. Given that increased complementarity can be naturally selected for relatively rapidly⁸, it should be possible for agronomists to design and improve crop species mixtures to enhance yields by maximizing the extent to which species complement one another. The same tools and technologies that have been developed and employed to optimize monoculture production could be readily applied to optimize polyculture production.

There are, however, many challenges that stand in the way of the diversification of agricultural ecosystems. An agricultural diversification strategy would, in many ways, be a reversal of the current trajectory of agricultural simplification. To date, agronomists have developed extremely low-diversity but high-yielding cropping systems, that are supported by equipment for planting and harvesting monocultures, and massive inputs of water, nutrients, herbicides and

pesticides, supplied to reduce spatiotemporal variability in the factors that limit plant growth. In stark contrast, a diversification strategy would require designing and developing complementary suites of crop species and genotypes that could perform well across spatially heterogeneous and temporally-fluctuating environments.

Despite these challenges, the diversification of agricultural systems could well become an increasingly profitable strategy for enhancing agricultural productivity as the climate changes and extreme events become increasingly common⁹, and as increasingly marginal lands are adopted or intensified for agricultural purposes. In these cases, environmental variability cannot be so easily avoided or anticipated. As illustrated by Prieto *et al.*, diversity can provide insurance against such unavoidable environmental variability.

Mixing existing crop genotypes would be an easy place to begin diversifying agroecosystems. As Prieto and colleagues¹ show, even this moderate level of

diversification could stabilize yields across harvests. Designing and developing diverse crop mixtures that include many complementary species and genotypes will be more challenging, but will likely become an increasingly necessary and profitable strategy for maintaining yields over the next few decades. □

Forest Isbell is at Cedar Creek Ecosystem Science Reserve and in the Department of Ecology, Evolution and Behaviour at the University of Minnesota, Saint Paul, Minnesota 55108, USA. e-mail: isbell@umn.edu.

References

1. Prieto, I. *et al.* *Nature Plants* **1**, 15033 (2015).
2. Schmid, B., Hector, A., Saha, P. & Loreau, M. *J. Plant Ecol.* **1**, 95–102 (2008).
3. Bullock, J. M., Pywell, R. F. & Walker, K. J. *J. Appl. Ecol.* **44**, 6–12 (2007).
4. Finn, J. A. *et al.* *J. Appl. Ecol.* **50**, 365–375 (2013).
5. Hector, A. & Hooper, R. *Science* **295**, 639–640 (2002).
6. Sanderson, M. A. *et al.* *Crop Sci.* **44**, 1132–1144 (2004).
7. Isbell, F. *et al.* *Nature* **477**, 199–202 (2011).
8. Zuppinger-Dingley, D. *et al.* *Nature* **515**, 108–111 (2014).
9. IPCC Summary for Policymakers in *Climate Change 2013: The Physical Science Basis* (eds Stocker, T. F. *et al.*) (Cambridge Univ. Press, 2013).