Within-field crop diversification reduces disease propagation and increases natural enemy abundance in temperate arable systems

Lenora Ditzler[1], Dirk F. van Apeldoorn[1], Walter A. H. Rossing[1]

[1]Wageningen University & Research, Farming Systems Ecology Group

Introduction

A focus on control in industrialized arable cropping has resulted in low-diversity production systems and replacement of ecological processes with non-renewable inputs. These systems are productive, but generate externalities that contribute substantially to undesirable global change. A fundamental redesign of industrial agriculture is now needed to facilitate a paradigm shift away from minimizing damages caused by agriculture and towards maximizing its potential benefits (Tittonell, 2014). We posit that through spatial, temporal, and genetic diversification, cropping systems can be designed to leverage the ecological processes that make biodiverse natural ecosystems productive and resilient. The objective of this study was to investigate the effects of increased within-field spatial and genetic crop diversity on processes of ecological control in temperate arable cropping systems. Through the example of strip cropping (the practice of growing two or more species in alternate, multi-row strips wide enough to allow independent cultivation), we examine the effect of multi-dimensional diversification on disease spread (*Phytophthora infestans*) in potato and potential for biocontrol of aphids in wheat.

Materials and methods

We analysed multi-year data (2012-2017) from two organically managed long-term strip cropping systems experiments in the Netherlands. The experiments were located at the Broekemahoeve Proeftuin near Lelystad and the Droevendaal Experimental Farm in Wageningen. At both locations and for both potato and wheat, two experimental treatments were compared against large-scale sole-cropped reference fields: 1) sole-crop, single cultivar strips, and 2) mixed strips. For potato, mixed strips consisted of a cultivar mixture which included one non-*PI* resistant cultivar and two *PI*-resistant cultivars. For wheat, mixed strips were sown as a polyculture including faba bean in an additive design. All strip treatments were 3 meters wide. In potato, *PI* infection was visually monitored and scored from first observed infection date until crop termination. In wheat, the activity density of epigeic natural enemies of aphids was assessed using pitfall trapping at regular intervals throughout the growing season. Treatment differences were analyzed using generalized linear mixed models and cross-year comparisons were conducted using effect size metrics applied in meta-analyses of ecological data (Fox *et al.*, 2015).

Results & Discussion

We found that *PI* infection in potato was significantly lower in strips ($p < 0.001$) than in the reference across all years at the Broekemahoeve experiment (Fig. 1A). Additionally, within a single growing season (2017 at Droevendaal), the rate of disease spread was slowest in mixed-cultivar strips compared to the reference ($p < 0.01$) (Fig. 1B).

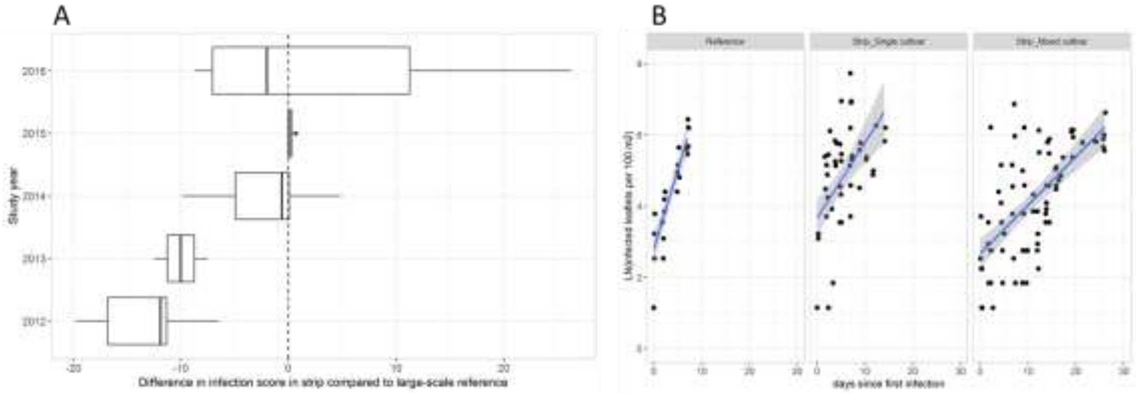

Figure 1. A) Range in absolute difference between *PI* infection scores in potato strips relative to scores in large-scale reference fields at the Broekemahoeve experiment in the Netherlands from 2012-2016. **B)** Disease progress over time in the reference, single cultivar strip, and mixed cultivar strip treatments at the Droevendaal experiment, 2017.

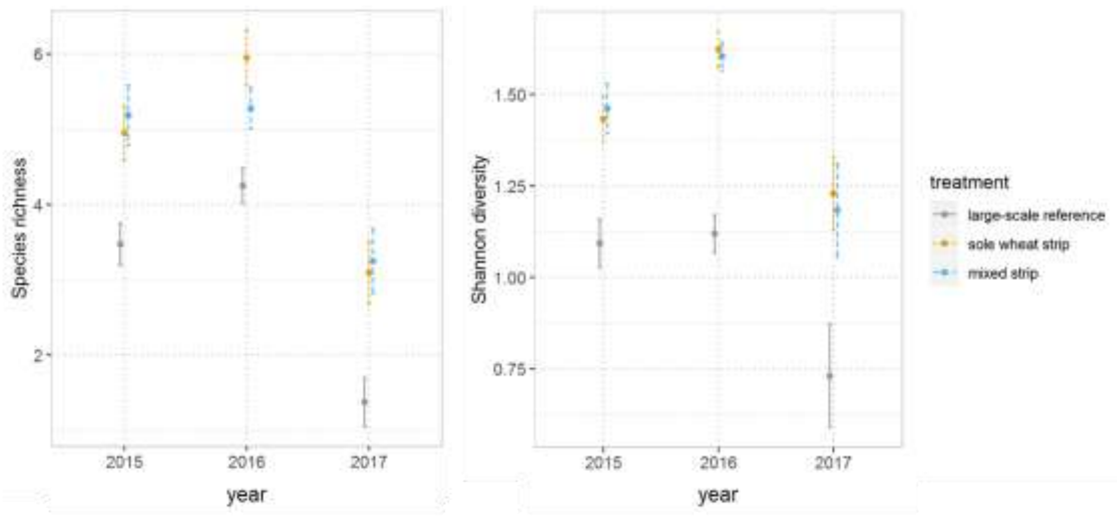

Figure 2. Diversity (species richness, ***left*** and Shannon diversity, ***right***) of epigeic natural enemies of aphids in wheat across three years at the Droevendaal experiment in Wageningen. Means per year in large-scale reference, sole wheat strip, and mixed wheat + faba strip treatments are plotted with error bars showing the standard error of the mean.

In strip-cropped wheat we found larger catches of all epigeic natural enemy groups except *Pterostichus* ground beetles compared to the reference. However, including faba beans in the wheat strips did not significantly increase natural enemy abundance compared to sole wheat strips. Catches in strip treatments scored significantly better ($p < 0.001$) than the reference on two diversity indices (species richness and Shannon diversity), but again there was no difference between sole wheat and mixed-species strips (Fig. 2).

The example of strip cropping provided here illustrates that different dimensions of diversity are needed to activate the delivery of different ecosystem services, as ecological processes operate at different scales. For potato, the stacking of spatial (strip arrangement) and genetic (cultivar mixing) strategies enhanced the benefits of diversification: the spatial dimension reduced total PI infection, and the addition of the genetic dimension slowed disease spread. The movement of *PI* spores occurs at a finer resolution (Skelsey *et al.*, 2005) than the movement of epigeic arthropods, so implementing two diversity measures at once returned increased benefits to disease mitigation. In the case of wheat, however, stacking genetic diversity with spatial diversity did not further enhance biocontrol potential. Here, strip cropping alone led to increased numbers of epigeic natural enemies of aphids, but adding plant-level genetic diversity did not further increase abundance nor diversity since many arthropods operate at a range wider than plant—plant (Tscharntke *et al.*, 2005).

Conclusions

Here we have shown that in some cases, strip cropping single species and cultivars may be enough to deliver the desired service, but in others the addition of the genetic dimension may be beneficial. These results point to the importance of designing cropping systems such that the activated diversity dimensions affect the ecological process scales of the desired ecosystem service(s). Overall, we conclude that strip cropping is a promising strategy for mobilizing the benefits of within-field crop diversity to enhance ecological control potential in temperate cropping systems, particularly because it can be implemented within the mechanical constraints of current farm technology.

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