Intercropping Promotes both Agronomic and Ecological Aims: The Case of Organic Strip Cropped Cabbage (*Brassica oleracea* L.)

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1 Introduction

Input-dependent intensification and ecosystem simplification in industrialized agriculture focuses on the maximization of only one ecosystem service: production. This single focus of yield maximization comes at the expense of other ecosystem services, for instance, sustainable pest control. Optimizing synergies between provisioning and non-provisioning ecosystem services is difficult because often trade-offs are incurred. In highly productive agricultural systems, increases in biodiversity may incur proportionate yield losses and vice versa (Gabriel *et al.*, 2013). In this study, we investigated the potential to simultaneously improve both agronomic and ecological outcomes of cropping systems through the implementation of various intercropping designs. Research has shown that intercropping delivers a higher yield through facilitation and complementarity, while suppressing pest via pest habitat dilution and/or habitat provision for natural enemies (Letourneau *et al.*, 2011; Yu *et al.*, 2015). Utilizing a network of crop diversification experiments across the Netherlands, we analyzed the effect of ten intercropping designs on cabbage yield and quality with the aim to answer two primary questions: 1) What is the effect of different intercropping designs with increasing complexity on cabbage leaf damage by herbivorous pests?; and 2) How does these designs affect cabbage yield? Focusing on the spatial and genetic dimensions of crop diversification, we hypothesized that increased system complexity via intercropping would reduce the magnitude of pest damage and would, therefore, allow organic cabbage growers to increase attainable productivity per plant.

2 Materials and Methods

This study was conducted in four organic farms in the Netherlands from May to November 2018. The agronomic specification of the intercropping designs is summarized in table 1. Cabbage (white cabbage (*Brassica oleracea* L. var. *capitata*) or cauliflower (*Brassica oleracea* L. var. *botrytis*)) was strip cropped in alternating strips with wheat (*Triticum aestivum* L.) or a grass—clover mixture (*Lolium multiforum* L., *Trifolium pratense* L. and *Trifolium repens* L.). In one of the designs, a wildflower strip was sown next to the cabbage strip. The presence of flowering plants supports biological control by parasitoids, though its effectiveness appears to depend on attractiveness and nectar accessibility (Wäckers, 2004).

Table 1. Overview of the experimental setup at the four locations with their associated intercropping designs, crops, sowing dates, fertilization and pesticide application.

Location	Intercropping design	Crop association[1]	Cabbage planting and harvest dates	Fertilizer application for cabbage	Pesticide application for cabbage
1. Droevendaal 0.75m (between-) and 0.38m (within-) row distances	a. Strips/Mono (3m) b. Strips/Substitutive c. Strips/Additive d-f. Strips/Rotation g. Pixel cropping h. Reference (sole crop)	a. W—C(r) b. W—C(r) and C(c) c. B + W—C(r) d-f. W—C(r)—G—L—G—P g. C(r) + C(c) and/or W, R, B, P, L h. C(r)	June 14, 2018 – October 31, 2018	20-25 t FYM + 2 t OPF 11-0-5	No
2. Broekemahoeve 0.75m (between-) and 0.38m (within-) row distances	a. Strips/Mono (3m) b. Strips/Substitutive c. Strips/Additive	a. W—C(r) b. W—C(r) and C(c) c. B + W—C(r)	June 14, 2018 – November 18, 2018	20-25 t FYM + 2 t OPF 11-0-5	No
3. Rozendaal 0.50m (between-) and 0.40m (within-) row distances	a. Strips/Mono (3m) h. Reference (sole crop)	a. R—C(s) h. C(s)	May 8, 2018 – October 12, 2018	30 t/ha liquid manure (5.93 kg/ton N and P)	0.2 L : 500 L /ha Spinosad July 9, 2018
4. ERF 0.75m (between-) and 0.50 (within-) row distances	a. Strips/Mono (6m, 12m, 24m) a. Strips/Mono (24m) h. Reference (48m)	a. G—C(b)—F + G a. G—C(b) —G (sowing error) h. C(b)	July 5, 2018 – October 18, 2018	35 m^3/ha liquid manure	1 kg/ha Xentari (Bt) Sep 17, 2018

[1] Abbreviations:
B: broad bean (*Vicia faba* L.) cultivar Pyramid*;* C(b): cauliflower (*Brassica oleracea* L. var. *botrytis*) cultivar Balboa; C(c): cabbage (*Brassica oleracea* L. var. *capitata*) cultivar Christmas Drumhead; C(r): cabbage (*Brassica oleracea* L. var. *capitata*) cultivar Rivera; C(s): cabbage (*Brassica oleracea* L. var. *capitata*) cultivar Storema; F: wildflower strip; G: grass (*Lolium multiforum* L.); L: leek (*Allium porrum* L.); P: potato (*Solanum tuberosum* L.); R: grass—clover mixture (*Lolium multiforum* L., *Trifolium pratense* L. and *Trifolium repens* L.); W: wheat (*Triticum aestivum* L.)
Bt: *Bacillus thuringiensis,* FYM: farm yard manure; OPF: organic plant fertilizer

3 Results

We quantified fresh weight and leaf damage by herbivorous pests for 476 individual cabbage plants. Across experiment sites, lower herbivore damage and maintained fresh marketable weight were observed in strips designs compared to sole crops. The presence of wildflower strips next to cabbage reduced feeding damage by more than 50% ($F_{4,101} = 13.89$, $P < 0.001$). No correlation was observed between herbivore damage and marketable weight. We found a negative correlation between crop diversity and damage level per cabbage: designs with a higher number of species and/or cultivars exhibited lower feeding damage (Figure 1). For every addition of one species or cultivar, crop damage was reduced by 10% ($F_{1,28} = 18.49$, $P < 0.001$). We observed no clear relationship between crop diversity and fresh marketable weight per cabbage, however, five out of seven intercropping designs produced total yields per area equivalent to the sole-crop reference.

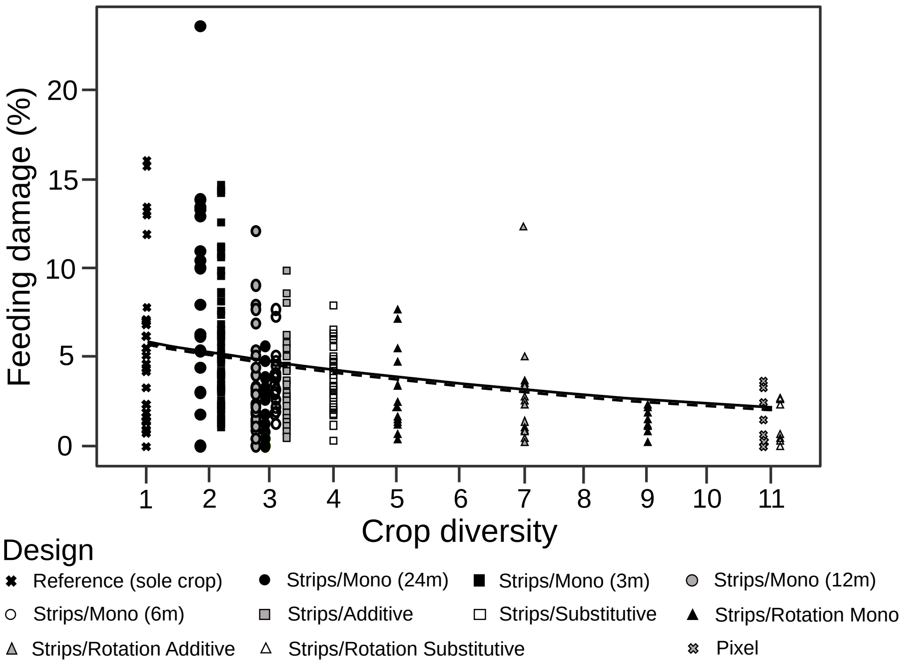

Figure 1. Relationship between crop diversity and feeding damage. The feeding damage was log back-transformed. Crop diversity was measured by summing the number of species in the design including different cultivars (E.g. it is 1 in Reference (sole crop), 2 in Strips/Mono and 4 in Strips/Substitutive). On each graph, two regression lines representing inclusion (dotted line) or exclusion (solid line) of the Pixel cropping design data were plotted; the respective equations are included in the graphs. Asterisks in regression equations indicate a significant fixed effect of crop diversity. Symbol represents design.

4 Discussion and Conclusions

Our results show that crop diversification via strip cropping can promote synergies between agronomic and ecological aims. While we rejected the hypothesis that there would be a direct correlation between damage level and attainable yield, five out of seven intercropping designs were able to maintain yield per unit area. These results provide a starting point for redesigning arable fields to enhance ecological resilience in the transition towards more sustainable farming systems. A better understanding of crop functionality and management needs in diverse arrangements will be relevant for such redesign.

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