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Intercropping for sustainability

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By ZISHEN WANG, BEI DONG, JOCHEM B EVERS, TJEERD-JAN STOMPH, PETER E L VAN DER PUTTEN and WOPKE VAN DER WERF

Centre for Crop Systems Analysis, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands

Summary

Intercropping is a potential pathway for ecological intensification of high input agriculture. There is, however, a shortage of knowledge about which species combinations and which management for intercropping could be advantageous under western European climate conditions. We therefore conducted a 2 year field experiment in the Netherlands to explore the yield advantages of maize, wheat, pea and faba bean when grown as strip intercrops with conventional management and fertiliser input tailored to species strips. Relative yield total (RYT) of relay strip intercrops with maize was well above one, while RYT of simultaneous intercrops without maize was lower than one. Maize and faba bean dominated in mixtures, with their relative yields exceeding the relative density, while pea had relative yields lower than the relative density. Wheat was overyielding when combined with maize but underyielding when combined with faba bean. The results suggest an important role for complementarity for light capture when crops are managed with sufficient nutrients and water. Under such conditions, intercrops with legumes did not perform better than intercrops without legumes. Faba bean manifested itself as a competitive species that dominated companion species with the same growing period.

Key words: Europe, intercropping, species combinations, relative yield

Introduction

Intercropping is the cultivation of more than one crop species on a parcel of land (Vandermeer, 1989) while strip intercropping is a system of intercropping in which species are grown in narrow strips (1–1.5 m wide) with a few rows in each strip (Li *et al*., 2013). Strip intercropping has a long history in China and is still in use in certain agro-ecological contexts where it is chosen by farmers because of efficient land use and good economic outcomes (Huang *et al*., 2015; Hong *et al*., 2017).

Wheat/maize relay strip intercropping was first tested in the Netherlands by Zhu *et al*. (2015) and Gou *et al*. (2016). This relay intercropping system enhances light capture compared to the sole crops and has therefore a land use advantage. Incorporating legumes in intercropping systems can contribute to production of plant protein and to lower nitrogen inputs in agriculture. However, no experience exists with other strip intercropping systems than maize-wheat in oceanic climates in Europe, and there is, for instance, no insight whether strip intercropping with legumes is advantageous compared to monocropping in terms of resource use efficiency and yield when species are managed to have sufficient nutrients. Therefore, in the current study, we ask the question which species combinations offer intercropping yield advantages when crops are managed in accordance with common agriculture practices for northwest Europe, particularly fertiliser input.

Materials and Methods

Field experiments were conducted in Wageningen, The Netherlands, using a randomised block design with 10 treatments and six (2018) or four (2019) replicates. Treatments comprised sole crops of maize, wheat, faba bean and pea, and each of the six bi-specific mixtures of these species. Mixtures were grown using 1.5 m-wide strips of each species. Plant densities in sole crops and within strip of intercrops were common densities used in practice: 383 plants m^{-2} (in 2018) and 369 plants m^{-2} (in 2019) for wheat, 10 plants m^{-2} for maize, 83 plants m^{-2} for pea and 44 plants m^{-2} for faba bean. The three mixtures with maize (maize-wheat, maize-faba bean and maize-pea) were relay-intercrops because maize was sown and harvested later than the other three species. The other three intercrops (faba bean-wheat, faba bean-pea, and wheat-pea) were approximately simultaneous due to similar sowing and harvest dates. Each species was fertilised in its strip according to standard recommendations: 20 kg N ha^{-1} for legumes, 125 kg N ha^{-1} for wheat and 170 kg N ha^{-1} for maize. Sprinkler irrigation was applied to avoid drought stress in summer. 6 m^2 of one species was harvested both in the sole crops and intercrops to determine the grain yield.

Relative yields per species were calculated as $RY_i = Y_i / M_i$ where RY_i is the relative yield of species i, Y_i is its yield in intercropping (per unit area of the whole intercrop), while M_i is the sole crop yield. Species responses in intercropping were characterized by overyielding proportion (OYP, in %), calculated as:

$$OYP = 100 \frac{Y_i - 0.5M_i}{0.5M_i} = 100(2RY_i - 1)$$

where 0.5 is the proportion of a species in the intercrop, and $0.5M_i$ is the expected yield of a species in the intercrop. Temporal niche differentiation is the proportion of the total duration of a crop system, from sowing of the earliest species till harvest of the latest species, that species are not in competition (Yu *et al.*, 2015).

Results

Overyielding proportion of maize varied from 6% when intercropped with faba bean to 30% when intercropped with wheat or pea (Table 1). Wheat had very slight overyielding when intercropped with maize or pea, but strong underyielding (-36%) when combined with faba bean. Pea underyielded in all intercrops, least (-8%) with maize, and most (-40%) with faba bean. Faba bean overyielded in all intercrops, most (30%) in intercrops with maize and least, but still substantially, in intercrops with pea (16%). Relative yield total was well above one in all systems with maize (relay systems due to the difference in growing period between maize and the other species) and close to or below one in systems without maize (all approximately simultaneous) (Table 2).

Average overyielding percentages per row in Table 1 indicate that maize and faba bean produced substantially (17% and 22%) more yield in intercropping than they did in sole crops, whereas wheat and pea produced less (-9% and -21%). Maize, wheat and pea were relatively benign companion crops allowing overyielding in companion species, whereas faba bean was a highly competitive companion species, causing on average 23% yield decline in companion species.

All intercrops with maize had a relative yield total above one, irrespective of whether they included legumes, but all intercrops without maize did not have a relative yield total above one, again irrespective of whether they included legumes (Table 2). Presence of a legume (faba bean or pea) did not systematically affect relative yield total, while faba bean was much more competitive than pea. Thus, pea allowed higher relative yields of its companion crops than faba bean did, but this advantage was offset by a low relative yield of pea.

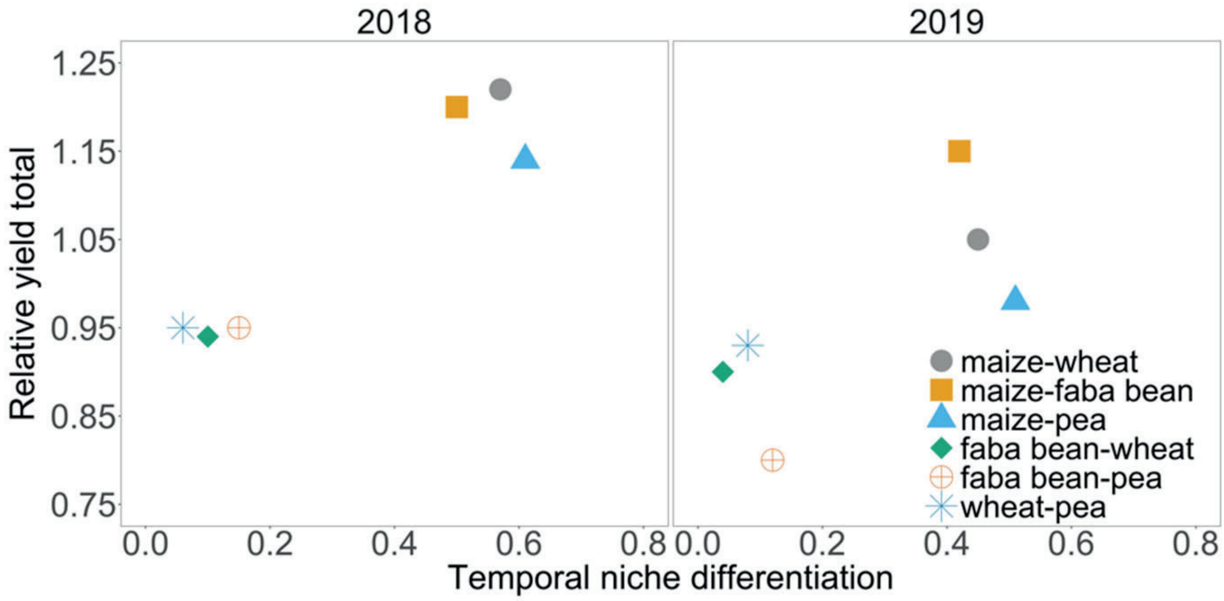

Fig.1 Relationship between temporal niche differentiation and relative yield total in six species combination in strip intercropping experiments in the Netherlands in 2018 and 2019.

Table 1. *Overyielding percentages (averages of 2 years) in strip intercropping of four crop species. Overyielding percentage is given for each species (rows) when combined with different companion species (columns)*

	Companion species				
Crop species	Maize	Wheat	Faba bean	Pea	Average
Maize	-	22	6	22	17
Wheat	6	-	-36	2	-9
Faba bean	30	20	-	16	22
Pea	-8	-14	-40	-	-21
Average	9	9	-23	13	2

Table 2. *Relative yield totals*

	Companion species			
Crop species	Maize	Wheat	Faba bean	Pea
Maize	-	1.14	1.18	1.07
Wheat	1.14	-	0.92	0.94
Faba bean	1.18	0.92	-	0.88
Pea	1.07	0.94	0.88	-

Simultaneous intercropping of cereals and legumes or of two legumes did not offer land use advantages while relay intercropping resulted in consistently larger RYT values, most of them greater than one (Fig. 1).

Discussion

Results of this experiment indicate that temporal complementarity between species was a key factor driving yield advantage in intercrops with maize. Overyielding was only achieved when species could to some extent avoid competition by neighbours, due to differences in growing period. The findings are in agreement with results of global meta-analyses (Yu *et al*., 2015; Li *et al*., 2020). Overall, the taller species gave higher yields, and the shorter species gave lower yields, suggesting that light competition in relation to plant height is a key factor driving competitiveness and relative yield of species. The lack of benefit of legumes in this study contrasts with results obtained at more limiting nutrient input levels in other European experiments, in which incorporation of legumes was beneficial (Bedoussac *et al*., 2015). Overall, the findings indicate that efficient cropping systems at adequate levels of fertiliser input do not require incorporation of legumes but do require temporal complementarity. Thus, this study provides insights that may be used to select well-tailored plant teams for different pedo-climatic conditions, input levels and production objectives.

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