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Intercropping for sustainability: Research developments and their application

Leaf functional traits in maize in intercropping

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Summary

Yield gains in intercropping are greatest in systems with maize. We studied functional trait plasticity in maize leaves in intercrops to assess the possible contribution to crop carbon accumulation. We compared leaves at different growth stages and positions on the maize plant in sole crops and intercrops. Responses of maize leaves to shading from faba bean or wheat as companion species resulted in thinner leaves with a lower nitrogen content per unit leaf area and a lower leaf nitrogen concentration. Photosynthesis was reduced in these thinner leaves with lower nitrogen content. The changes in leaf functional traits were especially apparent in border row maize plants. During late maize development, the photosynthetic capacity of maize leaves in intercrops did not recover from earlier competition. The results show that plasticity in leaf functional traits in intercropped maize in response to wheat and faba bean reduces the potential for crop carbon accumulation.

Key words: Leaf traits, photosynthesis, plasticity, relay intercropping

Introduction

Overyielding in intercrops can result from enhanced resource capture and/or resource conversion. There is ample evidence that complementarity is an important mechanism for increased resource capture and crop yields in intercropping, while modelling studies have shown that plant morphological plasticity plays a role in enhanced light capture in intercropping (Zhu *et al*., 2015). It is largely unknown whether above ground functional trait plasticity in intercrops contributes to a more efficient use of the acquired resources.

Photosynthesis is the primary physiological process driving plant growth and crop production. The rate of photosynthesis in intercrops can differ from that in sole crops, due to the spatial and temporal heterogeneity in resource availability. Inclusion of maize in intercrops is associated with larger intercropping yield benefits (Li *et al*., 2020). The aim of this study was to determine whether maize leaves acclimate to intercropping, and whether maize leaves could have higher carbon accumulation in intercropping than in sole maize. To this end, we analysed the responses of leaf physiological traits of crop plants in maize-wheat and maize-faba bean relay strip intercropping. We compared maize plants at the strip border, which experience great interspecific competition, with plants from inner rows of the strip in intercrops and with sole crops, which experience little interspecific competition.

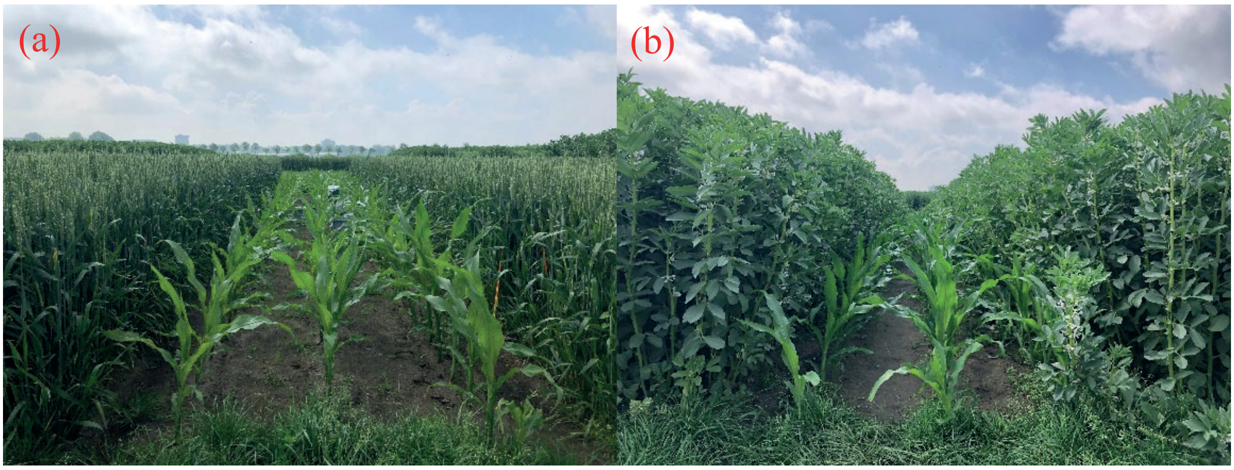

Fig. 1 Maize-wheat relay intercropping (a) and maize-faba bean relay intercropping (b).

Materials and Methods

Field experiments were made in 2018 and 2019 in Wageningen, the Netherlands (51°59'20''N, 5°39'16''E). We compared maize leaf traits in three crop configurations: sole maize, a strip relay intercrop of maize and faba bean, and a strip relay intercrop of maize and wheat (Fig. 1). We used the maize variety 'LG30.223', the faba bean variety 'Nobless', and the wheat variety 'Fanfare'. Maize, faba bean and wheat were grown in 1.5 m-wide strips, with three rows of maize in each strip or six rows of faba bean or wheat. The relative density (intercrop relative to sole crop) was for all species equal to 0.5. The experimental design was a randomised complete block design with six replicates in 2018 and four replicates in 2019. Total nitrogen application was 170 kg N ha^{-1} in maize strips, 20 kg N ha^{-1} in faba bean strips, and 125 kg N ha^{-1} in wheat strips.

Leaf photosynthetic rate (μmol m^{-2} s^{-1}), stomatal conductance for water (mol m^{-2} s^{-1}; g_{sw}), specific leaf area (cm^2 leaf area kg^{-1} leaf dry matter; SLA), leaf nitrogen concentration (kg N kg^{-1} leaf DM), specific leaf nitrogen (kg N m^{-2} leaf area; SLN), and chlorophyll content (SPAD) were quantified in upper and lower leaves in both inner and border rows of maize strips at the V6, R1 and R4 stage of maize in 2019. At the V6 stage, one leaf per plant was selected, which was leaf 6. At the R1 and R4 stage, leaves 7 and 14 were selected. We used two portable photosynthesis systems (LI-6400XT, USA; LI-6800, USA) to measure leaf photosynthesis. The greenness of the leaf, as a proxy of chlorophyll content, was measured using a SPAD Meter (SPAD-502, Minolta Camera, Tokyo Japan). The area of the leaf blade, excluding the midrib, was measured using a leaf area meter (LI-3100 area meter USA). Leaf N concentration was analysed using an element C/N analyser (Flash 2000, Thermo Scientific) based on the Micro-Dumas combustion method. Distribution of photosynthetically active radiation (PAR) in the maize canopy was measured using a SunScan canopy analysis system (SunScan SS1, Delta-T Devices Ltd, UK). Light measurements were done at the R4 stage of maize in 2018, and the V6, R1 and R4 stage in 2019.

Results

At the V6 stage, intercropped maize plants were still small and shaded by wheat or faba bean. Maize leaves in intercrops showed shade adaptation with higher SLA (thinner leaves), lower SLN, and SPAD than leaves of sole maize. The changed leaf traits were especially apparent in border row maize plants adjacent to faba bean. Maize leaves in border row maize intercropped with faba bean had higher SLA, lower SLN and lower leaf photosynthetic rate than maize leaves in sole maize, inner row maize intercropped with faba bean, and both border row and inner row maize intercropped with wheat. These changes in maize indicate that shading by early sown species caused changes in maize functional leaf traits in intercropping. Later, at the R1 and R4 stages, maize leaf 14 in intercrops had better light conditions than leaves with the same rank in sole maize, due to the lower plants of the companion crop. Leaf photosynthetic rate of leaf 14 in intercropped maize was not higher than that of leaf 14 in sole maize. Competition with wheat and faba bean in intercrops resulted in lower leaf N concentration than sole maize, especially border row maize.

Table 1. *Leaf traits of maize in sole maize, both border row and inner row maize in maize-faba bean intercropping (MB-Border; MB-Inner), and both border row and inner row maize in maize-wheat intercropping (MW-Border; MW-Inner) at maize V6, R1 and R4 stages*

Stage	Leaf	Treatment	SLA (m^2 leaf g^{-1} leaf)	NC (mg N g^{-1} leaf)	SLN (g N m^{-2} leaf)	SPAD	Photosynthesis (µmol CO_2 m^{-2} s^{-1})
V6	leaf 6	Sole maize	245	40	1.7	54	44
		MB-Border	366	42	1.2	50	36
		MB-Inner	315	42	1.4	49	41
		MW-Border	288	39	1.4	47	39
		MW-Inner	279	39	1.5	51	44
		LSD	17.8	1.7	0.1	4	5
R1	leaf 14	Sole maize	191	34	1.8	58	42
		MB-Border	203	31	1.5	49	42
		MB-Inner	184	33	1.8	54	43
		MW-Border	183	31	1.7	54	42
		MW-Inner	173	33	1.9	57	42
		LSD	18.2	2.4	0.2	5	4
R4	leaf 14	Sole maize	157	27	1.7	57	39
		MB-Border	184	25	1.3	49	36
		MB-Inner	153	25	1.6	53	37
		MW-Border	149	24	1.5	53	36
		MW-Inner	147	23	1.5	50	34
		LSD	9.14	2.8	0.2	4	5

Discussion

As compared to sun leaves, shade leaves are thinner (higher SLA), have a lower leaf nitrogen content (SLN) and lower leaf photosynthetic rate (Anten *et al*., 1995), which was confirmed in the responses of maize leaves to the shading from early sown crops during early maize growth stage. Intercropped maize had lower leaf nitrogen concentration and leaf nitrogen content than sole maize, indicating interspecific nitrogen competition with companion crops, confirming results of Gou *et al*. (2018). Overall, the results show that maize leaves acclimate to the changed availability of light and nutrients under intercropping conditions, but not enough to compensate for the heavy competition early in the crop season. We did not find evidence that maize leaves in intercropping have leaf traits that would enable an increased resource use efficiency. Hence, we infer that overyielding in intercrops with maize is mostly due to enhanced light interception rather than enhanced light use efficiency. Further work is ongoing to test this conjecture.

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