Biomass and nitrogen accumulation of hairy vetch–cereal rye cover crop mixtures: a meta-analysis

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Introduction

Cover crops provide several important services in agroecosystems, but individual cover crop species vary in their capacity to provide specific services:

- Grasses (e.g. cereal rye, *Secale cereale* L.) provide excellent N scavenging and weed suppression,
- Legumes (e.g. hairy vetch, *Vicia villosa* Roth.) fix atmospheric N_2 and release plant-available N.

Hairy vetch–cereal rye mixtures can provide the services lent by the component species. They can also produce more biomass and accumulate more N than one or both of the species in monoculture.

Objectives

- To determine the extent that hairy vetch–cereal rye mixtures outperform monocultures in terms of biomass production and N content.
- To determine the effects of environmental and management variables on the biomass and N content of mixtures relative to monocultures.

Literature review and data collection

Data were collected from published studies that reported biomass and N content of cereal rye monocultures, hairy vetch monocultures, and hairy vetch–cereal rye mixtures. We also included data from an unpublished study conducted by the authors (Table 1).

Table 1. A summary of the studies used in the cover crop mixture meta-analysis.

Reference	Location	No. site-years[1]	Factors[2]	n[3]
Clark et al. 1994	MD	2	KD, SR	24
Ranells and Wagger 1996	NC	2	-	2
Clark et al. 1997	MD	4	KD	8
Teasdale and Abdul-Baki 1998	MD	2	-	2
Kuo and Jellum 2002	WA	4	-	4
Ruffo and Bollero 2003	IL	4	-	4
Sainju et al. 2005	GA	3	-	3
Clark et al. 2007	MD	2	N	5
Parr et al. 2011	NC	2	KD	8
Hayden et al. 2014	MI	2	SR	10
Poffenbarger et al. (accepted)	MD	4	SR	16
Total		31		86

[1]The number of site-years from each study used in our review. For some studies, not all site-years met criteria for inclusion in our analysis.
[2]KD= kill date, SR = mixture seeding rate, N = soil inorganic N.
[3]The number of unique cases from each study used in the meta-analysis

Means and standard deviations from every site-year and factor level (i.e. each case) were entered into a spreadsheet individually. The summary statistics for the data gathered from all 11 studies are presented in Figure 1.

The following variables were recorded for each case:

- Hairy vetch sown proportion in mixture,
- Sum of sown proportions,

$$Sum\ of\ sown\ proportions = \left(\frac{Hairy\ vetch\ seeding\ rate_{mixture}}{Hairy\ vetch\ seeding\ rate_{mono}}\right) + \left(\frac{Cereal\ rye\ seeding\ rate_{mixture}}{Cereal\ rye\ seeding\ rate_{mono}}\right)$$

- Growing degree days (base = 4^o C).

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Meta-analytical methods

For each case, the yield (biomass or N content) of the mixture was compared to that of each monoculture using the log response ratio:

$$\ln(Response\ Ratio) = \ln\left(\frac{Yield_{mixture}}{Yield_{mono}}\right)$$

The log response ratios were calculated using three different monocultures:

- Hairy vetch,
- Cereal rye,
- The monoculture with the greatest yield within each case (Max).

The log response ratios were analyzed using mixed-effects linear models in S Plus (package nlme; Pinheiro et al. 2013). The models included:

- Weights based on the log response ratio variances,
- Site-year and study as nested random effects,
- Error variance set as a fixed constant.

Summary statistics

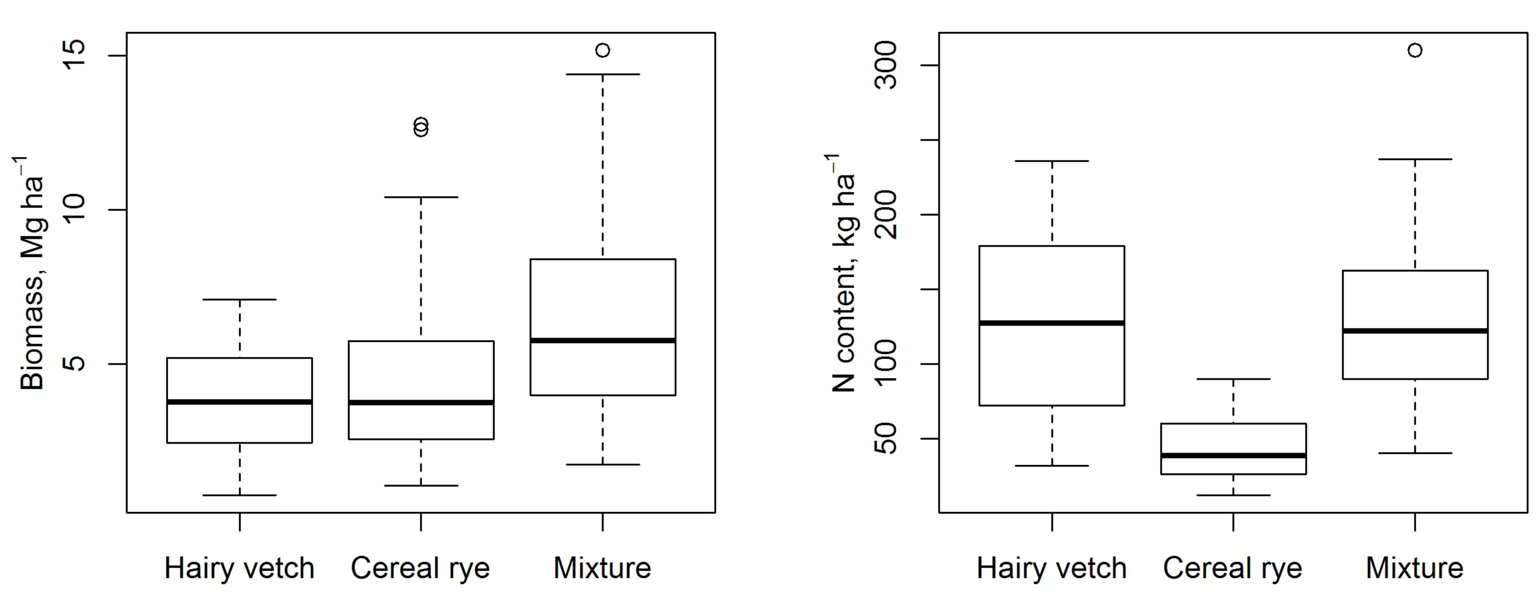

Figure 1. Box and whisker plots for biomass (left panel) and N content (right panel) of hairy vetch monocultures, cereal rye monocultures, and hairy vetch–cereal rye mixtures.

Biomass and N content of mixtures relative to monocultures

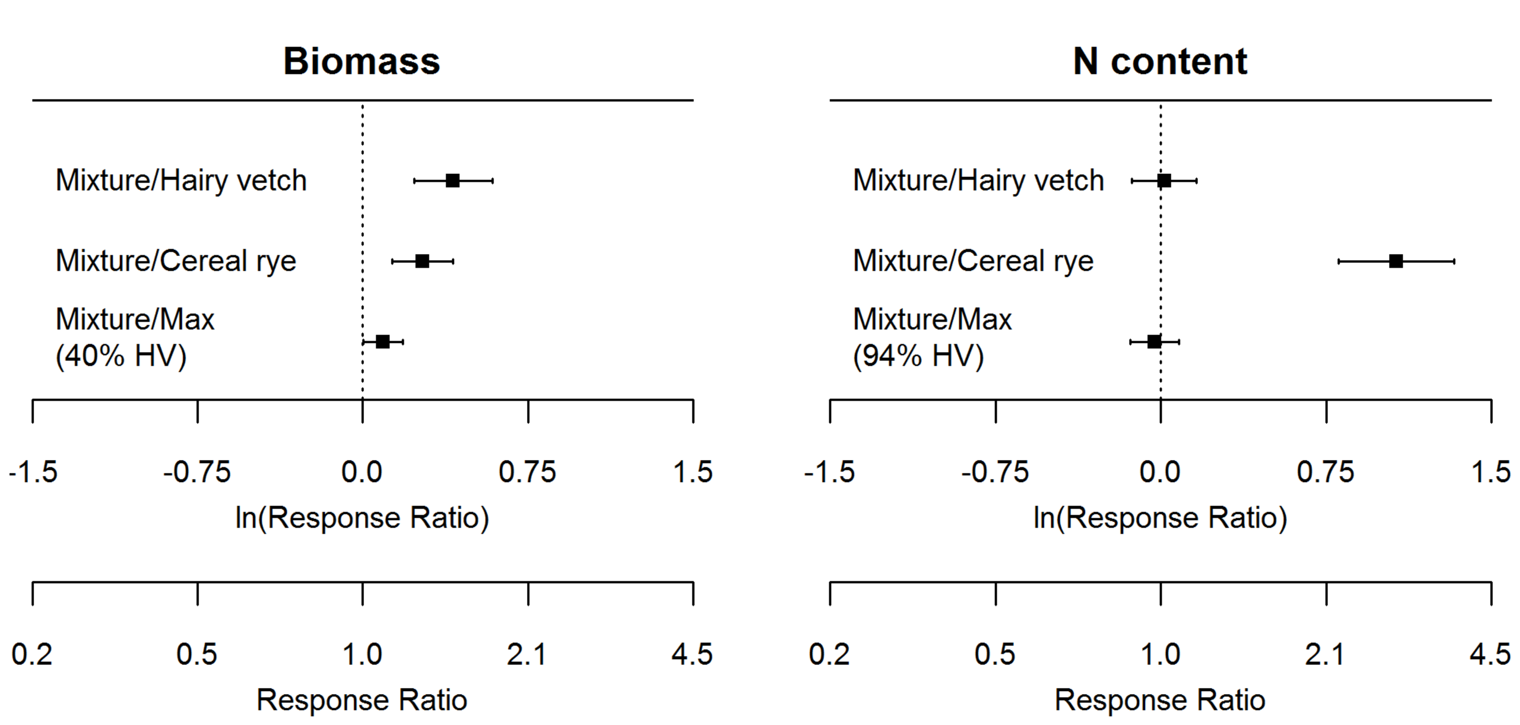

Figure 2. The biomass (left panel) and N content (right panel) log response ratios for cover crop mixtures relative to hairy vetch monocultures, cereal rye monocultures, and the monocultures with greatest yield in terms of biomass or N content (Max). The values in parentheses after the "Mixture/Max" label indicate the percentage of the cases in which hairy vetch was the maximum monoculture. Error bars are 95% confidence intervals.

- Hairy vetch–cereal rye mixtures outperformed hairy vetch monocultures by 50% and cereal rye monocultures by 30% terms of biomass production, and marginally outperformed the more productive of the two monocultures (Max) (Figure 2 left panel).
- The N content of mixtures was similar to the N content of hairy vetch monocultures and the monocultures with greatest N content (Max), but nearly three times that of cereal rye monocultures (Figure 2 right panel).

Factors affecting biomass and N content of mixtures

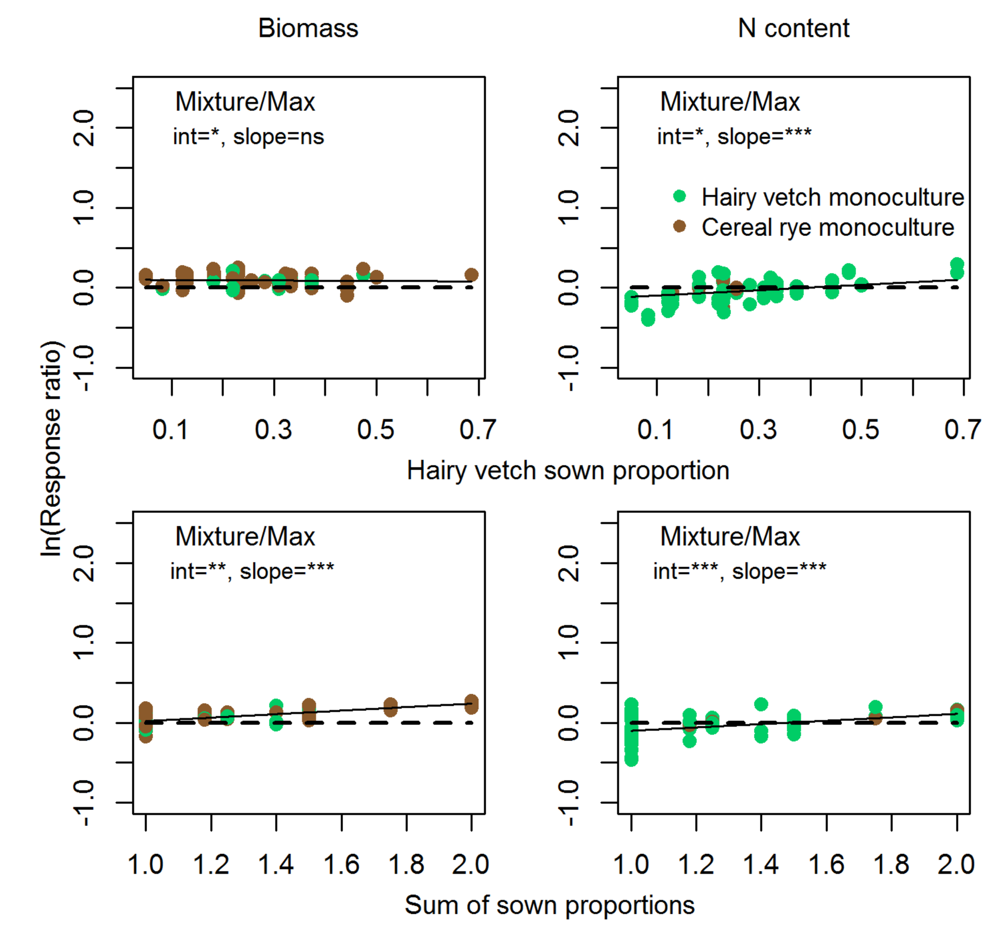

*Figure 3. The relationship between seeding rate variables and biomass (left panels) and N content (right panels) log response ratios for cover crop mixtures relative to the monocultures with greatest yield in terms of biomass or N content (Max). Dashed lines represent the log response ratio corresponding to equivalent performance of mixtures and monocultures. Symbols are used to indicate P values associated with intercept and slope estimates: "ns" not significant, * P<0.05, ** P<0.01, *** P<0.001.*

As the hairy vetch sown proportion increased:

- The N content of mixtures increased relative to the N content of Max monocultures (Figure 3 top right).
- Mixtures accumulated more N than the monocultures with greatest N content when at least 44% of the mixture seeding rate was hairy vetch.

As the sum of sown proportions increased:

- The biomass and N content of mixtures increased relative to the biomass and N content of Max monocultures (Figure 3 bottom panels).
- The biomass and N content of mixtures were similar to the biomass and N content of the Max monocultures at a sum of sown proportion near one.

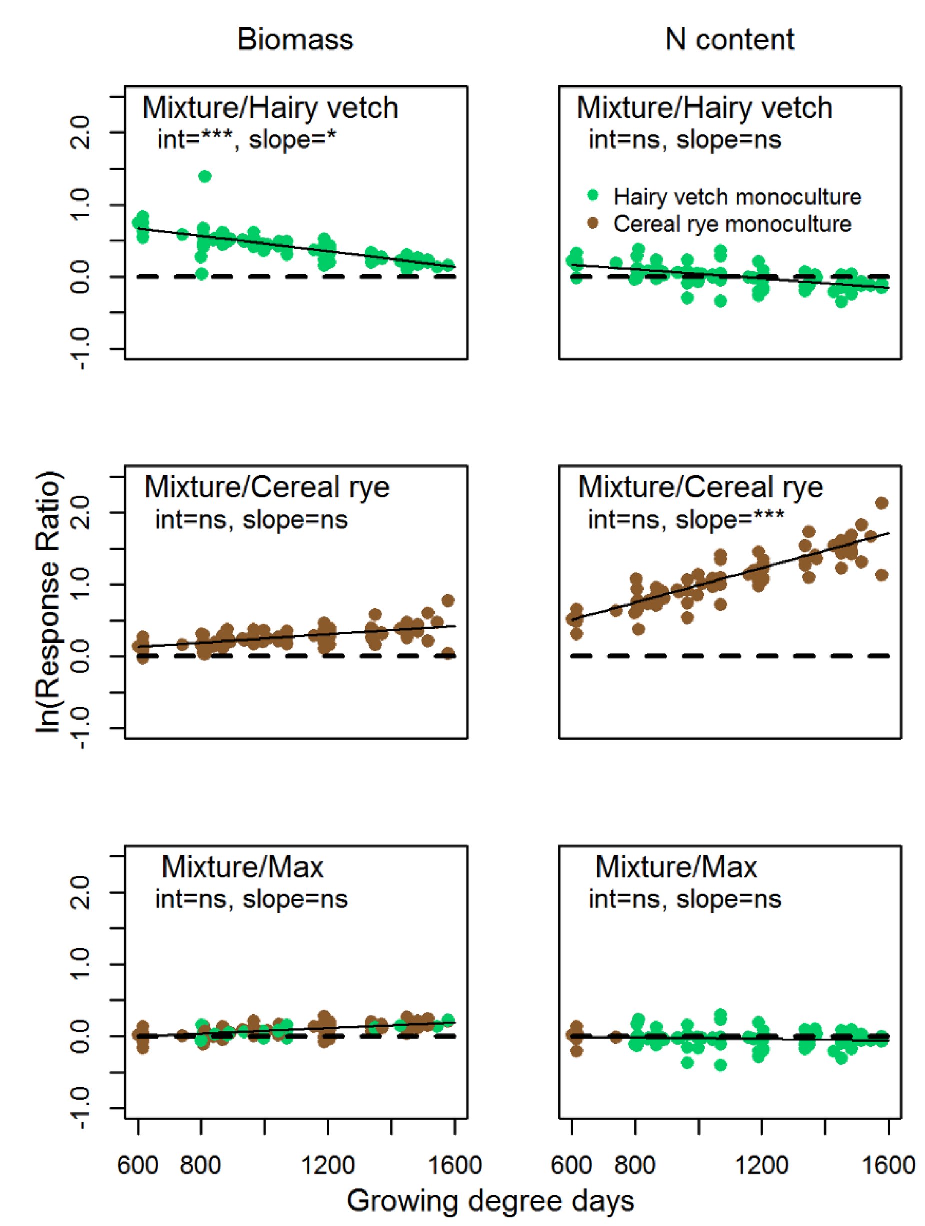

*Figure 4. The relationship between growing degree days and biomass (left panels) and N content (right panels) log response ratios for cover crop mixtures relative to hairy vetch monocultures, cereal rye monocultures, and the monocultures with greatest yield in terms of biomass or N content (Max). Dashed lines represent the log response ratio corresponding to equivalent performance of mixtures and monocultures. Symbols are used to indicate P values associated with intercept and slope estimates: "ns" not significant, * P<0.05, ** P<0.01, *** P<0.001.*

As growing degree days increased:

- The biomass of mixtures decreased relative to the biomass of hairy vetch monocultures, while the N content of mixtures increased relative to the N content of cereal rye monocultures (Figure 4 top left and middle right).
- These trends may reflect slower growth of hairy vetch than cereal rye in fall and early spring, followed by rapid hairy vetch growth in late spring.

Conclusions

Hairy vetch–cereal rye mixtures produced more biomass than both monocultures and accumulated as much N as hairy vetch monocultures. The proportion of hairy vetch seed in mixture, amount of seed applied in mixture, and the number of growing degree days accumulated during cover crop growth all affected how mixtures performed relative to monocultures.