Neutral weed community: the junction point between crop production, biodiversity and ecosystem services

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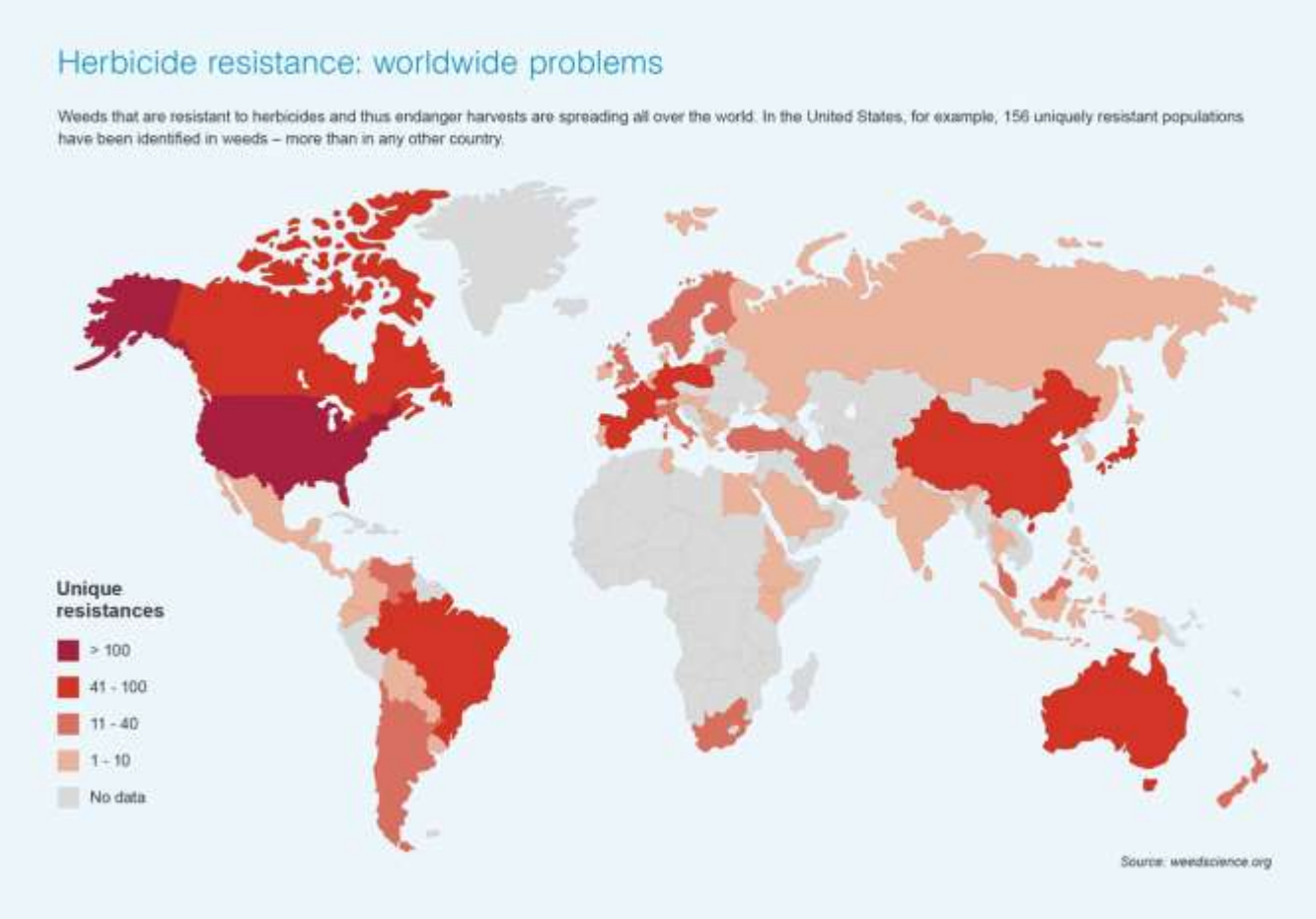
Background

Herbicide application



273 species (156 dicots and 117 monocots)

Resistance to 21 of the 31 known herbicide sites of action

Herbicide-resistant weeds have been reported in 101 crops in 72 countries

Heap, I. The International Herbicide-Resistant Weed

Background

Intensive Soil Tillage

Do not allow for weed control during the whole cultivation season

Expensive and laborious

Alteration of soil physicochemical properties and biological communities

Source: https://www.vaderstad.com/ca-en/know-how/farming-practises/conventional-tillage

Neutral weed communities

- Identification of new weed management strategies to reduce the application of herbicides and soil tillage while maintaining crop yield, ecosystem service provision, and biodiversity

- Strategies that reflect the knowledge about the ecological interactions between weeds and crops

- We introduce the concept of *Neutral Weed Communities*

- These are communities that coexist with the crops and do not significantly reduce crop yield or quality compared to weed-free conditions

Evidence of neutral weed communities

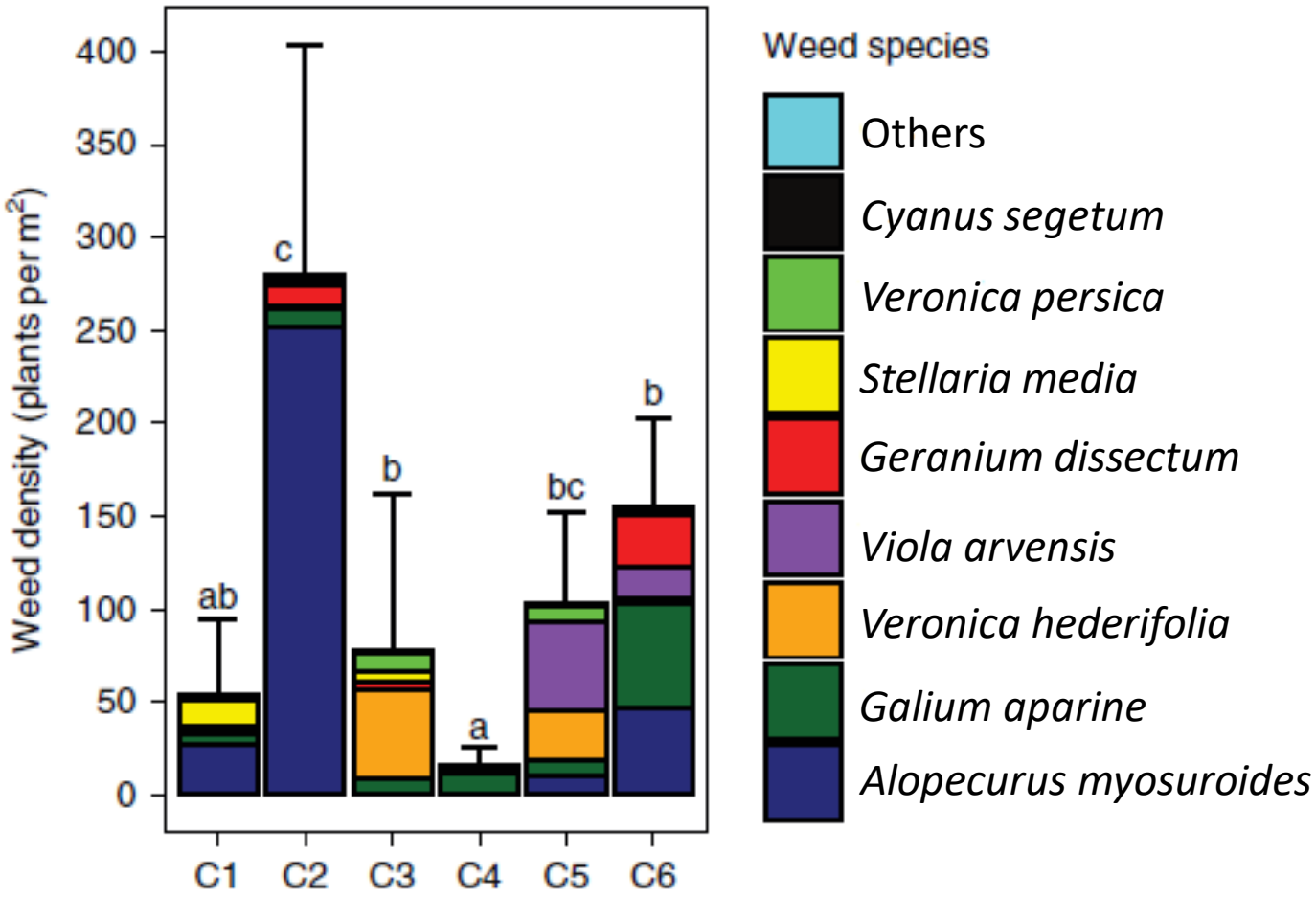


Fig.1 Observed mean weed density and composition in the six Weed community clusters (denoted C1 to C6) obtained by hierarchical classification

- Experiment conducted in France to study the effects of different weed communities on winter cereal growth and production
- Three years of observations of weed densities, weed biomass and crop biomass at four critical growth stages of winter cereals

Adeux, et al. "Mitigating crop yield losses through weed diversity." *Nature Sustainability* 2.11 (2019): 1018-1026.

Evidence of neutral weed communities

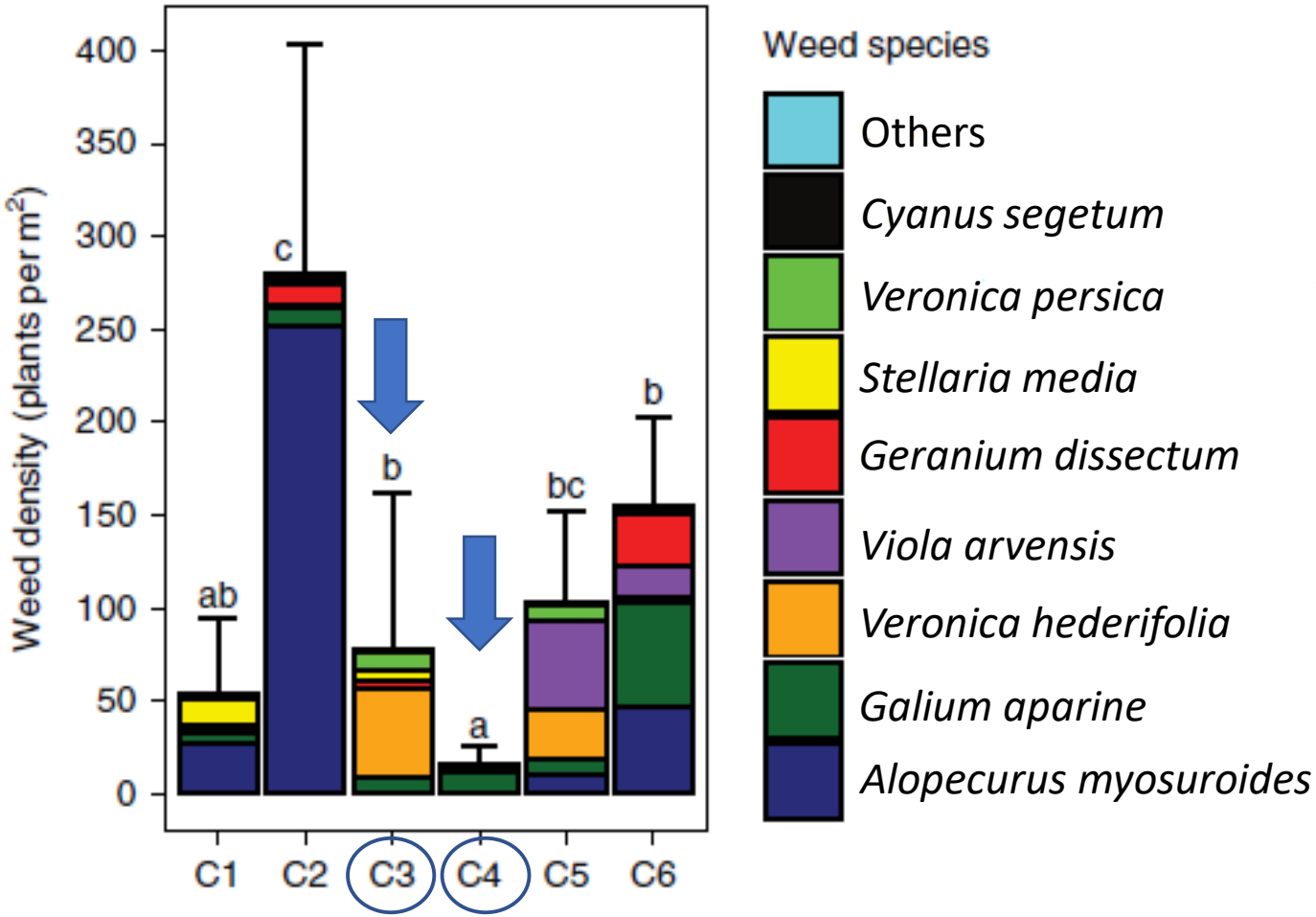
Management type	Response variables	WCC	Weed-free	Weedy	% difference	*P* value
NWC	Number of ears per plant	C1	2.42 (0.13)	1.90 (0.11)	22	**0.0004**
		C2	2.81 (0.18)	1.71 (0.11)	39	**<0.0001**
		C3	1.92 (0.13)	1.94 (0.13)	−1	0.87
		C4	2.34 (0.15)	2.12 (0.14)	9	0.2
		C5	2.21 (0.12)	1.86 (0.10)	16	**0.0096**
		C6	2.09 (0.13)	1.43 (0.09)	31	**<0.0001**
	Number of grains per ear	C1	30.5 (1.1)	26.7 (1.0)	12	**0.0094**
		C2	32.4 (1.4)	21.5 (1.0)	34	**<0.0001**
		C3	34.0 (1.5)	31.1 (1.4)	9	0.1
		C4	33.5 (1.4)	31.6 (1.3)	6	0.29
		C5	31.0 (1.1)	27.6 (1.0)	11	**0.015**
		C6	30.3 (1.2)	24.5 (1.0)	19	**0.001**
	1,000-kernel weight (g)	C1	34.9 (1.1)	34.6 (1.1)	1	0.76
		C2	33.4 (1.2)	33.0 (1.4)	1	0.8
		C3	34.9 (1.4)	36.5 (1.4)	−5	0.17
		C4	34.0 (1.3)	34.9 (1.3)	−3	0.42
		C5	35.0 (1.2)	35.5 (1.2)	−1	0.63
		C6	35.3 (1.2)	28.6 (1.1)	19	**<0.0001**
	Grain yield (g m^{-2})	C1	560 (34)	419 (25)	25	**0.0007**
		C2	588 (42)	258 (18)	56	**<0.0001**
		C3	534 (40)	522 (39)	3	0.78
		C4	588 (41)	538 (38)	8	0.35
		C5	548 (33)	445 (27)	19	**0.01**
		C6	518 (35)	254 (17)	51	**<0.0001**

Table 1 Effect of weed communities on grain yield and yield components. Pre-planned contrasts between weed-free and weedy quadrats are shown for three different yield components (number of ears per plant, number of grains per ear and 1,000-kernel weight) and grain yield.
Source: Adeux et al., 2019

- C1, C2, C5, and C6 (*detrimental communities*) resulted in significant reductions in grain yield and yield components compared to weed-free treatment
- C3 and C4 (*neutral communities*) did not affect the yield components or grain yield compared to weed-free treatment

Adeux, et al. "Mitigating crop yield losses through weed diversity." *Nature Sustainability* 2.11 (2019): 1018-1026.

Evidence of neutral weed communities



- Density is not always a good predictor of the weed competitive potential (i.e., C4 vs C1)
- Weed species composition is the main driver of weed community competitive potential

Fig.1 Observed mean weed density and composition in the six Weed community clusters (denoted C1 to C6) obtained by hierarchical classification

Adeux, et al. "Mitigating crop yield losses through weed diversity." *Nature Sustainability* 2.11 (2019): 1018-1026.

Evidence of neutral weed communities

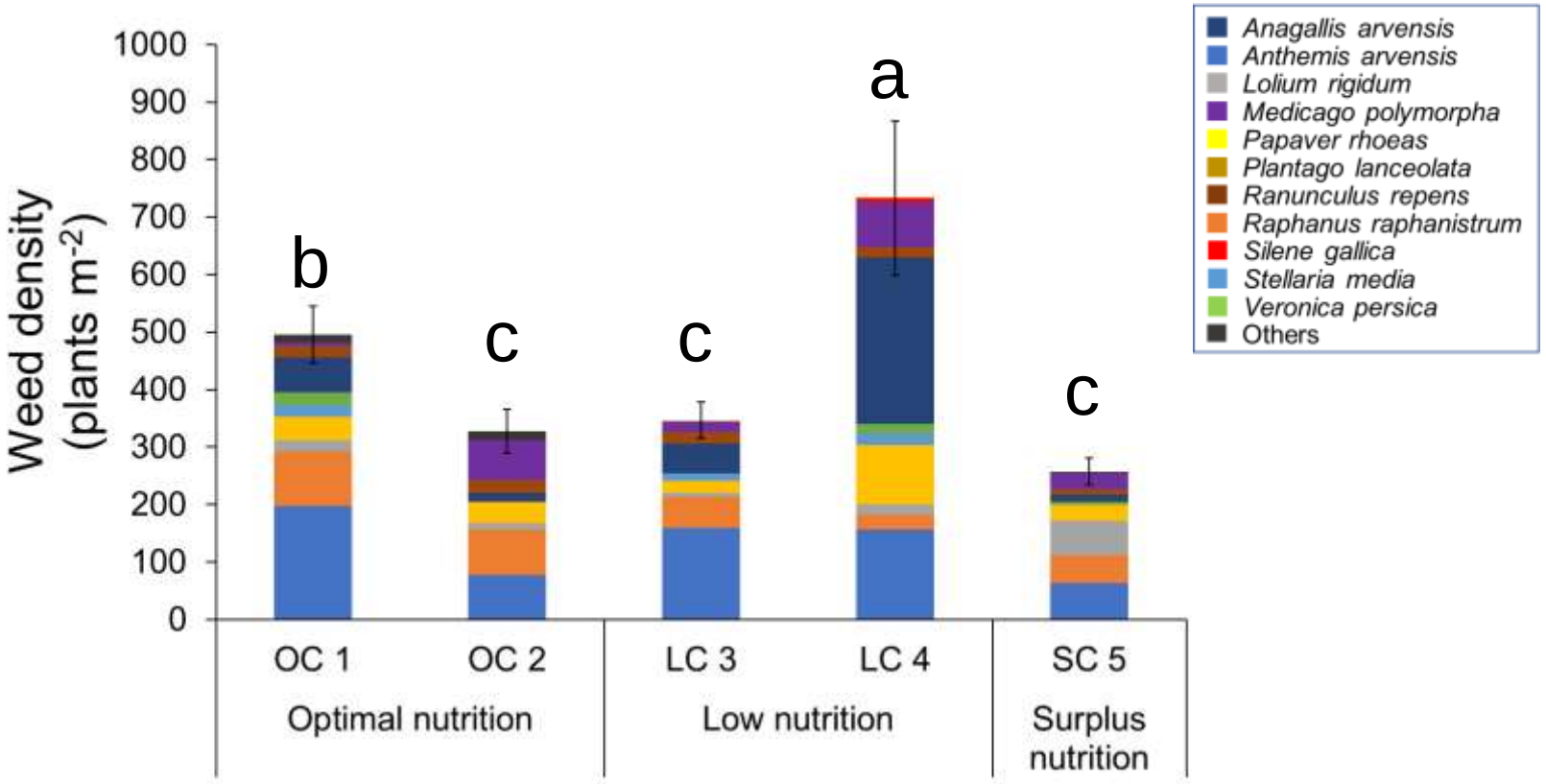


Fig.2 Weed community clusters identified by hierarchical cluster analysis and their density under optimal, low, and surplus nutritional treatments

OC (1,2): weed communities under optimal nutrition;
LC (3,4): weed communities under low nutrition;
SC5: weed community under surplus nutrition.

- Experiment conducted in Italy to study the effect of three nutritional treatments (optimal, low, and surplus) on weed community formation
- Studying the effects of different weed communities on winter wheat growth and production

Esposito et al., *2023*

Evidence of neutral weed communities

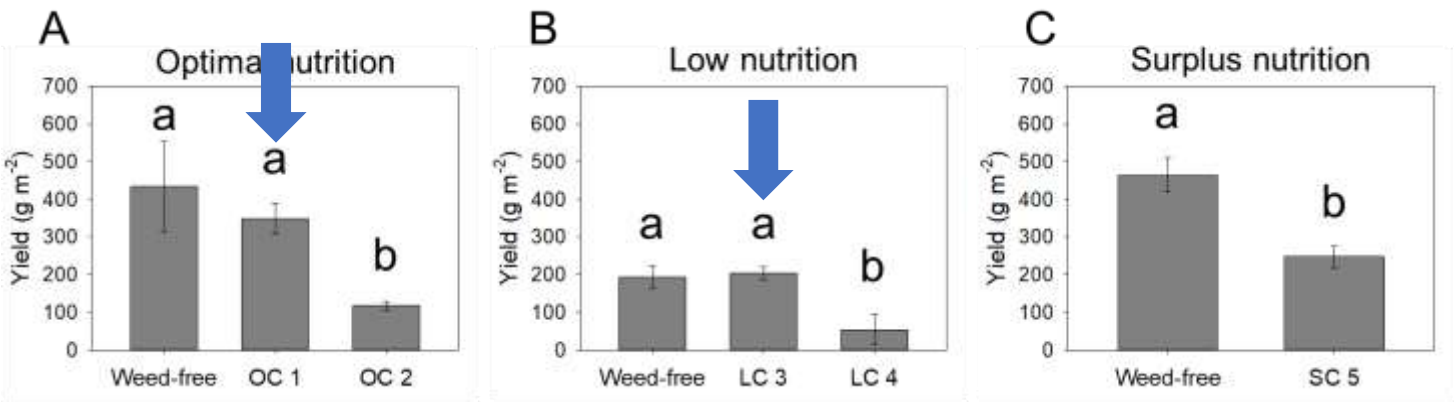


Fig.3 Wheat yield at ripening stage without (weed free) or with the presence of weed community clusters under optimal (A), low (B), and surplus (C) nutritional treatments

OC (1,2): weed communities under optimal nutrition
LC (3,4): weed communities under low nutrition
SC5: weed community under surplus nutrition

- OC2, LC4, and SC5 (*detrimental communities*) negatively affected the wheat yield
- OC1 and LC3 (*neutral communities*) did not significantly affect the wheat yield

Evidence of neutral weed communities

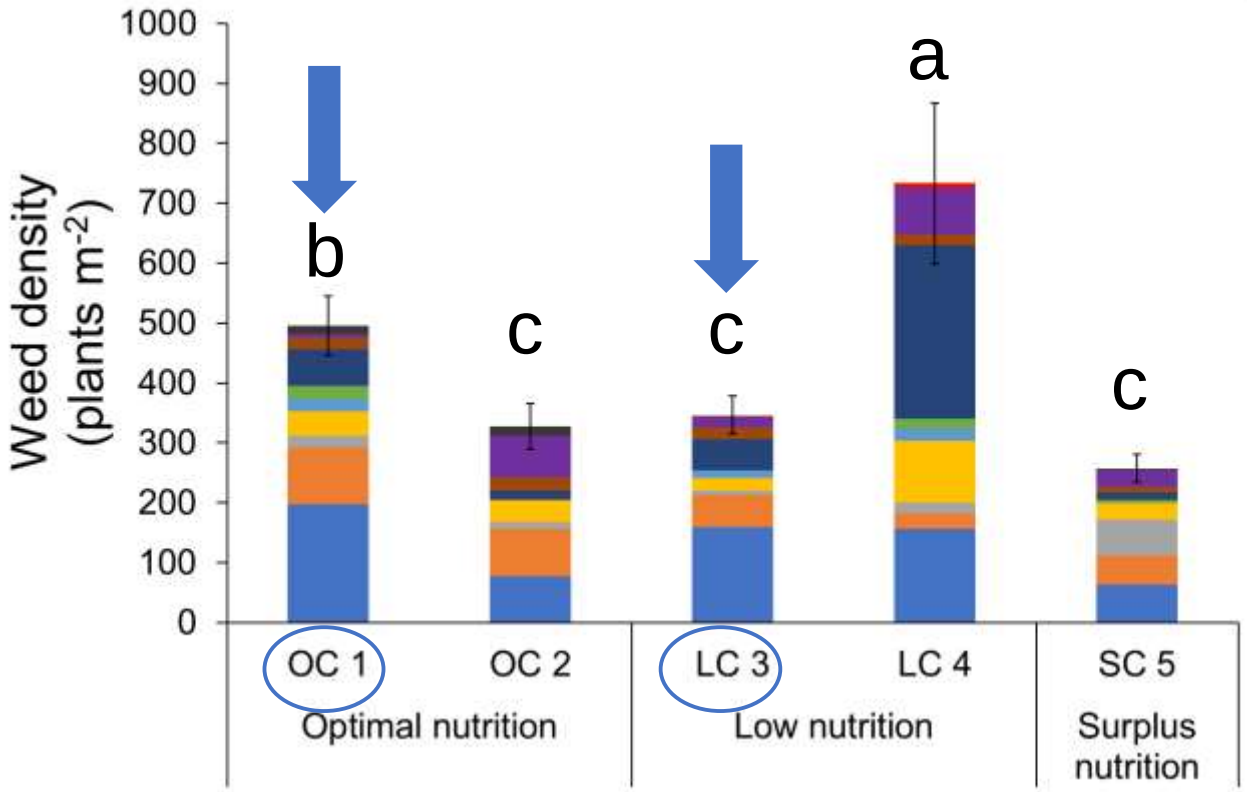
Treatments		Protein	Hectoliter weight	Carotenoids	1000 seeds weight	Gluten content	Kernels Moisture
		% d.m.	Kg 100 L^{-1}	ppm	g	% d.m.	%
Optimal nutrition	Weed-free	17.8 a	81.5 a	4.5	35.6	13.6 a	11.6
	OC 1	15.1 b	85.2 a	4.1	32.4	10.2 b	11.5
	OC 2	15.9 b	78.5 b	4.7	30	10.8 b	11.6
p-value		*	*	ns	ns	*	ns
Low nutrition	Weed-free	13.2	83.5 a	3.9	34 a	8.1	11.5
	LC 3	11.04	80.4 b	3.7	34.3 a	5.5	11.3
	LC 4	12.8	80.7 b	4.7	28.9 b	7.7	11.3
p-value		Ns	*	ns	*	ns	ns
Surplus nutrition	Weed-free	17.3	76	4.8	31.4	12.4	11.53
	SC 5	17.5	73.6	5	29	13	11.54
p-value		Ns	ns	ns	ns	ns	ns

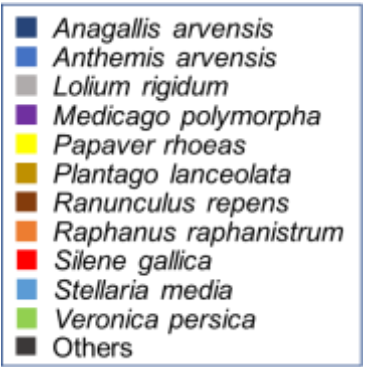
Table 2 Wheat kernel and flour qualitative parameters without (weed free) or with the presence of weed clusters under optimal, low, and surplus nutrition treatments

OC (1,2): weed communities under optimal nutrition
LC (3,4): weed communities under low nutrition
SC5: weed community under surplus nutrition

- OC2, LC4 (*detrimental communities*) negatively affected the wheat kernel qualitative parameters compared to weed-free treatments
- OC1 and LC3 (*neutral communities*) did not significantly affect most of the kernel qualitative parameters compared to weed-free treatments

Evidence of neutral weed communities





- Density is not always a good predictor of the weed's competitive potential
- Weed species composition is the main driver of competitive potential

OC (1,2): Weed communities under optimal nutrition
LC (3,4): Weed communities under low nutrition
SC5: Weed communities under low nutrition

Source: **Esposito** *et al.*, 2023

Evidence of neutral weed communities

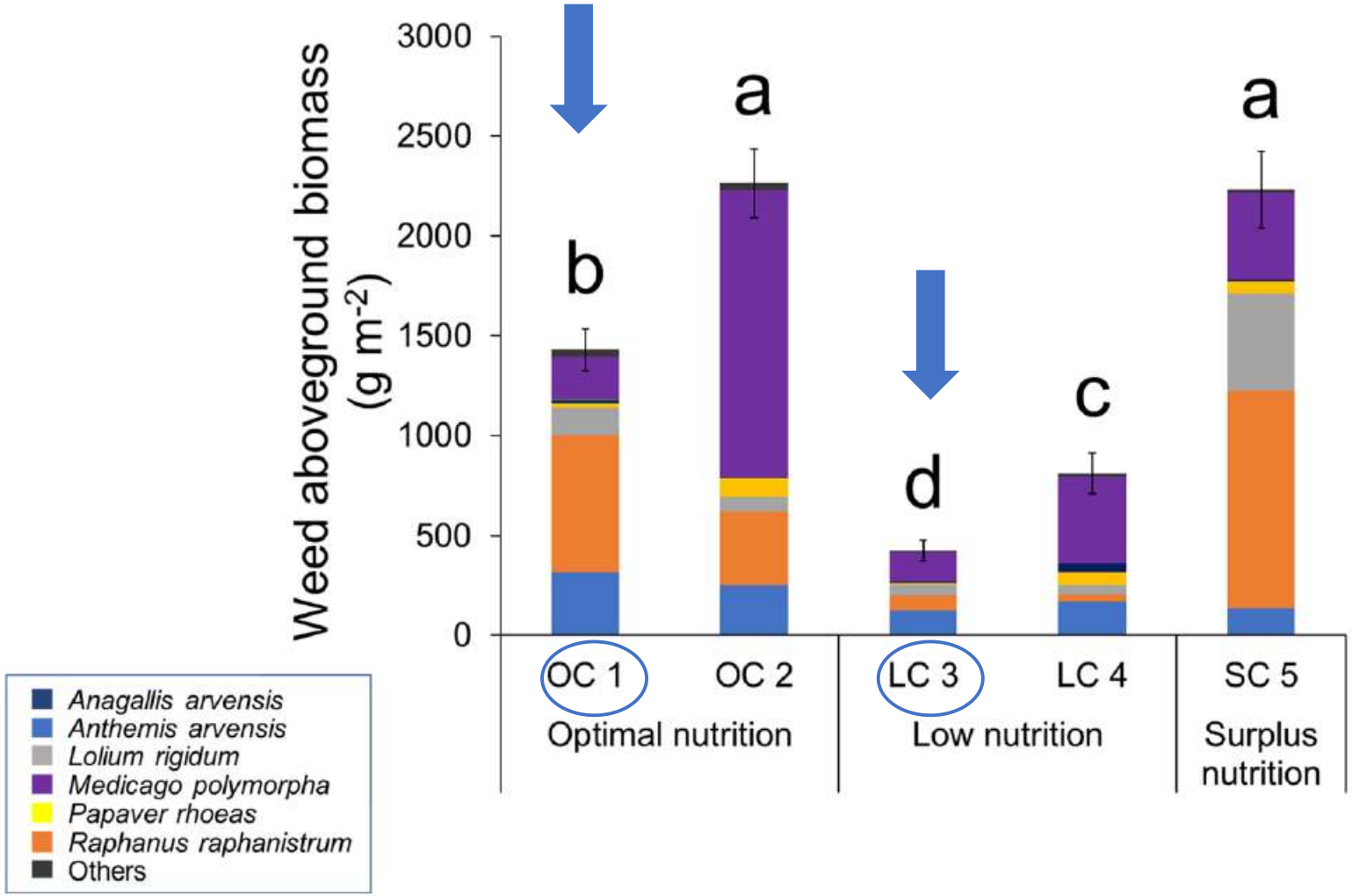
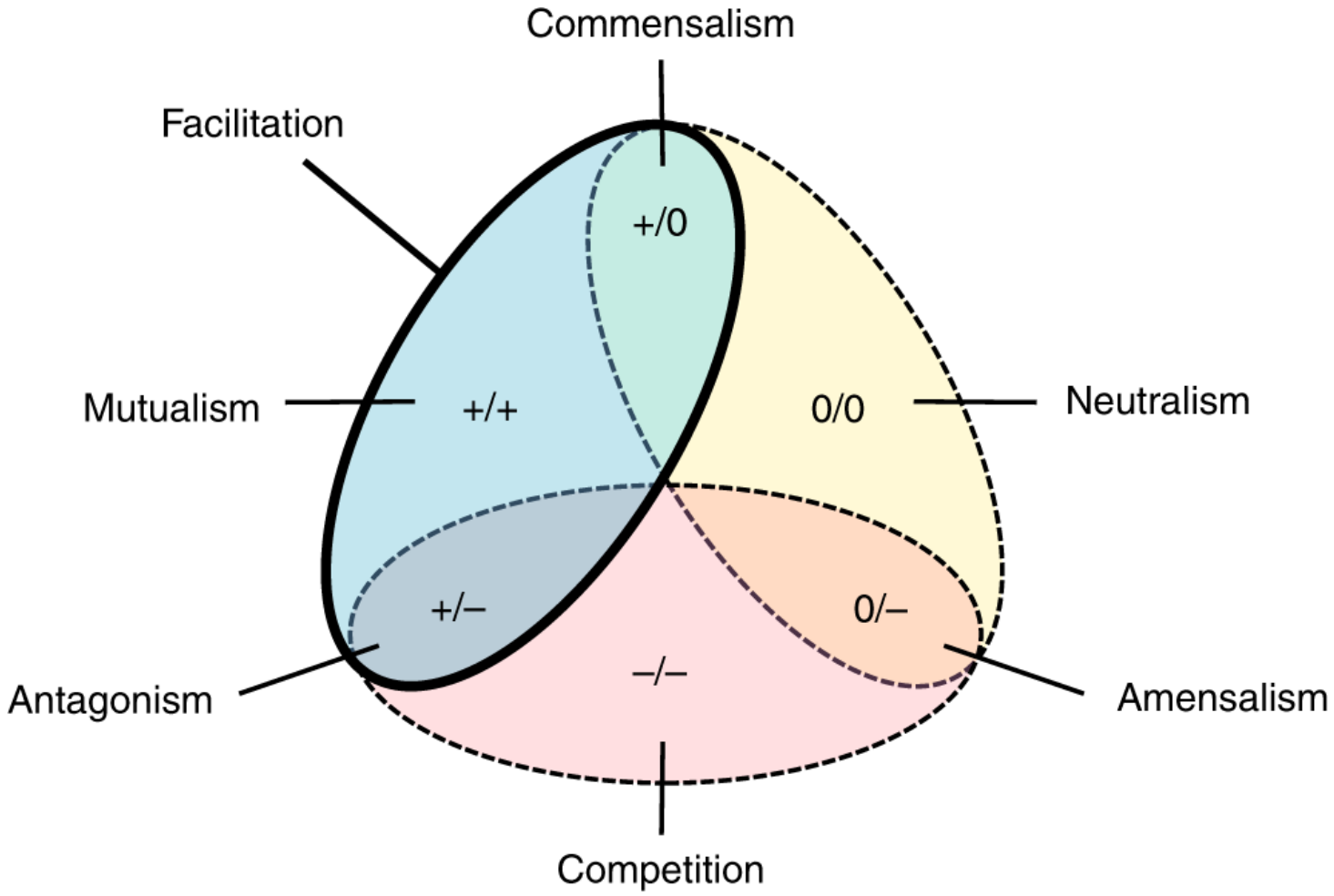


Fig. 4. Weed community clusters identified by hierarchical cluster analysis and their aboveground biomass under optimal, low, and surplus nutrition. Each color represents a weed species. The width of each color represents the proportion of each weed species. Statistical analysis has been employed on the total aboveground weed biomass (the sum of each weed species aboveground biomass). The letters indicate significant differences according to the Duncan post-hoc test ($p < 0.05$). OC (1,2), weed communities under optimal nutrition; LC (3,4), weed communities under low nutrition; SC5, weed community under surplus nutrition. Bars indicate the standard errors.

Why are some weed communities neutral?

Why are some weed communities neutral?



Zélé, F., Magalhães, S., Kéfi, S., & Duncan, A. B. (2018). Ecology and evolution of facilitation among symbionts. Nature communications, 9(1), 4869.

Why are some weed communities neutral?

- Some crops tolerate competition
- Not all “weeds” have traits associated with crop yield loss
- Weeds and crops may occupy different niches (different resource use in space and time)
- Lower niche overlap between weed species and crops decreases weed–crop competition

Why are some weed communities neutral?

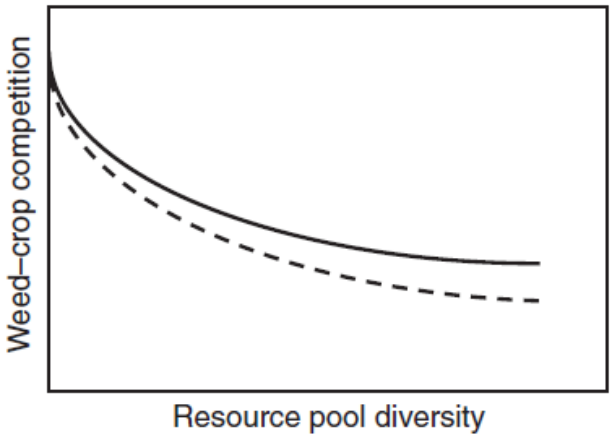


Fig.4 Intensity of weed–crop competition decreases with resource diversity. Source: Smith et al., 2009

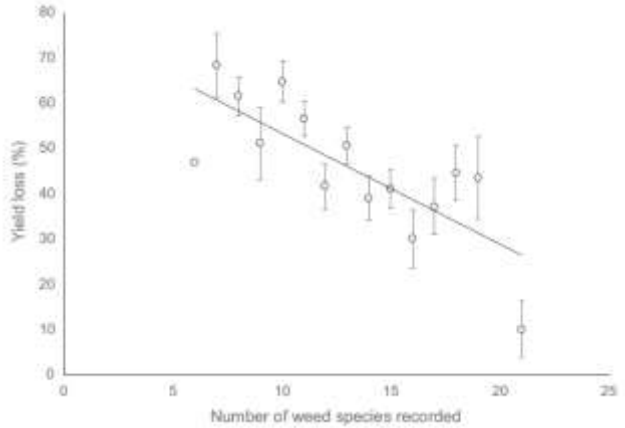


Fig. 5 Relationship between weed species richness and crop yield loss on the Broadbalk winter wheat experiment(r^2=0.59,P<0.001. Source: Storkey et al., 2018

- Resource Pool Diversity Hypothesis (Smith et al. 2010): diverse soil resource pools promote resource partitioning among species → less crop yield loss per unit weed density
- Higher weed diversity is associated with lower dominance of competitive weeds that cause substantial yield loss (Brooker et al., 2020; Adeux et al., 2019)
  - Broadbalk winter wheat experiment (Moss et al., 2004)
- Positive effect of weed on crops?

Why are some weed communities neutral?

Table 4. Mycorrhizal responsiveness of agricultural weed species to three inoculum types (organic, Org; transitional, Trans; conventional, Conv) in Experiments 1 and 2.

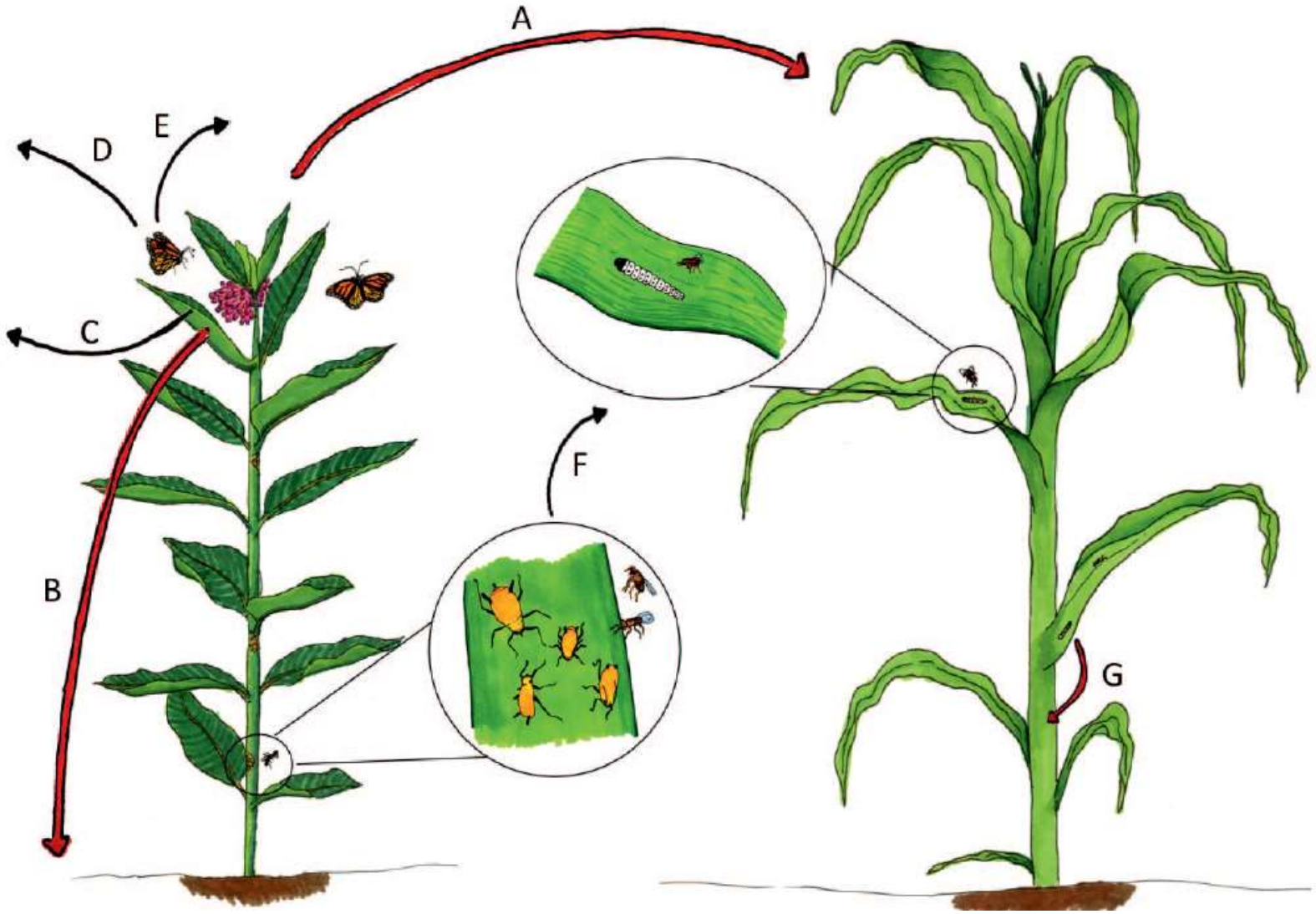
			Mycorrhizal responsiveness					
			Experiment 1[1]			Experiment 2[1]		
Category	Species	Common name	Org	Trans	Conv	Org	Trans	Conv
Strong host	*Abutilon theophrasti*	Velvetleaf	9	4	20	−179*	29	55
	Ambrosia artemisifolia	Ragweed	45**	54**	49**	14	26	25*
	Cirsium arvense	Canada thistle	51	68*	67	20	42	27
	Solanum nigrum	Nightshade	4	12	−1	−14	−28	−15
	Xanthium strumarium	Cocklebur	nd	nd	nd	38	−74	18
Weak host	*Agropyron repens*	Quackgrass	−51	−24	−106	−2	−6	−21
	Setaria faberi	Giant foxtail	24	22	16	−23	−32	−45
	Setaria lutescens	Yellow foxtail	−15	31	−10	59*	−54*	−87
Non-host	*Amaranthus retroflexus*	Pigweed	17	42	−24	nd	nd	nd
	Brassica kaber	Mustard	6	23	16	−1	12	−76**
	Chenopodium album	Lambsquarters	13	26	32	68	63	−116
	Polygonum lapathifolium	Smartweed	31	−57	9	28	42	44
	Portulaca toleracea	Purslane	21	−11	−3	−83	58	−51
	Rumex crispus	Curly dock	−85*	12	−24	−44	−19	−42

[1] Mycorrhizal response (%) = [(biomass in AMF presence (g) − biomass in AMF absence)/biomass in AMF presence] × 100.
Total biomass of inoculated plant significantly different from non-inoculated control as determined by ANOVA (* $P < 0.05$; ** $P < 0.005$).
nd signifies no data available.

From **Vatovec, C., N. Jordan, and S. Huerd**. "Responsiveness of certain agronomic weed species to arbuscular mycorrhizal fungi." *Renewable Agriculture and Food Systems* 20.3 (2005): 181-189.

- Weeds can be a source of beneficial soil microorganisms (Sarathambal *et al*. 2014; Sorty et al. 2016; Sturz *et al.* 2001)
- Some agricultural weeds are strong hosts of arbuscular mycorrhizal fungi (AMF), although many weeds are weak AMF hosts (Vatovec *et al.* 2005)
- AMF host weeds may be harnessed to promote AMF colonization of annual crops (Brito *et al.* 2013; Feldmann and Boyle 1999)
- Mycorrhizal symbiosis might be increased when the plants involved are phylogenetically distant (Montesinos-Navarro *et al.* 2019) and differ in their AMF assemblages (Montesinos-Navarro *et al.* 2012)

Presence of beneficial organisms



DiTommaso, A, *et al*. "Integrating insect, resistance, and floral resource management in weed control decision-making." *Weed Science* 64.4 (2016): 743-756.

Presence of beneficial organisms

- The presence of pests (*Spodoptera frugiperda*, *Rhopalosiphum maidis*, and *Colopterus* spp.) is less abundant in weedy plots compared with weeded plots
- Predators of corn pests, such as *Calosoma calidum*, are more abundant in weedy plots
- Corn yield did not differ significantly between weedy and weed-free plots

Table 1. on maize plants grown in plots with weeds (weedy) or under a strict weed control regime (clean). Data are means ± SE of the sum of both subplots (total 40 plants/block).

	Interval post-planting								Analysis[1]	
	20 days		32 days		44 days		56 days		Time	Interaction
	Clean	Weedy	Clean	Weedy	Clean	Weedy	Clean	Weedy		
Spodoptera frugiperda larvae	97.5 ± 45.2	35.5 ± 16.0	11.0 ± 3.1	18.0 ± 1.2	0.3 ± 0.2	2.3 ± 1.6	0.0 ± 0.0	26.3 ± 1.2	***	*
Other lepidopteran larvae	6.0 ± 0.4	0.8 ± 0.4	2.1 ± 0.2	0.5 ± 0.2	0.8 ± 0.3	1.0 ± 0.4	0.6 ± 0.4	3.2 ± 1.2	NS	NS
Aphid colonies	3.6 ± 1.9	6.2 ± 2.7	4.2 ± 1.2	1.8 ± 0.4	5.6 ± 2.8	2.5 ± 0.1	0.4 ± 0.2	0.0 ± 0.0	***	*
Phytophagous Coleoptera	7.4 ± 3.2	6.3 ± 3.2	22.2 ± 2.4	8.5 ± 1.6	35.1 ± 6.0	22.0 ± 6.4	54.6 ± 1.6	25.1 ± 2.4	***	*
Other phytophagous insects	6.6 ± 2.5	3.0 ± 0.4	19.9 ± 4.2	15.6 ± 5.1	16.4 ± 8.6	13.1 ± 6.0	30.6 ± 15.2	21.3 ± 9.5	***	NS
Earwigs	2.4 ± 1.2	2.8 ± 2.4	6.6 ± 4.8	3.3 ± 2.7	26.4 ± 6.7	16.5 ± 1.6	65.2 ± 12.4	63.5 ± 20.8	***	NS
Chrysoperla spp.	0.2 ± 0.2	0.8 ± 0.4	7.8 ± 1.6	13.5 ± 6.4	32.2 ± 10.8	22.7 ± 13.6	136.7 ± 40.1	117.3 ± 58.3	***	NS
Spiders	8.8 ± 1.5	2.5 ± 0.4	9.8 ± 0.7	5.5 ± 1.1	20.2 ± 0.8	19.5 ± 0.8	24.6 ± 4.7	25.5 ± 3.2	**	NS
Solenopsis spp.	0.2 ± 0.2	0.5 ± 0.3	13.8 ± 5.9	12.7 ± 9.2	72.1 ± 27.2	135.5 ± 97.2	25.4 ± 4.8	21.7 ± 10.7	*	NS
Predatory Coleoptera	4.8 ± 1.9	1.9 ± 0.4	3.0 ± 1.1	5.5 ± 1.6	23.1 ± 10.7	15.0 ± 1.6	15.6 ± 4.8	15.5 ± 5.5	NS	NS
Other natural enemies	6.4 ± 2.1	6.8 ± 2.3	8.0 ± 1.6	14.3 ± 2.9	10.2 ± 3.6	10.3 ± 3.5	8.4 ± 3.0	6.0 ± 3.1	NS	NS

[1]Repeated measures analysis of variance of the number of arthropods observed at each sample point and the interaction time*treatment. *$p < 0.075$, **$p < 0.01$, ***$p < 0.001$, NS = Not significant $p > 0.075$.

Penagos, D. I., *et al.* "Effect of weeds on insect pests of maize and their natural enemies in Southern Mexico." *International Journal of Pest Management* 49.2 (2003): 155-161.

Presence of beneficial organisms

Numbers of aphid plants, leaf percent N and pod + seed yield in different experiments and treatments. Values are means and standard errors[1]

Experiment and treatment	No. of plots	Aphid plants m^{-2}	Leaf percent N	Pod + seed yield ($g\ m^{-2}$)
I Minus fertilizer	5	1.80 (0.52)		
Plus fertilizer	5	3.90* (1.05)		
IIa No harrowing				
Plus weeds	8	2.50 (0.91)		342 (45.3
Minus weeds	8	6.38+ (3.44)		429 (92.6)
IIb Harrowed once				
Plus weeds	10	1.60 (0.69)		529 (56.1)
Minus weeds	10	7.60** (2.67)		528 (78.0)
IIc Harrowed once				
Plus weeds	5	2.60 (1.54)		
Minus weeds	5	6.00 (3.42)		
IId No harrowing, seeded twice				
Plus weeds	7	2.14 (0.80)		342 (45.8)
Minus weeds	7	4.14+ (1.05)		418 (66.5)
IIe Harrowed once, seeded twice				
Plus weeds	5	0.40 (0.24)		
Minus weeds	5	0.40 (0.24)		
II All plots				
Plus weeds	35	1.89 (0.39)		
Minus weeds	35	5.37** (1.16)		
III Fababeans × barley	5	1.00 (0.55)	5.48 (0.12)	378 (45.3)
Fababeans × oats	5	1.40 (0.87)	5.57 (0.16)	327 (57.3)
Fababeans, 20 cm between rows	5	11.0 (5.62)	6.03 (0.27)	374 (22.7)
Fababeans, 10 cm between rows	5	15.6 (5.62)	5.84 (0.20)	379 (45.3)
Fababeans × cereal plots, combined	10	1.20 (0.49)	5.53 (0.095)	
Fababean only plots, combined	10	13.3* (5.17)	5.94* (0.16)	
IV Not fertilized, plus weeds	6	6.67 (2.22)	5.08 (0.12)	530 (110)
Not fertilized, minus weeds	6	12.8 (6.56)	5.19 (0.18)	341* (35.6)
Fertilized plus weeds	6	3.50 (2.94)	5.09 (0.10)	298 (55.1)
Fertilized, minus weeds	6	13.3 (5.94)	5.32 (0.01)	430 (68.4)
Plus weeds, all plots	12	5.08 (1.82)		
Minus weeds, all plots	12	13.1+ (4.22)		
No fertilizer, all plots	12	9.75 (3.43)		
Plus fertilizer, all plots	12	8.42 (3.49)		

- Black bean aphids (*Aphis fabae* Scopoli) are less numerous in weedy faba bean (Vicia faba L.) plots relative to weed-free plots
- No significant faba bean yield reduction was reported in weedy plots compared with weed-free plots

[1]Significant differences between treatments at $0.1^{(+)}$, $0.05^{(*)}$ and $0.01^{(**)}$ levels of significance. Differences i numbers of aphid plants were assessed by non-parametric tests (Wilcoxon rank sum tests for Experiments I II; Friedman's test for the 4 treatments in each of Experiments III and IV; combined treatments in Experimen III were compared using the Mann–Whitney U-test, and combined treatments in Experiment IV by the Wil coxon rank sum test; one-tailed tests for +/− fertilizer comparisons, all others were two-tailed tests). Differ ences in N% in Experiment III were assessed by 2-way ANOVA, and in Experiment IV (composite samples) by 1-way ANOVA. Differences in yields were tested by paired *t* tests in Experiment II, and 2-way ANOVA i Experiment III. Three-way (split plot) ANOVA indicated significant weed × fertilizer interactions in Exper iment IV; differences within fertilizer treatments were tested by 2-way ANOVA.

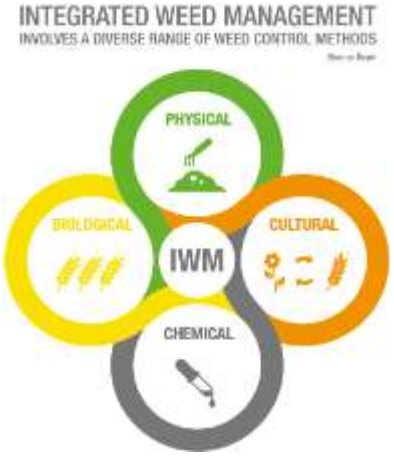
Patriquin, D. G., *et al.* "Aphid infestation of fababeans on an organic farm in relation to weeds, intercrops and added nitrogen." *Agriculture, ecosystems & environment* 20.4 (1988): 279-288.

How to attain neutral weed communities?

- Two approaches proposed in order to:
  - Promote sustainable weed management
  - Enable reduced herbicide use and soil tillage
  - Increase biodiversity without significant crop yield losses

Approach 1

Crop diversification. Source: https://ourenvironment.berkeley.edu/



Cropping system diversification, fertility management, integrated weed management

Management of the weed biodiversity

Principal aim
Maximization of the weed diversity

More diversified weed communities

- ⬆ Functional diversity
- ⬇ Dominance of competitive weed species
- ⬆ Probability of niche overlapping (Adeux et al. 2019)
- ⬇ Intensity of niche overlapping (Adeux et al. 2019)

Approach 2

Artificial intelligence, field robots, drones, biotechnology

Species-specific weed management

Principal aim
Selectively manage the growth of specific weed species (weed presence and their density)

Weed communities shaped based on the ecology of the crops

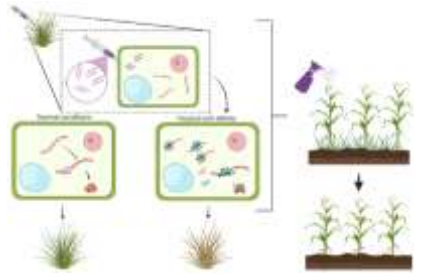
- ⬆ Functional diversity
- ⬇ Dominance of competitive weed species
- ⬇ Niche overlapping between weeds and crop

⬆ Neutrality of a weed community

- ⬇ Herbicide spread
- ⬇ Soil tillage
- ⬆ Biodiversity
- ⬆ Weed ecosystem services
- ⬇ Crop yield losses

Autonomous weeder robots. Source: https://rowesys.ethz.ch

Agricultural drones. Source: https://www.technologyreview.com



Sprayable RNAi is a spray-induced gene silencing (SIGS) technology proposed for weed management. Source: Zabala-Pardo et al., 2022

More research is needed!

- **First year:** United States, Cornell University
  Experiment in corn (*Zea mays* L.)

- **Second year:** Italy, Sant'Anna School of Advanced Studies of Pisa
  Experiment in wheat (*Triticum aestivum* L.)

- **Third year:** China, Zhejiang University
  Experiment in rice (*Oryza sativa* L.)

MARIE CURIE ACTIONS

European Commission | Horizon 2020 European Union funding for Research & Innovation

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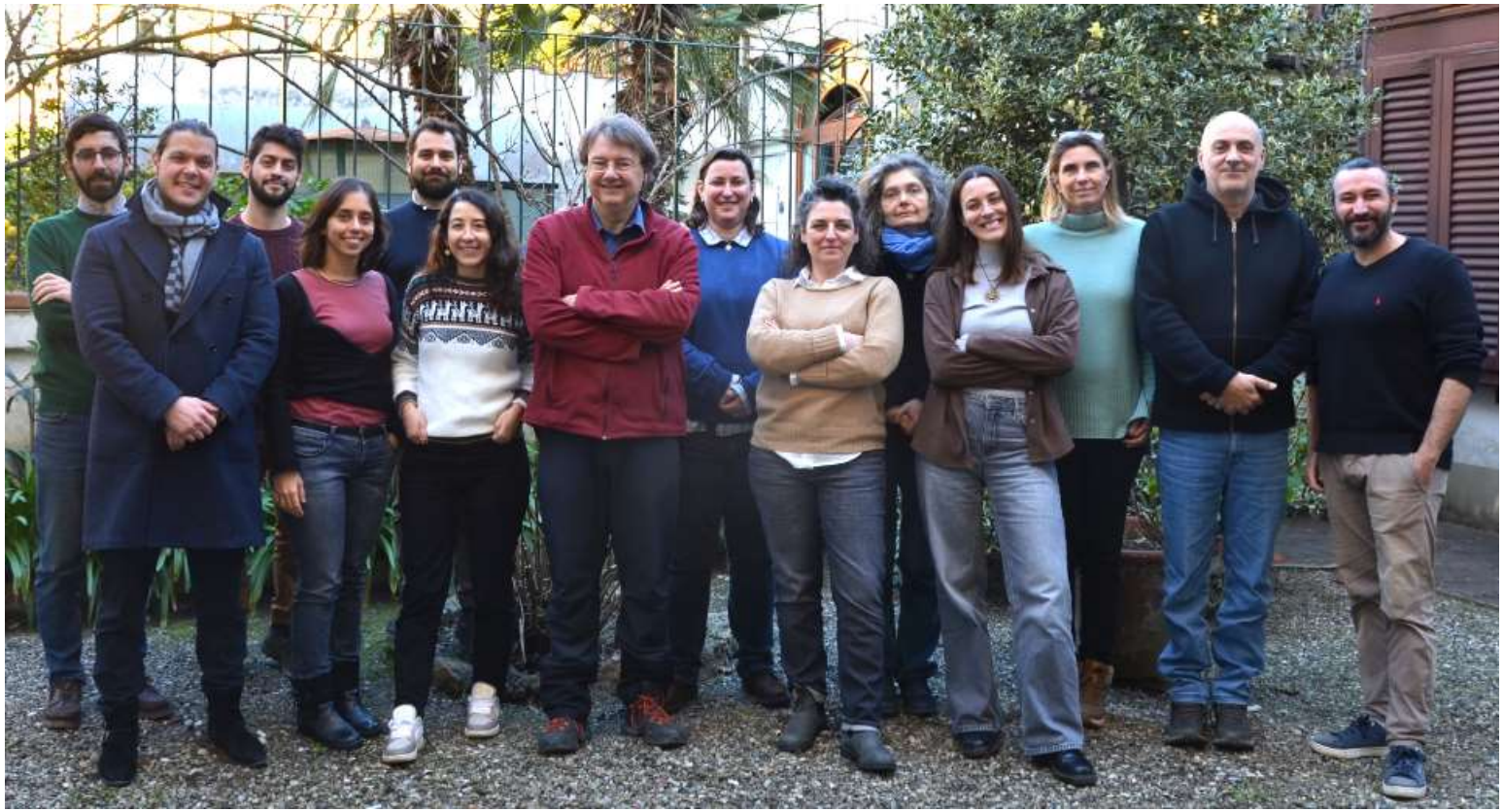
Available 24/7

NEUTRAWEED
WEED-CROP COEXISTENCE

INSTITUTE
OF PLANT
SCIENCES

Sant'Anna
School of Advanced Studies – Pisa

Thanks for your attention



Evidence of neutral weed communities

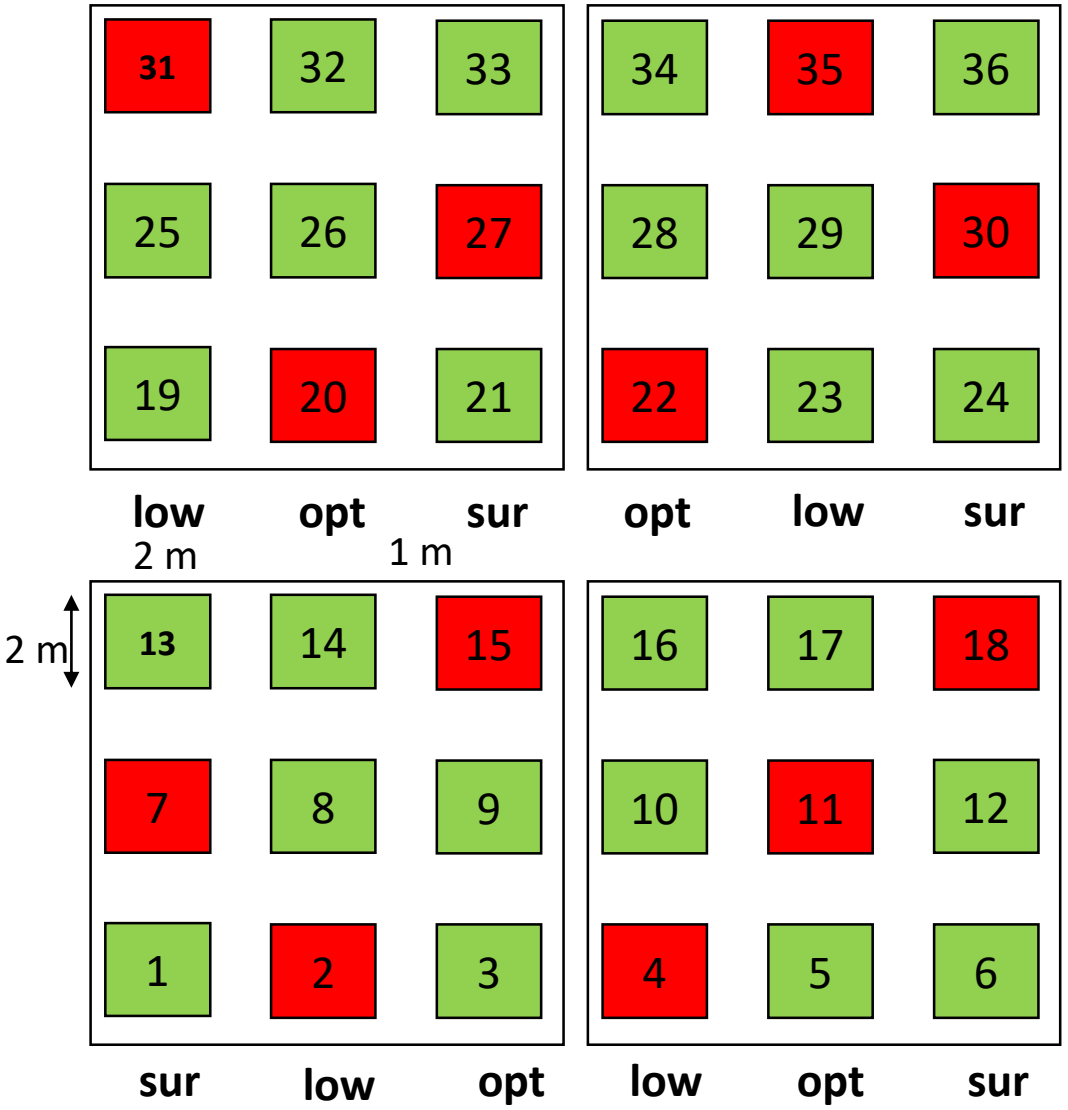
- **Penagos et al., 2003**

Cyperus rotundus L. (Cyperaceae), *Phillanthus niruri* L. (Euphorbiaceae), *Eleusine indica* (L.) (Gramineae), *Euphorbia hirta* L. (Euphorbiaceae), *Ipomoeae sp*. (Convolvulaceae), *Digitaria sanguinalis* Scop. (Poaceae), *Portulaca oleracea* L. (Portulaceae), *Echinochloa colonum* Link (Poaceae), and *Cucumis* sp. (Cucurbitaceae)

- **Patriquin et al., 1988**

The predominant weeds at mid-season (2 July) in order of decreasing abundance were *Taraxacum officinale* Weber, *Equisetum spp., Cirsium arvense* (L.) Scop*., Raphanus raphanistrum* L*., Ambrosia artemisiifolia* L*., Galeopsis tetrahit L.,* and *Sonchus arvensis L.*

Experimental design



Weed-free=Control

Weedy

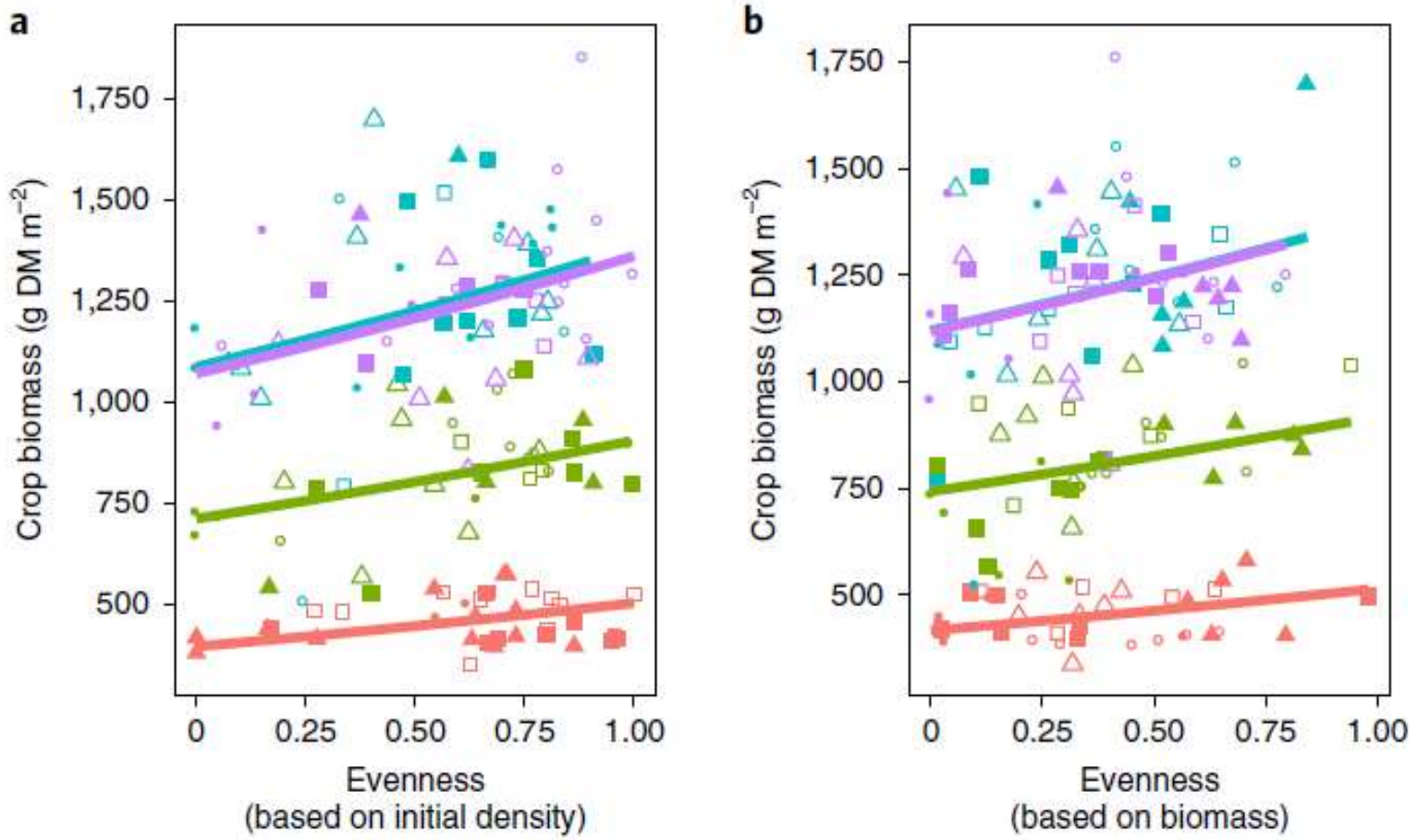
Low nutritional level (low)
Optimal nutritional level (opt)
Surplus (sur)

Wheat sowing: 15th of December 2020

Wheat harvesting: 30th of June 2020

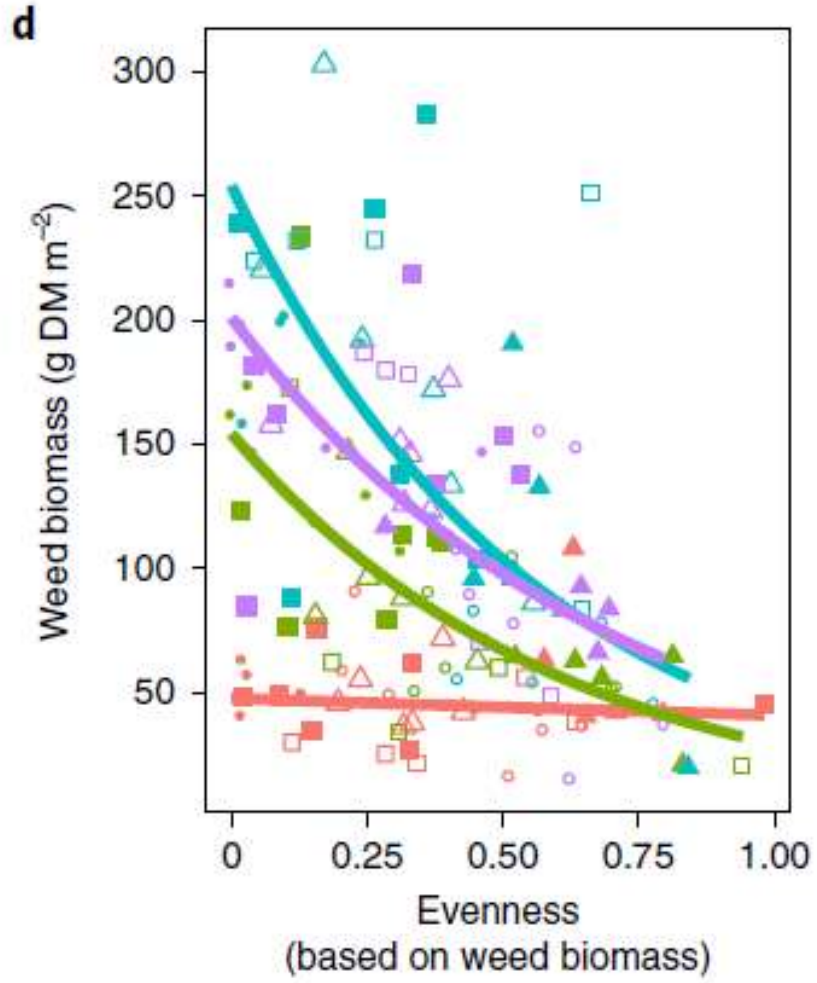
Herbicide: Timeline Trio®
Active substances: Pinoxaden, Clodinafop-propargyl, and Florasulam

Evidence of neutral weed communities



Adeux, et al. "Mitigating crop yield losses through weed diversity." *Nature Sustainability* 2.11 (2019): 1018-1026.

Evidence of neutral weed communities



Adeux, et al. "Mitigating crop yield losses through weed diversity." *Nature Sustainability* 2.11 (2019): 1018-1026.

Evidence of neutral weed communities

Indigofera cordifolia
Source:https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:499181-1

- Analysis of the effects of *Indigofera cordifolia* on the two major rain-fed crops: *Pennisetum glaucum* (L.) R. Br.] and *Sesamum indicum* L.
- Two years of experiment in the Indian rainfed desert of Jodhpur
- *I. cordifolia* is a leguminous weed species

Bhandari, D. C., and D. N. Sen. "Agro-ecosystem analysis of the Indian arid zone *I. Indigofera cordifolia* Heyne ex Roth. as a weed." *Agro-Ecosystems* 5.3 (1979): 257-262.

Evidence of neutral weed communities

Effect of *I. cordifolia* on different growth parameters, yield and pigments of *Pennisetum typhoideum* (bajra) crop plants

Experiment	Length of shoot (cm)	No. of tillers/ plant	No. of cobs/ plant	Length of cob (cm)	Diameter of cob (cm)	Yield (kg/ha)
Bajra (without *I. cordifolia*)	194.6 ± 13.4	9	11	24.5 ± 1.2	2.0	409.5
Bajra (with *I. cordifolia*)	200.0 ± 4.3	11	20	24.5 ± 1.1	2.5	490.6*

*Significant at 1% level.

Bhandari, D. C., and D. N. Sen. "Agro-ecosystem analysis of the Indian arid zone *I. Indigofera cordifolia* heyne ex roth. as a weed." *Agro-Ecosystems* 5.3 (1979): 257-262.

Evidence of neutral weed communities

Effect of *I. cordifolia* on different growth parameters, yield and pigments of *Sesamum indicum* (til) crop plants

Experiment	Length of shoot (cm)	No. of branch-es	Length of branches (cm)	No. of pods on		Length of inflores-cence (cm)	
				Main branch	Side branch	Main branch	Side branch
Til (with-out *I. cor-difolia*)	140.0 ± 2.4	8	60.0 ± 2.2	22	18	58.0	25
Til (with *I. cordi-folia*)	152.0 ± 4.2	7	74.0 ± 2.8	30	24	68.0	46.0

*Significant at 1% level.

Bhandari, D. C., and D. N. Sen. "Agro-ecosystem analysis of the Indian arid zone *I. Indigofera cordifolia* heyne ex roth. as a weed." *Agro-Ecosystems* 5.3 (1979): 257-262.

Evidence of neutral weed communities

Pod size (cm)		Yield (kg/ha)	Percentage increase in yield	Chlorophylls (mg/g)		Carotenoids (mg/g)
Main branch	Side branch			*a*	*b*	
2.5	2.5	242.5	0.0	1.4560	0.2890	0.4150
3.0	2.5	296.8*	22.4	1.6690	0.3143	0.4192

Bhandari, D. C., and D. N. Sen. "Agro-ecosystem analysis of the Indian arid zone *I. Indigofera cordifolia* heyne ex roth. as a weed." *Agro-Ecosystems* 5.3 (1979): 257-262.