Legumes Translated Report 2

Effects of legume crops on biodiversity

Leonardo Amthauer Gallardo
Georg Everwand
Jens Dauber

Thünen Institute of Biodiversity &
Thünen Institute of Agricultural Technology

May 2022

Legumes Translated

Legumes Translated (Translating knowledge for legume-based farming for feed and food systems) is an international research and development project funded by the European Union through the Horizon 2020 Programme under grant agreement number 817634. The Legumes Translated research consortium comprises 17 partners in 9 countries.

Disclaimer

Copyright

Citation

Please cite this report as follows:

Amthauer Gallardo, L., Everwand, G. and Dauber, J., 2022. Effects of legume crops on biodiversity. Legumes Translated Report 2. Available from www.legumehub.eu

Legumes Translated (Translating knowledge for legume-based farming for feed and food systems) has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817634

Contents

Definitions

Activity density: the number of individuals or species moving over a defined area or crossing a defined border in a given time.

Cover grade: the proportion of the land or soil surface covered by plants, usually given as fraction 0-1, or percentage.

Density: the number of individuals per unit of area or space.

Evenness: how equal the distribution of individuals of species is between samples. This is a structural parameter for comparing different communities.

Frequency: the number of times a species occurs in a defined area in a given time.

Hierarchical richness index: comparative assessment index of dominance of different organism groups calculated from abundance scores.

Species richness: the number of species per unit area.

Shannon diversity index: an index of diversity based on the number of species and number of individuals per species.

Taxa richness: the number of taxa per unit area.

Alpha diversity: the mean species diversity in sites or habitats at a local scale.

Beta diversity: the ratio between regional and local species diversity which consider the role of rare species.

Gamma diversity: the total species diversity in a landscape.

Summary

The expansion of the arable land area has displaced natural habitats and reduced the diversity of entire landscapes. Policymakers, scientists and land managers are developing strategies to mitigate the effects on biodiversity. Increasing the diversity of crop cover by introducing legumes into otherwise cereal dominated cropping systems is one option. While the positive impact of forage legumes, especially perennial forage species, on habitats is well estabished, this is not the case with grain legumes. For grain legumes, the evidence about effects on biodiversity is mostly qualitative. While we can find several studies on the effect of management measures or general crop-related landscape effects, studies comparing single crops, especially grain legumes, are rare. This review studies the effect of soybean, as the most studied grain legume crop, on biodiversity. We carried out a literature search with combinations of the key words 'abundance', 'biodiversity', 'species richness' 'plant' 'arthropod' and 'glycine max', resulting in 2,320 articles published between 1983 and 2019. We excluded studies on fungi, meso-, and microorganisms, mammals, and birds. After an intensive examination of literature, which included checking the presence of average comparisons between crop or management treatments, we picked up a total of 56 studies. The analysis was based on averages percent differences, while the effect's direction was given. We categorized the information into three driver categories: crop, management, landscape, and two ecosystem supporting services: biocontrol, and pollination. For accompanying vegetation, we gathered information about the plant biomass, cover grade, density, evenness, frequency, Shannon diversity index, species richness, alpha, beta, and gamma diversity. We gathered information from several organism groups (taxa and trophic groups) for the parameters activity density, evenness, Shannon diversity index, hierarchical richness index, and species and taxa richness of invertebrates. Overall, the information was limited.

This literature review's main results are summarised as follows: The non-crop vegetation (‘weed’) biomass was higher in maize, sorghum, sunflower, and wheat compared to soybean. Soy had a higher non-crop vegetation plant density than maize, and wheat had a higher density than soy. Soybean showed higher Shannon diversity and species richness compared to maize. For invertebrates, *Aranea* activity density was lower in soybean than alfalfa, while soy had from nine individual comparisons with other arable crops in six cases higher activity density of *Aranea*. There was no consistent difference between maize and soybean within tropic groups. Longer crop sequences using soybean got higher accompanying plant biomass and Shannon diversity compared to shorter ones. The use of ryegrass or alfalfa as an annual crop in sequences augmented the effect of soy on species richness and plant density. For invertebrates, the difference caused by sequence length or soybean use was slight, except for *Lumbricidae*. A pre-crop effect on *Arthropoda* and *Carabidae* could be identifed from the literature: after soybean cultivation, the activity density was increased. In intercropping systems, the partner crop to soybean seemed to play a decisive role in its influence on plant diversity parameters. Most diversity parameters for accompanying vegetation in soy were negatively affected by all polycropping measures, whether cover crop use, double-crop, or intercropping. The same applied to invertebrates.

Overall for all management factors, the evidence foundation is weak. This scarcity of information, since soybean is usually not fertilised, does not provide an evidence base on effects related to fertilisation. Soybean systems showed a trend to improved plant diversity when tillage was reduced, while the response of invertebrates to tillage was

mixed. Crop protection measures resulted in more even plant communities, while species richness and diversity remained almost unaffected. *Arthropoda* reacted to increased weed control measures, mainly with a decrease in biodiversity parameter. Moreover, the landscape richness on semi-natural habitats positively affected both accompanying vegetation and invertebrates in soybean fields. A high concentration of soybean cultivation on the other side resulted in biodiversity losses.

The biocontrol and pollination services provided or used by soybean were affected by several factors. The exclusion of predators resulted in high aphid populations and increased leaf damage. Moreover, all polycropping strategies served as a biocontrol measure since they decreased herbivore pressure. The landscape richness also acted as a biocontrol measure since predator presence was increased. All yield parameters, total yield, pod amount, and pod weight were improved through pollinators' presence.

The main explanation for variations in diversity parameters as affected by soy cropping was attributed to influences on microclimatic factors such as temperature and humidity in different ways. Crop structure is believed to be more important than the presence of prey. Furthermore, every crop has its way of being managed, from fertilisation, sowing, and harvesting, that affects different biodiversity parameters. The way the canopy of different crops offers higher trophic level predators such as mammals and birds a higher chance of getting invertebrate prey was also discussed. Central for the discussion was the better biomass quality of soy in terms of nitrogen and protein than other crops. Summarizing this review's findings, we found reports of slight benefits of soybean cropping on flora, pollinators, parasitoids, and other natural pest control agents. The quality and amount of information remains scarce.

Background

Due to the agricultural progress and intensification of the past decades, agricultural productivity per hectare has enormously increased. This has occurred with a substantial loss of biodiversity and the increased need to move towards sustainable agriculture.[1] To date, Europe strongly depends on imported protein crops, mainly soybeans and soybean products, to feed livestock.[2] This process began after WWII when Europe's agricultural policy promoted agricultural productivity to secure the food supplies. According to Magrini et al.[3], interrelated factors, such as breeding, public subsidies, and food systems, have favored increasing cereals' cultivation area while grain legumes cropped area decreased. In contrast to cereals, European grain legume production was not prioritized and sufficiently subsidized to compete with imported soybeans. This lead until now to increased cereals' productivity and a decline of grain legume production as a whole in Europe but, with a simultaneous increase of area cropped with soybean worldwide. The development of the soybean cultivation in Europe is diverse, while in western Europe and Germany in particular, the increase of soybean cultivation is only moderate, the actual cultivated area in the east of Europe is high, especially in Ukraine and Russia.[4] [5] The area under soybean cultivation in the EU as whole amounts to 831,360 ha. Only in France and Romania areas are larger than 100,000 ha.[6]

To reduce the dependence on imported soybean for feed and food as well as mitigating the need for nitrogen fertilisers, the EU encourages European farmers to grow more leguminous crops, such as soybean, faba bean (*Vicia faba*), peas (*Pisum sativum*) or lupin (e.g., *Lupinus albus*, *L. angustifolius* or *L. luteus*). Therefore, legumes' cultivation was included as an ecological focus area (EFA) in the EU-Regulation known as Greening in the standard agricultural policy (CAP) with its reform in 2015. Consequently, it may be assumed that the cropped area with legumes will increase in the future. Although legumes are generally seen as crops that provide ecosystem services, it is not clear if annual grain legumes increase biodiversity and the provision of regulating ecosystem services such as pest biocontrol and pollination. It is well established that perennial legumes such as clover and alfalfa provide such services.[7] Possibly, the assumption that grain legumes perform similarly originates from this. Until now, existing biodiversity assessment of legumes in the agroecosystems are of qualitative nature.[8] [9] Our search for

---

[1] Reidsma, P., Tekelenburg, T., Van den Berg, M., & Alkemade, R. (2006). Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union. Agriculture, Ecosystems & Environment, 114(1), 86-102.

[2] Watson, C. A., Reckling, M., Preissel, S., Bachinger, J., Bergkvist, G., Kuhlman, T., ... & Zander, P. (2017). Grain legume production and use in European agricultural systems. In Advances in Agronomy (Vol. 144, pp. 235-303). Academic Press.

[3] Magrini, M. B., Anton, M., Cholez, C., Corre-Hellou, G., Duc, G., Jeuffroy, M. H., ... & Walrand, S. (2016). Why are grain-legumes rarely present in cropping systems despite their environmental and nutritional benefits? Analyzing lock-in in the French agrifood system. Ecological Economics, 126, 152-162.

[4] Böhm, H., Dauber, J., Dehler,M., Amthauer Gallardo, D. A., de Witte, T., Fuß, R., Höppner, F., Langhof, M., Rinke, N., Rodemann, G., Rühl, G., Schittenhelm, S. (2020). Fruchtfolgen mit und ohne Leguminosen: ein Review, Journal für Kulturpflanzen, 72 (10-11), 489–509

[5] Terzić, D., Popović, V., Tatić, M., Vasileva, V., Đekić, V., Ugrenović, V., Popović, S., & Avdić, P. (2018). Soybean area, yield and production in world. XXII Eco-Conference®2018, Ecological Movement of Novi Sad, 136-145.

[6] Terzić, D. et al. 2018; see above.

[7] Miller, D. A. (1996). Allelopathy in forage crop systems. Agronomy Journal, 88(6), 854-859.

[8] Cass, S., Williams M., Stout J. (2014): Biodiversity and ecosystem services in legume-supported cropping. 44-86. In: Williams, M., Stout, J., Roth, B., Cass, S., Papa, V., Rees, B. 2014: Environmental implications of legume cropping. Legume Futures Report 3.7. Available from www.legumefutures.de/results/environmentaleffects.html

[9] Everwand, G., Cass, S., Dauber, J. Williams, M., Stout, J. (2017). Biodiversity and ecosystem services in legume-supported cropping. In: Legumes in Cropping Systems. Murphy-Bokern, D., Stoddard, F., Watson, C. (Hrsg.) CABI, Wallingford. S. 55-69.

systematic literature reviews about the quantitive effects of grain legumes cultivation on different biodiversity parameters remained without results. To determine whether grain legumes contribute to biodiversity and provide ecosystem services, we started a systematic quantitative review of the international literature about this topic. In this review, because of its extension in world agriculture, we focus on the biodiversity effects of soybean cropping and soybeans in cropping systems. The literature on other grain legumes like pea or faba bean is too scarce and insufficient to compile a review[10].

Figure 1 gives an overview of agrobiodiversity factors' complexity and which we considered during our review for the crop soybean.

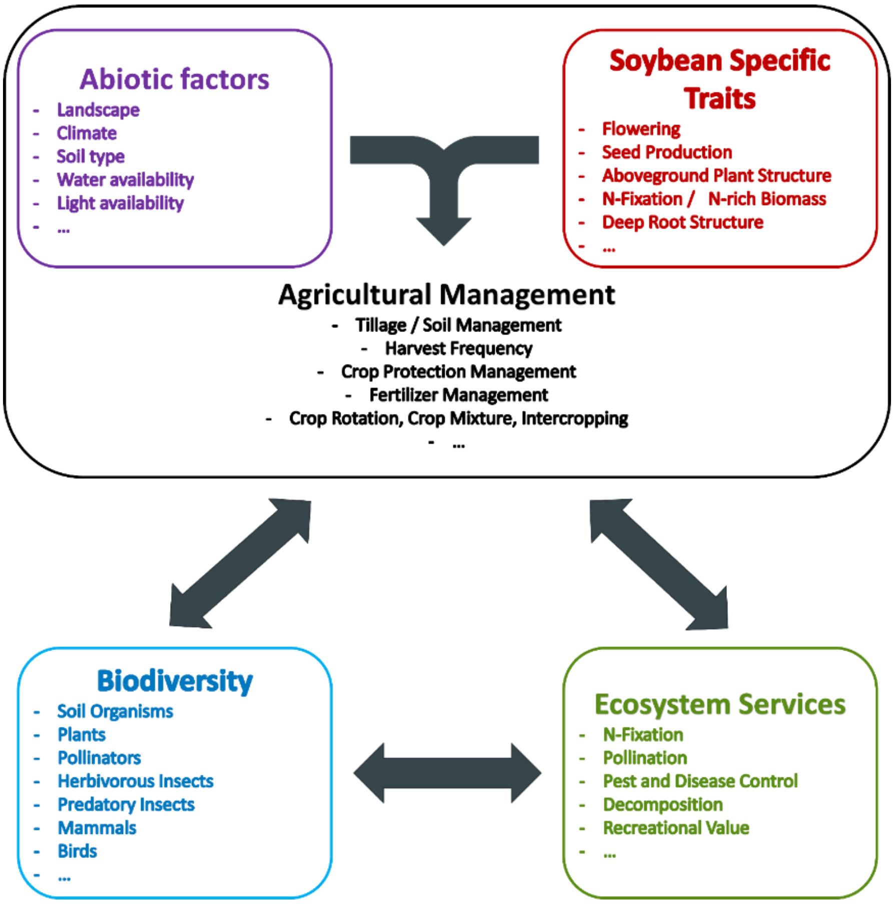

Figure 1. Conceptual model of agricultural management interactions, abiotic factors, and soybean specific trait effects on biodiversity and ecosystem services. Soybean, with its crop or cultivar specific traits in combination with the local abiotic factors, determines the choice of the farmers on agricultural management measures. Together, abiotic factors, soybean traits, and agricultural management influence biodiversity and ecosystem services, which are also interdependent.

---

[10] It is important to note here, that results coming from the Crop Diversification Cluster (https://www.cropdiversification.eu/) or any other projects e.g. on cool-season legumes, which were running in parallel to Legumes Translated, were not available at the time the literature review was undertaken.

The soybean

The soybean performs optimally in the temperature range of 25-32°C, has a moderate moisture requirement of 400-800 mm rainfall, and can be cultivated in various ecological zones. It is a short-day plant yet thrives in day-neutral environments as it occurs in the equator's immediate environment.[11] The climatic condition in Europe is not very suitable for soybeans as a short-day plant and breeding of adapted varieties is in progress.[12] Several rhizobia nodulate in soybean and enable biological nitrogen fixation (BNF), but two species predominate, *Sinorhizobium fredii* on neutral to alkaline soils *Bradyrhizobium japonicum* on acid or saline soils.[13] Since these species are not widespread in European cropland soils, it is necessary to inoculate soybeans before sowing the crop for the first time in a field.[14] Due to the BNF, no nitrogen fertiliser or only minimal fertiliser application is necessary to grow soybeans. However, potassium and calcium are essential for the growth of plant and grain yield, and sulphur is essential for protein production.[15]

Role of plant and invertebrate biodiversity in the cropping systems

The conservation of biodiversity is often seen as a moral, aesthetic or social issue, but there is increasing evidence that the biodiversity in agroecosystems provides several valuable ecological functions. The presence of accompanying vegetation for example helps in providing resources (seeds, nectar, and biomass) for non-pest and beneficial insects which can provide ecosystem services such as biocontrol, pollination and nutrient cycling. Hansen et al.[16], for example, show a higher abundance of predatory beetles in weedy soybean fields in comparison to hand weeded or herbicide-treated fields. Therefore maintaining a diverse weed community below bio-economic thresholds may provide ecosystem services for the crop and the surrounding ecosystem. Furthermore, managing accompanying vegetation species diversity will promote the overall diversity of other trophic levels in the agroecosystem, including insects, birds, and larger animals.[17]

Data and methods

To gather the relevant literature on biodiversity measures such as species richness, diversity, or abundance, we used the following search string in google scholar on 22.02.2019 (abundance biodiversity compar* crop* "species richness" plant OR arthropod OR insect OR weed "glycine max"). We scored 2,320 results. We used the same search string criteria in Scopus on 22.02.2019 and added the 166 most relevant articles to our database. After an intensive proofing of literature, we picked up a total of 56 studies, published between 1983 and 2019, which report on impacts of soybean cropping or soybeans in cropping systems on biodiversity in comparison to other crops or

---

[11] Nwokolo, E., & Smartt, J. (Eds.). (1996). Food and feed from legumes and oilseeds. London, England: Chapman & Hall.

[12] Fogelberg, F., & Recknagel, J. (2017). 7 Developing Soy Production in Central and Northern Europe. Legumes in Cropping Systems. Murphy-Bokern, D., Stoddard, F., Watson, C. (Eds) CAB International, 109-124.

[13] Saeki, Y., Kaneko, A., Hara, T., Suzuki, K., Yamakawa, T., Nguyen, M. T., ... & Akao, S. (2005). Phylogenetic analysis of soybean-nodulating rhizobia isolated from alkaline soils in Vietnam. *Soil Science & Plant Nutrition*, *51*(7), 1043-1052.

[14] Fogelberg and Recknagel 2017; see above.

[15] Sexton, P. J., Naeve, S. L., Paek, N. C., & Shibles, R. (1998). Sulfur availability, cotyledon nitrogen: sulfur ratio, and relative abundance of seed storage proteins of soybean. Crop Science, 38(4), 983-986.

[16] Hansen, A. A., Chatterjee, A., Gramig, G., & Prischmann-Voldseth, D. A. (2018). Weed and insect management alter soil arthropod densities, soil nutrient availability, plant productivity, and aphid densities in an annual legume cropping system. Applied Soil Ecology, 130, 120-133.

[17] Wortman, S. E., Lindquist, J. L., Haar, M. J., & Francis, C. A. (2010). Increased weed diversity, density and above-ground biomass in long-term organic crop rotations. Renewable Agriculture and Food Systems, 281-295.

cropping systems without soybean. We excluded studies on fungi, meso-, and microorganisms.

Many studies apply a broader perspective and show the effects of soybean as a crop compared to other crops and compare different rotations or management systems. Some show only effects on biomass, density, or abundance of studied organisms, and others show results on species richness, diversity, community composition, or ecosystem services. We found a range from low input, low disturbance systems, with mechanically removed cover crops and direct sown main crops in no-till environments to highly intensified systems with several soil disturbance events, mechanical weed control, and herbicide and fertiliser application.[18] [19] To classify the information that allowed plausible interpretations, we divided the information into three driver categories, i) crop drivers to which the factor crop identity, crop sequence, and multicropping counted; ii) management drivers, which included tillage, fertilisation, and pesticide regimes; iii) landscape aspects and two ecosystem service categories iv) biocontrol and v) pollination. After trying a qualitative approach, we decided to drive a quantitative approach, which compares the quantitative outcomes of different treatments in multiple studies.[20] For this, each group's values were extracted directly from the text, tables, and graphs. Graph data was taken indirectly using the free software PLOTDIGITIZER version 2.5.0 for Windows available on the Web to read the data accurately. Most studies included comparisons of more than one legume crop or legume-based cropping system or more than one driver. We considered each comparison every year and for every experimental treatment as an independent observation. Standard errors, standard deviations, or pairwise statistics were not available in several studies. The analysis is based on averages percent differences while the effect's direction was given by plus/minus sign. For example, within the factor crop identity, driver species richness (e.g., weed biomass in no-till compared with conventional tillage), for a value of 20 for soy and 10 for maize, the difference would have been 100% and the sign; plus in direction to soybean. Additionally, we chose a colour system to highlight the intensity of these differences; absolute differences (independent of the effect direction) from up to 10% were marked in grey, differences between 11 and 35% received a light colour label, 36 - 75% a medium colour label and above 76% a dark colour label. The colours chosen were blue for positive effect direction and red for negative effect direction.

The quality of the sources was also assessed. The quality level "plus" was given when a pairwise comparison between averages was available when sample sizes exceeded four, and more than four sources were available to average results. Otherwise, the quality was assessed as "plus-minus." The majority of the created tables with the results of the data analysis were added to the annex.

Gathering biodiversity knowledge from practice

Another critical part of our work was gathering knowledge from partners within legumes translated. This task was done using a questionnaire on biodiversity. The main intention was to gather as much information from the actor groups, but at least one filled survey from every actor group. We requested disservices as well as services-oriented biodiversity information:

---

[18] Ashford, D. L., & Reeves, D. W. (2003). Use of a mechanical roller-crimper as an alternative kill method for cover crops. American Journal of Alternative Agriculture, 37-45.

[19] Pannacci, E., & Tei, F. (2014). Effects of mechanical and chemical methods on weed control, weed seed rain and crop yield in maize, sunflower and soyabean. Crop Protection, 64, 51-59.

[20] Thacker, S. B. (1988). Meta-analysis: a quantitative approach to research integration. Jama, 259(11), 1685-1689.

Disservices oriented

- Weed species in grain legumes
- Most detrimental weeds in grain legumes
- Weed management
- Pest organism
- Pest control

Services oriented

- Beneficial organism
- Arthropod diversity
- Pollinator diversity
- Soil organism diversity
- Soil services
- Intercropping

Overview of gathered information

We found 56 papers that looked at the effects of soybean on various biodiversity parameters for the different drivers and ecosystem services chosen. The majority (95%) of these sources' originate from North and South America; altogether. In descending order, they amounted to 38 from the USA, seven from Argentina, five from Canada, two from Brasil, and each one source from Japan, Peru, Italy, and Poland.

We summarized methodological information about seed characteristics, fertilisation regime, tillage, and herbicide regime of all studies in Table 1. Of the majority of studies, 31 used conventional soybean, 11 used herbicide tolerant seeds, eight were mixed since the studies were carried out in heterogeneous landscapes. The remaining six studies did not specify if the soybean was herbicide tolerant or not. Regarding fertilisation, in 14 studies, the soil was fertilised with inorganic fertiliser. There was a single study with organic fertilisation, 23 studies did not specify, and ten studies received different fertilisation treatments. In most studies, tillage was not specified, 16 studies got different tillage treatments, 11 studies were carried out with no-till, eight were landscape studies, and only three studies got conventional tillage. Finally, the weed management from the studies was 24 times conventional, nine times the studies were about different weed management treatments, 12 times not specified, eight times they were not specified, and three times there was no weed management. The gathered studies show high variability of management drivers characteristics, which we did classify to make a differentiated analysis possible. Thanks to the fact that more than half of the studies were carried out with conventional soybean, the results of this literature review can, to some extent, be applied to European conditions that banned herbicide tolerant soybean.

Table 1. Specifications of soybean seed, fertilisation, tillage, and weed control used in the studies chosen for this review

Specification	Management			
	Seed	Fertilisation	Tillage	Weed control
	[n]			
Conventional[a]	31	14	3	24
Treatments[b]	-	10	16	9
Not specified	6	23	18	12
Mixed[c]	8	8	8	8
Herbicide tolerant	11			
Organic		1		
No-till			11	
No herbicide				3

[a] Conventional means: not herbicide tolerant for seed, inorganic for fertilisation, moldboard plow for tillage, and herbicide broadcast for weed management

[b] Treatment was indicated when in the experiment many management variations were tried out

[c] Mixed management aspects were available in experiments taken out in varying experimental sites in the landscape

Plants

Our literature research found 25 sources containing information about associated flora (Table 2). To the area of crop drivers, we found 19 sources and management drivers by 16 sources. There were 11 available sources to crop identity, four to crop sequence, and eight to multicropping topics (Table 3). Tillage was covered by eight, fertilisation by three, and weed control by seven sources. Considering the landscape aspect, we could find four sources. The plant parameters which were studied the most were weed density, biomass, species richness, and Shannon diversity. Other parameters, such as seed production, weed cover, evenness, hierarchical index, alpha, beta, and gamma diversity, were only seldom found in the literature. The parameter weed density was treated except for fertilisation and landscape in all drivers, with at least four sources for the drivers crop identity, tillage, and weed control. Accompanying biomass was sufficiently treated within the driver crop identity and polycropping. The same holds for the factor species richness. Shannon diversity only occurred in more than four studies for the drivers' crop sequence and tillage.

Invertebrates

For insects and soil organisms, we found a total of 23 sources. Out of this, 16 sources were about crop drivers, each 12 for the factor crop identity, six for crop sequence, and two for multicropping.[21] Five sources were about management drivers, each for tillage, one for fertilisation, and two for herbicide/weed regime. We found four sources about the landscape. Overall the most studied parameter was activity density, and it was present in every driver studied. It was followed by species richness, which was not continously observed in every driver category. Shannon diversity, evenness, and hierarchical richness index were only seldom studied.

---

[21] In some sources several drivers were treated.

Focusing on the different organism groups and functional groups, we can observe that at this level, the information is very scarce (Table 4). For the parameter activity density, there were pieces of information for every driver studied. Within the driver crop identity, eight different organism groups and six functional groups; in crop sequence, seven organism groups, and within the driver multicropping, one organism group and two functional groups were represented. In fertilisation, one organism group and two functional groups were studied. In tillage, we found information about three different organism groups and five functional groups. Within the driver weed control, only gathered information about the specific organism. For the driver herbicides, we found information about two organism groups. For landscape aspects, there was information about activity density for one organism group and three functional groups,

For the parameter species richness, we found only two organism groups and two functional groups for the driver crop identity, one organism group in crop sequence, one organism group, and two functional groups in multicropping. Within the landscape driver, there was information available for two organism groups and three functional groups. Depending on which driver and organism group, we gathered only one to three sources.

Ecosystem services

In this study, we focused on two specific ecosystem services: biocontrol and pollination. Most sources belonged to the service biocontrol, 14 sources, and only two were about pollination in and supported by soybean. Three studies analyzed the effect on activity density of aphids and predatory species with exclusion experiments. Six sources compiled information about the effect of different multicropping strategies on different pest organisms or predators; two studies addressed each the landscape effect on biocontrol and plant damage.

It is clear to see that, even for soybean, one of the most cultivated crops worldwide and the most cultivated grain legume, there is by far not enough information to make explicit statements regarding its effect on biodiversity. The most studied factor for all drivers, crop or management, was activity density. Activity density is a parameter which is limited in giving information about diversity as such. Suppose we have had not considered activity density; this review would not have been possible to do because of the scarcity of sources that deal with, for example, species richness and Shannon diversity. Since we do not know other reviews about the biodiversity parameter for one specific crop, it is not easy to compare this publication with others from literature.

Table 2. Specifications of soybean seed, fertilisation, tillage, and weed control used in the studies chosen for this review

Study category	Drivers			
	All	Crop	Management	Landscape
	[n]			
Plants	25	19	16	1
Invertebrates	23	16	5	4
Biocontrol*	14	7	1	2
Pollination*	2	-	-	-
All categories	56	-	-	-

* Biocontrol included studies that analyzed infection directly as well as herbivore increment within exclusion experiments. These studies could not be categorized in the same drivers as plants and invertebrates

* As in biocontrol, pollination studies consisted of exclusion experiments

Table 3: Amount of studies and single comparisons found for every driver area and diversity parameter for each wild plant and wild plant seeds/seed bank

Drivers / Factor		Biodiversity parameter for organism groups and functional groups for plants and plant seeds (se) [n studies] , [n comparisons]													
		B	C	D	E	F	H	He	HRI	P	RA	S	α	β	γ
Crop	Crop identity	6.7	3.4	6.4	**-**	1.1	2.1	-	-	-	-	5.4	2.1	1.1	1,1
	Crop sequence	1.3	-	1.1. se2.4	se1.3	-	1.3. se1.3	-	-	se1.1	-	1.1. se2.4		-	-
	Polycropping	4.10	1.2	1.2	-	-	2.4	-	-	-	-	4.12	1.2	1.2	-
Management	Fertilisation	3.3	-	-	**-**	-	1.1	-	-	-	-	1.1	-	-	-
	Tillage	1.1	-	5.4. se2.3	se1.3	-	1.3. se4.3	1.1	-	-	-	1.3. se2.3	-	-	-
	Weed control	3.3	1.1	4.2	2.3	-	2.3	-	1.1	-	1.1	2.3	-	-	-
Landscape		-	-	-	-	-	-	-		-	-	-	1.3	1.3	-

*With: B: Biomass C: Weed cover, D: Density, E: Shannon evenness, F: frequency, H: Shannon diversity index, He: Plant height, HRI: Hierarchical richness index, P: Production (seed), RA: relative abundance, S: Species richness, α: alpha diversity, β: beta diversity, γ: gamma diversity

Table 4: Amount of studies and comparisons found in every driver area and diversity parameter for each invertebrate organism group and functional group, the last given as an abbreviation

Driver / Factor		Biodiversity parameter for invertebrate organism groups and functional groups [group abbreviation] ^ [n studies] , [n comparisons]					
		AD	E	H	HRI	S	T
Crop	Crop identity	$A^{3,1}$, $Ar^{3,3}$, $C^{2,2}$, $D^{1,1}$, $F^{1,1}$, $G^{1,1}$, $L^{1,2}$, $Ac^{1,1}$ - $\mathrm{De}^{1,1}$, $\mathrm{Fu}^{1,1}$, $\mathrm{He}^{1,1}$, $\mathrm{Pa}^{1,1}$, $\mathrm{Po}^{1,1}$, $\mathrm{Pr}^{1,1}$	$C^{2,3}$	$C^{2,3}$	$C^{1,3}$	$A^{1,1}$, $Ar^{4,9}$, $C^{2,3}$ - $\mathrm{Pa}^{1,8}$, $\mathrm{Po}^{1,1}$	-
	Crop sequence	$A^{2,2}$, $Ar^{1,1}$, $C^{3,2}$, $D^{1,1}$, $F^{1,1}$, $G^{1,1}$, $L^{2,4}$	$C^{1,1}$	$C^{2,3}$	-	$C^{2,3}$	-
	Polycropping	$A^{2,2}$ - $\mathrm{He}^{1,1}$, $\mathrm{nHe}^{1,1}$	-	-	-	$A^{2,2}$ - $\mathrm{He}^{1,1}$, $\mathrm{nHe}^{1,1}$	-
Management	Fertilization	$Ar^{1,1}$ - $\mathrm{He}^{1,1}$, $\mathrm{Pr}^{1,1}$	-	-	-	-	-
	Tillage	$A^{1,1}$, $Ar^{1,1}$, $C^{1,1}$ - $\mathrm{De}^{1,1}$, $\mathrm{Fu}^{1,1}$, $\mathrm{He}^{1,1}$, $\mathrm{Pa}^{1,1}$, $\mathrm{Pr}^{1,1}$	-	-	-	-	-
	Weed control	$\mathrm{SO}^{1,2}$	$C^{1,1}$	$C^{1,1}$	$C^{1,1}$	$A^{1,1}$, $\mathrm{C}^{1,1}$	-
Landscape		$Ap^{1,1}$ - $\mathrm{He}^{1,1}$, $\mathrm{Po}^{1,1}$, $\mathrm{Pr}^{1,1}$	-	-	-	$Ap^{1,1}$, $F^{1,1}$ - $\mathrm{He}^{1,1}$, $\mathrm{Po}^{1,1}$, $\mathrm{Pr}^{1,1}$	$Ap^{1,1}$, $F^{1,1}$

*With: AD: Activity density, E: Shannon evenness, H: Shannon diversity index, HRI: Hierarchical richness index, S: Species richness, T: Taxa richness
A: Arthropoda, Ar: Aranea, C: Carabidae, D: Diplopoda, F: Formicidae G: Grillydae, L: Lumbricidae, Ac: Acari, Ap: Apis spec.**, SO: Single organism specie, De: Detritivores, Fu: Fungivore, He: Herbivores, nHe: not Herbivores, Pa: Parasitoid, Po: Pollinator, Pr: Predator.**

Crop drivers

In the following, we will discuss the crop drivers crop identity, crop sequence, and polycropping.

Crop identity

That the crop does affect several factors of accompanying vegetation was stated by many authors e.g., Thomas & Frick[22], Wicks et al.[23] and Fried et al.[24]. Whereas increased accompanying flora diversity is not necessarily associated with reduced yields.[25]

Plants

We found information about plant biomass, cover grade, plant density, frequency, Shannon diversity, species richness, alpha, beta, and gamma diversity comparing soybean with other crops for the driver crop identity. The parameters we found the most in literature were plant biomass, cover grade, density (these all three being disservices oriented plant parameters), and species richness. There were altogether comparisons with maize in all nine parameters named, with a sunflower in four parameters, with okra and lima bean in three parameters, with wheat in two parameters, and with sorghum in one parameter (Table A1).

We first analysed the effect of crop identity on accompanying vegetation biomass. Soy always had lower biomass values than all other studied crops, including maize, sorghum, sunflower, and wheat. This comparison is based all on at least four single values (see Section 2). The differences were, except for sunflower, high reaching from 175 to 483%. Within the factor cover grade, we observed similar behavior like in plant biomass, soy showed lower values than all other crops, with values ranging between 76 and 131%.[26] [27] [28] The plant density, defined as the number of individuals in a given area, was higher in soy than in maize (65%), while sunflower and wheat had higher weed densities by each 58 and 21%. Regarding the frequency of weed Rauber et al. [29] reported similar values for soybean and maize. The Shannon diversity was much higher in soy than in maize, the difference amounted 216%. The species richness was the focus of five studies; soybean had a higher weed species richness compared to maize by 21%, a similar compared to lima bean and lower compared to okra and sunflower by each 17 and 41%. [30] [31] [32] [33] [34]

---

[22] Thomas, A. G., & Frick, B. L. (1993). Influence of tillage systems on weed abundance in southwestern Ontario. Weed Technology, 699-705.

[23] Wicks, G. A., Mahnken, G. W., & Hanson, G. E. (1995). Influence of small grain crops on weeds and ecofallow maize (Zea mays). Weed Science, 128-133.

[24] Fried, G., Norton, L. R., & Reboud, X. (2008). Environmental and management factors determining weed species composition and diversity in France. Agriculture, Ecosystems & Environment, 128(1-2), 68-76.

[25] Légère, A., Stevenson, F. C., & Ziadi, N. (2008). Contrasting responses of weed communities and crops to 12 years of tillage and fertilization treatments. Weed Technology, 22(2), 309-317.

[26] Palmer, M. W., & Maurer, T. A. (1997). Does diversity beget diversity? A case study of crops and weeds. Journal of Vegetation Science, 8(2), 235-240.

[27] Pannacci & Tei (2014); see above.

[28] De la Fuente, E. B., Suárez, S. A., Lenardis, A. E., & Poggio, S. L. (2014). Intercropping sunflower and soybean in intensive farming systems: evaluating yield advantage and effect on weed and insect assemblages. NJAS-Wageningen Journal of Life Sciences, 70, 47-52.

[29] Rauber, R. B., Demaría, M. R., Jobbágy, E. G., Arroyo, D. N., & Poggio, S. L. (2018). Weed Communities in semiarid rainfed croplands of Central Argentina: comparison between maize (Zea mays) and soybean (Glycine max) crops. Weed Science, 66(3), 368-378.

[30] Poggio, S. L., Chaneton, E. J., & Ghersa, C. M. (2013). The arable plant diversity of intensively managed farmland: Effects of field position and crop type at local and landscape scales. Agriculture, Ecosystems & Environment, 166, 55-64.

[31] Palmer & Maurer (1997); see above.

[32] Légère, A. et al. (2208); see above.

Alpha diversity of plants in maize was 22% higher than of soy. Beta diversity was 22% higher in soybean fields and gamma diversity 74% higher than maizefields.[35] [36]

The way a crop interacts with accompanying vegetation is related to the canopy and rhizosphere traits.[37] Many authors address the same physiological background with a slightly different angle. Rauber et al.[38] wrote about above and below ground microenvironment characteristics as primary drivers for the differences in plant parameters. De la Fuente et al.[39] mentioned that the difference in plant parameters is justified through different resource assimilation among crops (water, light), canopy structure and weed management. Wortmann et al.[40] conclude that the variation in weed communities and parameters is driven by a combination of environmental and management factors. Palmer & Maurer[41] justified the effects of environmental microheterogeneity created by different crops. No one of these authors specifies which environmental factor is affected by different crops. De la Fuente et al.[42] pointed out that the accompanying vegetation parameters are not understood and should be further studied.

It was possible to assess differences in associated vegetation for soy compared to maize and wheat. Maize has a tall canopy, but it is not closed like soybean[43]; it leaves space for accompanying vegetation to grow. Soy can suppress accompanying vegetation which is shorter than soy because of its closed canopy.[44] [45] The soybean reaches ground cover earlier than maize.[46] Furthermore, soybean is a crop that got, independently of herbicide tolerant or not, intensive weed control to accomplish a closed canopy without being outcompeted by the accompanying vegetation resulting in yielding losses. Poggio et al.[47] mention the dense canopy of cereals can suppress both growth and germination of seeds. Pannacci & Tei[48] mentioned the competitiveness of crops, which is at highest in sunflower, intermediate for maize, and lowest for soybean. Thomas & Frick[49], in a survey of southern Ontario, tilled and no-tilled fields, also observed weed communities in soybean and maize were more similar to each other than the weed communities in wheat and that the crop effect was more important than the tillage system. Some other authors did not discuss the crop's effect in accompanying vegetation in detail since the crop identity aspect was not the main focus of their work.[50] [51] [52] [53]

---

[33] Molina, G. A., Poggio, S. L., & Ghersa, C. M. (2014). Epigeal arthropod communities in intensively farmed landscapes: effects of land use mosaics, neighbourhood heterogeneity, and field position. Agriculture, Ecosystems & Environment, 192, 135-143.

[34] de la Fuente, E. B. (2014); see above.

[35] Poggio, S. L. et al. (2013); see above.

[36] Rauber, R. B. (2018); see above.

[37] Gomez, P., & Gurevitch, J. (1998). Weed community responses in a maize-soybean intercrop. Applied Vegetation Science, 1(2), 281-288.

[38] Rauber, R. B. et al. (2018); see above.

[39] de la Fuente, E. B. et al. (2014); see above.

[40] Wortman, S. E (2010); see above.

[41] Palmer & Maurer (1997); see above.

[42] de la Fuente, E. B. et al. (2014); see above.

[43] Maddonni, G. A., Otegui, M. E., & Cirilo, A. G. (2001). Plant population density, row spacing and hybrid effects on maize canopy architecture and light attenuation. Field Crops Research, 71(3), 183-193.

[44] Smith, R. G., & Gross, K. L. (2007). Assembly of weed communities along a crop diversity gradient. Journal of Applied Ecology, 44(5), 1046-1056.

[45] Pengelly, B. C., Blamey, F. P. C., & Muchow, R. C. (1999). Radiation interception and the accumulation of biomass and nitrogen by soybean and three tropical annual forage legumes. Field Crops Research, 63(2), 99-112.

[46] Flénet, F., Kiniry, J. R., Board, J. E., Westgate, M. E., & Reicosky, D. C. (1996). Row spacing effects on light extinction coefficients of maize, sorghum, soybean, and sunflower. Agronomy Journal, 88(2), 185-190.

[47] Poggio, S. L. et al. (2013); see above.

[48] Pannacci & Tei (2014); see above.

[49] Thomas, A. G. (1993); see above.

[50] Légère, A. et al. (2008); see above.

Invertebrates
We could gather information comparing soybean and other crops, with a number of replications of four or more, about *Aranea*, total *Arthropoda, Carabidae* and *Lumbricidae* and the functional group of the parasitoids. Furthermore, information was available about the taxonomic groups *Diplopoda*, *Formicidae*, *Grillydae*, and the functional groups detritivore, fungivore, herbivore, parasitoid, pollinator, and predator. The most used crop was maize, being present in the invertebrate organism group and parameter, maize was followed by wheat and alfalfa (Table A2). As already mentioned before, the most used parameter was activity density studied in 13, species richness in four, evenness, Shannon diversity, and hierarchical richness index each in one invertebrate organism group.

For *Aranea*, we found information regarding activity density and species richness.[54] [55] [56] [57] Spiders showed higher activity density in alfalfa than soy for both annual and perennial cultivation by 48 and 500% (n>4). Maize and soy showed similar values (n<4). *Aranea* showed higher species richness values in soy than almost all other studied crops maize (93%), guar (403%), peanuts (100%), rice (249%), sorghum (197%), and sugarcane (91%). Only alfalfa and cotton had slightly higher spider species richness than soy.

Three studies that analyzed *Arthropoda* activity density showed, on average, 26% higher values in soy than maize.[58] [59] [60] For the parameter species richness, Nelson et al.[61] found out that soya had by 89% higher species richness than maize (Table A2). *Carabidae* were more active in soy than in maize, while soy and alfalfa did not differ greatly. Unfortunately, no category showed n>3, so the observations are limited in their validity.
Soybean showed a higher *Carabidae* activity density than maize (55%), a lower evenness (38%), Shannon diversity (28%) and hierarchical richness index (36%) as well as a similar species richness compared to maize.[62] [63] [64] The comparison between soybean and

---

[51] Swanton, C. J., Shrestha, A., Clements, D. R., Booth, B. D., & Chandler, K. (2002). Evaluation of alternative weed management systems in a modified no-tillage maize–soybean–winter wheat rotation: weed densities, crop yield, and economics. Weed Science, 50(4), 504-511.
[52] Swanton, C. J., Booth, B. D., Chandler, K., Clements, D. R., & Shrestha, A. (2006). Management in a modified no-tillage maize–soybean–wheat rotation influences weed population and community dynamics. Weed Science, 54(1), 47-58.
[53] Anderson, R. L. (2009). A 2-year small grain interval reduces need for herbicides in no-till soybean. Weed Technology, 23(3), 398-403.
[54] Culin, J. D., & Yeargan, K. V. (1983a). Comparative study of spider communities in alfalfa and soybean ecosystems: Foliage-dwelling spiders. Annals of the Entomological Society of America, 76(5), 825-831.
[55] Culin, J. D., & Yeargan, K. V. (1983b). Comparative study of spider communities in alfalfa and soybean ecosystems: ground-surface spiders. Annals of the Entomological Society of America, 76(5), 832-838.
[56] Dunbar, M. W., O'Neal, M. E., & Gassmann, A. J. (2016). Increased risk of insect injury to maize following rye cover crop. Journal of Economic Entomology, 109(4), 1691-1697.
[57] Young, O. P., & Edwards, G. B. (1990). Spiders in United States field crops and their potential effect on crop pests. Journal of Arachnology, 1-27.
[58] Dunbar, M. W. et al. (1983); see above.
[59] Nelson, J. L., Hunt, L. G., Lewis, M. T., Hamby, K. A., Hooks, C. R., & Dively, G. P. (2018). Arthropod communities in warm and cool grass riparian buffers and their influence on natural enemies in adjacent crops. Agriculture, Ecosystems & Environment, 257, 81-91.
[60] Adams III, P. R., Orr, D. B., Arellano, C., & Cardoza, Y. J. (2017). Soil and foliar arthropod abundance and diversity in five cropping systems in the coastal plains of North Carolina. Environmental Entomology, 46(4), 771-783.
[61] Nelson, J. L. et al. (2018); see above.
[62] Ellsbury, M. M., Powell, J. E., Forcella, F., Woodson, W. D., Clay, S. A., & Riedell, W. E. (1998). Diversity and dominant species of ground beetle assemblages (Coleoptera: Carabidae) in crop rotation and chemical input systems for the Northern Great Plains. Annals of the Entomological Society of America, 91(5), 619-625.
[63] French, B. W., Chandler, L. D., Ellsbury, M. M., Fuller, B. W., & West, M. (2004). Ground beetle (Coleoptera: Carabidae) assemblages in a transgenic maize–soybean cropping system. Environmental Entomology, 33(3), 554-563.

alfalfa resulted in similar activity densities, evenness, and species richness as well as a slightly lower Shannon diversity (12%) and much higher hierarchical richness index (213%) in soy.[65] [66] Wheat and soybean had some little differences. The evenness was lower in soy (15%), Shannon diversity higher (11%), hierarchical richness index much higher (134%), and species richness higher (17%). The community was more diverse in soy than in wheat but less divers than in maize and alfalfa. In terms of evenness, alfalfa and soy showed similar values, maize had higher values than soy, and wheat only slightly higher values than soy. The hierarchical richness index showed only higher values for maize compared with soy.

Three studies in the literature analyzed the factor activity density.[67] [68] [69] For the organism group *Lumbricidae*, and the functional groups fungivore, herbivore, parasitoid, and predator, the number of experiments was higher than four. The main comparison crop was maize. Detritivores activity density was similar in maize and soy, Fungivore was higher in maize than in soy by 25%, Herbivore activity density was much higher in soy than in maize (3552%), *Lumbricidae* activity density was higher in soy than in maize (14%), Parasitoid activity density was similar, and predator activity density was higher in soy than in maize (82%) (Table A3). The invertebrates organism groups for which we found activity density information with n<4 compared to maize were *Diplopoda*, *Formicidae*, *Grillydae*, and the functional group pollinator. Soy showed lower activity density values in soy compared to maize for *Diplopoda* (12%) and pollinator (17%) and higher in soy compared to maize for *Formicidae* (24%) and *Grillydae* (39%). A single comparison between cotton and soy was found for *Lumbricidae*. The values were much higher in soy than in cotton (223%).

It was possible to find literature on parasitoid for different crops compared to soybean, punctually about species richness. The results in Mujica & Kroschel´s[70] study were strongly dependent on crop identity. While soybean and pea showed similar values, the species richness was much higher in soy compared to vegetables (seven different species, on average 225%), maize (86%), and chickpeas (225%). Alfalfa and common bean showed much higher species richness than soy by each 101 and 115%; however, faba bean and potato had higher values than soybean by 38 and 15%.

Some authors, O'Rourke et al.[71], for example, explained the crop identity effect through crop ability to influence microclimatic factors like temperature and humidity in different ways. In fact, for predators, plant structure is even more important than the presence of prey.[72] Furthermore, every crop has its own way of being managed, from fertilisation, sowing, and harvesting. Molina et al.[73] supposed that the larger plant size and opener canopy of maize offered higher trophic level predators like mammals and birds a higher

---

[64] O'Rourke, M. E., Liebman, M., & Rice, M. E. (2014). Ground beetle (Coleoptera: Carabidae) assemblages in conventional and diversified crop rotation systems. Environmental Entomology, 37(1), 121-130.

[65] Ellsbury, M. M. et al. (1998); see above.

[66] O'Rourke, M. E. et al. (2014); see above.

[67] Dunbar, M. W. et al. (1983); see above.

[68] Ashworth, A. J., Allen, F. L., Tyler, D. D., Pote, D. H., & Shipitalo, M. J. (2017). Earthworm populations are affected from long-term crop sequences and bio-covers under no-tillage. Pedobiologia, 60, 27-33.

[69] Adams III, P. R. et al. (2017); see above.

[70] Mujica, N., & Kroschel, J. (2011). Leafminer fly (Diptera: Agromyzidae) occurrence, distribution, and parasitoid associations in field and vegetable crops along the Peruvian coast. Environmental Entomology, 40(2), 217-230.

[71] O'Rourke, M. E. et al. (2014); see above.

[72] Greenstone, M. H. (1984). Determinants of web spider species diversity: vegetation structural diversity vs. prey availability. Oecologia, 62(3), 299-304.

[73] Molina, G. A. et al. (2014); see above.

chance of getting invertebrate prey. Possibly because of this, some invertebrate group's parameter was lower in maize compared to soy.

Furthermore, they mentioned the low ground cover, and less intensive weed control can let *Arthropoda* be more exposed to predation and parasitism. Ellsbury et al.[74] indicated that the broader spaces within rows in maize compared to soy enhance several invertebrates' movement chances while French et al.[75] saw the variation in arthropods' abundance related to different prey availability from maize and soybean fields. The activity density of *Arthropoda* seems to be influenced by the plant stem density. Ground beetles activity density was higher when stem density was lower, which depended on the planting or sawing density of the crops.[76] Other study explained the differences between soybean and sunflower might reside in differing weed communities, canopy structures, and pest management.[77] They also connected higher species richness and abundance in soy compared to sunflower because of soybean plant material being a good protein source for invertebrates.[78]

The increase of the invertebrate factor activity density in perennial cultivation is not surprising since undisturbed habitat with additionally good plant quality offers the best conditions for developing different invertebrate communities.[79] [80] [81] The perennial alfalfa traits count a dense vegetation cover and a thatch formation in which spiders can overwinter. The yearly disturbances in soybean impede a stable community structure since spiders need to build a new assemblage every new growing season. When both soy and alfalfa were cultivated annually, it seems to have the same biodiversity potential as alfalfa. The differences in spider biodiversity parameter within different crops stay in relationship with crop structural complexity.[82] Multiple branching dicotyledonous crops like legume crops, cotton and guar showed higher species richness than monocotyledonous crops like rice, grain sorghum, sugarcane, and maize.

Concerning the findings of *Carabidae* many authors corroborated the effects of the crop on carabid assemblage and activity density.[83] [84] [85] [86] Mujica et al.[87] , in its study about parasitoids, remarked that the mechanism for which a crop differs from the other in terms of biodiversity effect remains unclear and can be influenced by climatic conditions as well as management factors. The effect of crop identity on pollinator is undoubtedly related to the small opening of soybean flowers, making them less attractive than

---

[74] Ellsbury, M. M. et al. (1998); see above.

[75] French, B. W. et al. (2004); see above.

[76] Larsen, K. J., Work, T. T., & Purrington, F. F. (2003). Habitat use patterns by ground beetles (Coleoptera: Carabidae) of northeastern Iowa. Pedobiologia, 47(3), 288-299.

[77] de la Fuente, E. B. et al. (2014); see above.

[78] Lenardis, A. E., Morvillo, C. M., Gil, A., & de la Fuente, E. B. (2011). Arthropod communities related to different mixtures of oil (Glycine max L. Merr.) and essential oil (Artemisia annua L.) crops. Industrial Crops and Products, 34(2), 1340-1347.

[79] Culin, J. D., & Yeargan, K. V. (1983a); see above

[80] Culin, J. D., & Yeargan, K. V. (1983b); see above

[81] Clark, M. S., Gage, S. H., & Spence, J. R. (1997). Habitats and management associated with common ground beetles (Coleoptera: Carabidae) in a Michigan agricultural landscape. Environmental Entomology, 26(3), 519-527.

[82] Young, O. P. & Edwards, G. B. (1990); see above.

[83] Tonhasca Jr, A. (1993). Carabid beetle assemblage under diversified agroecosystems. Entomologia Experimentalis et Applicata, 68(3), 279-285.

[84] Honek, A., Martinkova, Z., & Jarosik, V. (2013). Ground beetles (Carabidae) as seed predators. EJE, 100(4), 531-544.

[85] Melnychuk, N. A., Olfert, O., Youngs, B., & Gillott, C. (2003). Abundance and diversity of Carabidae (Coleoptera) in different farming systems. Agriculture, Ecosystems & Environment, 95(1), 69-72.

[86] Dybing, D. C. (1994). Soybean flower production as related to plant growth and seed yield. Crop science, 34(2), 489-497.

[87] Mujica, N. & Kroschel, J. (2011); see above.

maize.[88] Dunbar et al.[89] supposed that *Formicidae* activity density being higher in soybean than maize is undoubtedly related to crop residues' quality. Another author observed in their experiments to *Lumbricidae* that despite maize producing two times more crop residues than soybean, earthworms' activity density was higher in soy.[90] Soy crops residues quality must have been a much better choice for these organism groups. The vast difference between soy and cotton can be explained through the fact that cotton got allelopathic compounds that diminish earthworm populations, and for cotton cultivation, the use of chemicals is increased, especially organophosphate. Two studies investigating earthworm activity density and cast densities determined that soybean monocrop had the highest values relative to the other crops, probably because of the better quality in terms of nitrogen and protein than the residue of maize or wheat.[91] [92] Like for plant parameters, there were studies which did not discuss the effect of the crop on invertebrate into detail since the crop identity aspect was not the main focus of their work.

Crop sequence

In the following, we show the results of investigations related to soybean integration into crop sequences. While some sources which corroborate that crop sequence impacts wild plant diversity and others showed little or no effect.[93] [94] [95] [96] [97]

Plants

We listed two sources that analyzed the effect of crop sequences containing soybean on plants and three sources handling about weed seeds. [98] [99] [100] [101] [102] Only both sources from Sosnoskie et al.[103] [104] contained n > 4. The weed biomass was more pronounced in longer crop sequences than shorter ones (Table A4).[105] Regarding the Shannon diversity values of longer crop sequences using soybean compared to the shorter ones, longer crop sequences showed higher values ranging between 24 and 94%. Furthermore, a maize-oat-hay sequence had higher species richness and density of accompanying vegetation

---

[88] Dybing, D. C. (1994). Soybean flower production as related to plant growth and seed yield. Crop science, 34(2), 489-497.

[89] Dunbar, M. W. et al. (1983); see above.

[90] Ashworth, A. J. et al. (2017); see above.

[91] Ashworth, A. J. et al. (2017); see above.

[92] Smith, R. G., McSwiney, C. P., Grandy, A. S., Suwanwaree, P., Snider, R. M., & Robertson, G. P. (2008). Diversity and abundance of earthworms across an agricultural land-use intensity gradient. Soil and Tillage Research, 100(1-2), 83-88.

[93] Liebman, M., & Dyck, E. (1993). Crop rotation and intercropping strategies for weed management. Ecological Applications, 3(1), 92-122.

[94] Cardina, J., Sparrow, D. H., & McCOY, E. L. (1995). Analysis of spatial distribution of common lambsquarters (Chenopodium album) in no-till soybean (Glycine max). Weed Science, 258-268.

[95] Légère, A., & Samson, N. (2004). Tillage and weed management effects on weeds in barley-red clover cropping systems. Weed Science, 881-885.

[96] Doucet, C., Weaver, S. E., Hamill, A. S., & Zhang, J. (1999). Separating the effects of crop rotation from weed management on weed density and diversity. Weed Science, 729-735.

[97] Barberi, P., & Lo Cascio, B. (2001). Long-term tillage and crop rotation effects on weed seedbank size and composition. Weed Research, 41(4), 325-340.

[98] Smith, R. G., & Gross, K. L. (2007); see above.

[99] Sosnoskie, L. M., Herms, C. P., & Cardina, J. (2006). Weed seedbank community composition in a 35-yr-old tillage and rotation experiment. Weed Science, 54(2), 263-273.

[100] Sosnoskie, L. M., Herms, C. P., Cardina, J., & Webster, T. M. (2009). Seedbank and emerged weed communities following adoption of glyphosate-resistant crops in a long-term tillage and rotation study. Weed Science, 57(3), 261-270.

[101] Kegode, G. O., Forcella, F., & Clay, S. (1999). Influence of crop rotation, tillage, and management inputs on weed seed production. Weed Science, 175-183.

[102] One source handled both named topics.

[103] Sosnoskie, L. M. et al. (2006); see above.

[104] Sosnoskie, L. M. et al. (2009); see above.

[105] Smith, R. G., & Gross, K. L. (2007); see above.

than a maize-soybean one by 21%.[106] The effect on accompanying vegetation seeds: maize monoculture showed a much higher density (76%) and similar evenness, Shannon diversity, and species richness compared with a maize-soybean-maize sequence. The seed production was higher in a soy-maize-soy-maize-soy sequence compared with a maize monoculture by 150%. Comparing a soy-maize-soy sequence and a maize-soy-maize sequence resulted in a 45% higher weed density and similar evenness, Shannon diversity, and species richness. The sequence maize-oat-hay had comparable weed seed densities with the maize-soy sequence but always higher evenness, Shannon diversity and species richness by each 28, 75, and 51%.

Summarizing the findings from the sources, we believe that accompanying vegetation parameters are affected by site characteristics such as site history, soil types and local environment variation, and microbial communities.[107] [108] Furthermore, management practices, like different planting and harvest dates of the crops, tillage, and plant protection regimes, especially their timing, seem very relevant.[109] [110] Crop factors like varying crop emergence times, canopy light interception, variations between autumn and spring-sown crops, and the presence of allelopathic chemicals indeed played a role. [111] [112] [113] Diversified sequences are supposed to have a variated light regime because every crop canopy possesses a different structure, and the management is crop-specific.[114] It was possible to find literature on wheat's and alfalfa's influence on plant diversity.[115] [116] [117] [118] The role of soybean, however, was more discussed from a perspective in which soybean monocultures in the Americas are enhanced through other crops like, for example, maize or soybean acting as a crop with a pre crop effect.[119] [120] [121] The methodical aspects of the measurements in crop sequences gain in importance. To capture differences caused by crop sequences in the long term, some authors analyzed instead of the plants themselves the seed and the seed bank.[122] [123] Murphy et al.[124] found out that the differences were more pronounced in the seed bank than in the emerged weeds.

---

[106] Sosnoskie, L. M. et al. (2009); see above.

[107] Andersson, L., & Milberg, P. (1998). Variation in seed dormancy among mother plants, populations and years of seed collection. Seed Science Research, 8(1), 29-38.

[108] Menalled, F. D., Gross, K. L., & Hammond, M. (2001). Weed aboveground and seedbank community responses to agricultural management systems. Ecological Applications, 11(6), 1586-1601.

[109] Swanton, C. J. et al. (2006); see above.

[110] Smith, R. G., & Gross, K. L. (2007); see above.

[111] Sosnoskie, L. M., (2009); see above.

[112] Smith, R. G.,& Gross, K. L. (2007); see above.

[113] Creamer, N. G., Bennett, M. A., Stinner, B. R., Cardina, J., & Regnier, E. E. (1996). Mechanisms of weed suppression in cover crop-based production systems. HortScience, 31(3), 410-413.

[114] Caporali, F., & Onnis, A. (1992). Validity of rotation as an effective agroecological principle for a sustainable agriculture. Agriculture, ecosystems & environment, 41(2), 101-113.

[115] Légère, A., and Samson, N. (1999). Relative influence of crop rotation, tillage, and weed management on weed associations in spring barley cropping systems. Weed Science, 112-122.

[116] Menalled, F. D. et al. (2001); see above.

[117] Chung, I. M., and Miller, D. A. (1995). Effect of alfalfa plant and soil extracts on germination and growth of alfalfa. Agronomy Journal, 87(4), 762-767.

[118] Weston, L. A. (1996). Utilization of allelopathy for weed management in agroecosystems. Agronomy Journal, 88(6), 860-866.

[119] Doucet, C. et al. (1999); see above.

[120] D́iaz-Zorita, M., Duarte, G. A., & Grove, J. H. (2002). A review of no-till systems and soil management for sustainable crop production in the subhumid and semiarid Pampas of Argentina. Soil and Tillage Research, 65(1), 1-18.

[121] Shrestha, B. M., McConkey, B. G., Smith, W. N., Desjardins, R. L., Campbell, C. A., Grant, B. B., & Miller, P. R. (2013). Effects of crop rotation, crop type and tillage on soil organic carbon in a semiarid climate. Canadian Journal of Soil Science, 93(1), 137-146.

[122] Sosnoskie, L. M. et al. (2009); see above.

[123] Murphy, S. D., Clements, D. R., Belaoussoff, S., Kevan, P. G., & Swanton, C. J. (2006). Promotion of weed species diversity and reduction of weed seedbanks with conservation tillage and crop rotation. Weed Science, 54(1), 69-77.

[124] Murphy, S. D. et al. (2006); see above.

Invertebrates

We gathered information regarding invertebrates about the effect of using soybean in the crop sequence. There were two kinds of data, one in which soybean was part of two sequences, but one sequence was short (2 years), and the other was long (4 years). The other kind of data were comparisons between sequences with and without soybean. Unfortunately, the amounts of repetition were for every driver and organism group lower than four. Three studies analyzed the effect of different sequences length on *Carabidae's* activity density. [125] [126] [127] The more extended sequence with one cultivation season of soybean produced 25% in activity density than the shorter sequence with one-time soybean (Table A5). Soybean in a four years sequence had slightly higher diversity (14%) and species richness (22%) as well as a lower evenness (22%) compared to the two years sequence. Maize monoculture and a maize-soy sequence did not differ considerably in terms of diversity or species richness. Nevertheless, in a more extended sequence, soybean and alfalfa, and wheat showed a higher species richness. The difference amounted to 23% compared to a maize-soybean rotation, while Shannon diversity remained almost equal.

About other invertebrate organism groups, we found three different sources. Comparing soy within a two and a three-year sequence, only *Diplopoda*, and *Grillydae* had higher activity densities in the more extended sequence.[128] *Aranea*, and *Formicidae* showed almost no response to the length of the different sequences. Taking all these groups together into account, all *Arthropoda*, the difference between the sequence length was marginal. Ashworth et al.[129] reported for *Lumbricidae* slightly higher activity densities in soy monoculture than soy in a two-year sequence, while Hubbard et al.[130] showed a soybean maize sequence having a much higher activity density than a wheat maize sequence (97%). Worm biomass was also higher in a soy-maize sequence compared to a wheat-maize sequence by 34%.

An exciting aspect we found in the literature was the role of soybean having a pre-crop effect on invertebrate biodiversity parameter in following crops. Brust et al.[131] reported a 19% higher activity density of *Arthopoda* and even a 100% higher activity density of *Carabidae* in maize after soybean compared to maize after maize (Table A6). The effect of different crop sequences in *Lumbricidae* was studied by Ashworth et al.[132]. For cotton, cotton after soybean showed a 197% higher activity density than cotton monoculture, while cotton after the maize had only a 43% higher activity density than cotton monoculture.

Like plant diversity, it can be assumed that with increasing crop diversity the diversification of environmental microvariability increases. It remains unclear if a longer rotation per se can increase biodiversity parameters and that the crops used in these sequences will have a primary grade of influence. [133] As factors, they mention canopy characteristics, less space for weeds, crop seed density, and therefore impact on

---

[125] O'Rourke, M. E. et al. (2014); see above.

[126] Dunbar, M. W. et al. (1983); see above.

[127] Ellsbury, M. M. et al. (1998); see above.

[128] Dunbar, M. W. et al. (1983); see above.

[129] Ashworth, A. J. et al. (2017); see above.

[130] Hubbard, V. C., Jordan, D., & Stecker, J. A. (1999). Earthworm response to rotation and tillage in a Missouri claypan soil. Biology and Fertility of Soils, 29(4), 343-347.

[131] Brust, G. E., Stinner, B. R., & McCartney, D. A. (1986). Predator activity and predation in maize agroecosystems. Environmental Entomology, 15(5), 1017-1021.

[132] Ashworth, A. J. et al. (2017); see above.

[133] O'Rourke, M. E. et al. (2014); see above.

invertebrate mobility. The concrete way they affect each other remains unclear. Hubbard et al.[134] discussed the positive effect of soybean in sequence by outpointing information about the better nutritional value of soybean plant material (above and below ground) compared to wheat and confirmed this result by citing further studies with similar observations.[135] [136] The observed pre crop effect on *Arthropoda*, *Carabidae*, and *Lumbricidae* stands possibly related to the high-quality plant residue of soybean.[137] [138] These authors postulate that *Arthropoda* and *Carabidae* get attracted to the soybean field after harvesting through the plant residues, and in this way, the amount of overwintering adults increases. It can also be assumed that the amount of overwintering *Arthropoda* and *Carabidae* larvae after soybean is higher than in other crops.

Polycropping

Polycropping strategies like intercropping and trap crops are widely accepted and studied approaches to decrease or suppress insect pests population density and stabilize yields, e.g., with the push-pull method.[139] [140] Those methods rely on manipulating host-finding mechanisms and can involve several kinds of intercropping (mixed intercropping, row intercropping, strip intercropping, relay intercropping).[141] The aim of using trap crops is to influence herbivorous organisms' preferences so that the main crop is spared.[142] There are contradictory results about the effect of cover crops on weed biodiversity. There were studies which corroborate that cover crops diminish weed density, and other remained the same. [143] [144] [145] [146] *Another option to reduce chemical inputs in production systems is to consider mixtures of several soybean cultivars within the same field to avoid the management problems with intercropping of different crops. This cultivar mixture can increase yield stability and improve disease resistance.*[147] [148] [149]

Plants

The quality of the information gathered was limited, with most of the comparison based on only one single experiment. The intercrops maize/soybean had a drastic decrease of accompanying vegetation biomass, especially compared to soybean alone (255%), and

---

[134] Hubbard, V. C. et al. (1999); see above.

[135] Satchell, J. E., & Lowe, D. (1967). G.(1967) Selection of leaf litter by Lumbricus terrestris. Graff, 0. and Satchell, J. E.(eds.). Progress in Soil Biology. North Holland, Amsterdam, 1024119.

[136] Shakir, S. H., & Dindal, D. L. (1997). Density and biomass of earthworms in forest and herbaceous microecosystems in central New York, North America. Soil Biology and Biochemistry, 29(3-4), 275-285.

[137] Brust, G. E. et al. (1986); see above.

[138] Dunbar, M. W. et al. (1983); see above.

[139] Altieri, M. A., Francis, C. A., Van Schoonhoven, A., & Doll, J. D. (1978). A review of insect prevalence in maize (Zea mays L.) and bean (Phaseolus vulgaris L.) polycultural systems. Field Crops Research, 1, 33-49.

[140] Cook, S. M., Khan, Z. R., & Pickett, J. A. (2007). The use of push-pull strategies in integrated pest management. Annual Review of Entomology, 52.

[141] Cook, S. M. et al. (2007); see above.

[142] Smith, H. A., & McSorley, R. (2000). Intercropping and pest management: a review of major concepts. American Entomologist, 46(3), 154-161.

[143] Barnes, J. P., & Putnam, A. R. (1986). Evidence for allelopathy by residues and aqueous extracts of rye (Secale cereale). Weed Science, 384-390.

[144] Teasdale, J. R., Beste, C. E., & Potts, W. E. (1991). Response of weeds to tillage and cover crop residue. Weed Science, 195-199.

[145] Teasdale, J. R., & Mohler, C. L. (1993). Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal, 85(3), 673-680.

[146] Swanton, C. J., Vyn, T. J., Chandler, K., & Shrestha, A. (1998). Weed management strategies for no-till soybean (Glycine max) grown on clay soils. Weed Technology, 660-669.

[147] Wolfe, M. (1985). The current status and prospects of multiline cultivars and variety mixtures for disease resistance. Annual Review of Phytopathology, 23(1), 251-273.

[148] Pan, P., & Qin, Y. (2014). Genotypic diversity of soybean in mixed cropping can affect the populations of insect pests and their natural enemies. International Journal of Pest Management, 60(4), 287-292.

[149] Watson, C. A. et al. (2017); see above.

maize (49%) (Table A7).[150] [151] *Another study compared common bean, maize, okra, soy, and sunflower with the multicrop of all of them.*[152] *In this case, the multicrop showed much higher weed biomass compared to soy (160%) while lower biomasses compared to the other single crops common bean, maize, okra, and sunflower by each 9%, 56%, 17%, and 18%. One experiment analyzed the cover grade of the accompanying vegetation for soybean and sunflower than an intercrop.*[153] *The weed cover was 200% higher in the intercrop than soy alone while it was similar to sunflower.*

For species richness, we found studies comparing different kinds of polycropping treatments such as double crop, intercrop, and multicroping.[154] [155] [156] *In the double-crop experiment, the single crops' species richness was higher than the double-crop by each 35 and 22% for maize and soy. Furthermore, other studies in Argentina comparing soy and a double crop of soy and wheat showed higher alpha and beta diversity for soy monoculture (25 and 38%). The maize monoculture also had higher alpha and beta diversity than the double-crop (33% and 49%). De La Fuente et al.*[157] *found out that intercropping enhanced biodiversity compared to single crops enhanced intercropping sunflower was added (132% increase) when soybean was added to sunflower (35%). So sunflowers' effect in addition to soybean lets species richness increase. Palmer's & Maurer*[158] *multicrop experiment showed partly higher species richness in the multicrop compared to single crops common bean (18%), soybean (24%), and sunflower (24%), partly similar species richness, compared to maize and okra. The study of Gomez & Gurevitch*[159] *gave insights about Shannon diversity. They found out that the intercrop showed 28% higher Shannon diversity than soybean. The use of cover crops in different sequences with soybean had apparent effects on weed biomass, density, species richness, and diversity (Table A8). For almost all cases, the use of cover crops resulted in a diminishing of all biodiversity parameters. The weed biomass was very strongly suppressed, while the effect was moderate for weed density and species richness. Weed diversity was also strongly affected by the use of cover crops. Thus this informations does base only on two studies.* [160] [161]

The results presented here offered a little hint about the effect of soybean within polycropping systems. Gomez & Gurevitch[162] *concerned themselves with intercropping; they revealed that the maximized crop densities in intercropping inhibited weed performance, especially in additive intercropping, producing higher crop yields and lower accompanying plants biomass.*[163] *Gomez & Gurevitch*[164] *explained the increase in Shannon diversity in a maize-soybean intercrop because of the specific lower weed suppression of major height weed. In this way, the dominance of specific species on the other side through increased environmental microheterogeneity in intercropping was permitted.*[165]

---

[150] Weil, R. R., & McFadden, M. E. (1991). Fertility and weed stress effects on performance of maize/soybean intercrop. Agronomy Journal, 83(4), 717-721.
[151] Gomez, P., & Gurevitch, J. (1998); see above.
[152] Palmer, M. W., and Maurer, T. A. (1997); see above.
[153] De la Fuente, E. B. et al. (2014); see above.
[154] Molina, G. A. et al. (2014); see above.
[155] De la Fuente, E. B. et al. (2014); see above.
[156] Palmer, M. W., & Maurer, T. A. (1997); see above.
[157] De la Fuente, E. B. et al. (2014); see above.
[158] Palmer, M. W.,& Maurer, T. A. (1997); see above.
[159] Gomez, P., & Gurevitch, J. (1998); see above.
[160] Smith, R. G., & Gross, K. L. (2007); see above.
[161] Shrestha, B. M. et al. (2000); see above.
[162] Gomez, P., & Gurevitch, J. (1998); see above.
[163] Weil, R. R., & McFadden, M. E. (1991); see above.
[164] Gomez, P., & Gurevitch, J. (1998); see above.
[165] Palmer, M. W., & Maurer, T. A. (1997); see above.

Poggio et al.[166] *explained their results in double crops causing reduced diversity values (alpha and beta) through the closed wheat canopy, which suppress growth and germination of weeds and due to the mulching effect of crop residues.*[167] [168] [169] [170] *The multicropping experiment possibly had a management aspect that influenced the effect of single crops; the field was cultivated without pesticides.*[171] *The highest increase in species richness in multicrop was in comparison to soybean. This last means soybean having the lowest species richness and biomass values under no weed control conditions can be interpreted as high competitiveness. The cropping system's increased competitiveness using cover crops significantly impacts accompanying plant parameters.* [172] *Other authors cited in Shresta et al.*[173] *reported lower weed abundance and improved yields when cover crops were used.*[174] [175] *While some cover crops got allelopathic properties it is mostly the resource competitiveness that caused a decrease of accompanying vegetation.*[176] [177] [178] *Gomez & Gurevitch*[179] *studied also cover crop effects in their experiments. They determined those cover crops had a more significant influence on accompanying plant communities than crops themselves.*

Invertebrates

Like the accompanying vegetation, the amounts of repetitions found in the literature were very low for the invertebrates.

Two studies revised the effect on activity density and species richness of total arthropods in each, a soybean-wheat intercrop and a soybean-sunflower intercrop (Table A9).[180] [181] The soybean-wheat intercrop had much higher activity density than the soy monoculture (82%), whereas the soy-sunflower intercrop had similar values than the soy monoculture. The soy-wheat intercrop and the soy monoculture were similar in terms of species richness. The soy-sunflower intercrop had a 47% lower species richness, surprisingly compared with soy monoculture. The study of O´Rourke et al.[182] gave us insights into the behavior of *Carabidae* in soy monoculture compared to a triticale-alfalfa intercrop. Carabidae's activity density was higher in soy than in the intercrop, *Carabidae* evenness, Shannon diversity, and species richness showed all higher values in the

---

[166] Poggio, S. L. et al. (2013); see above.

[167] Batlla, D., Kruk, B. C., & Benech-Arnold, R. L. (2000). Very early detection of canopy presence by seeds through perception of subtle modifications in red: far red signals. Functional Ecology, 14(2), 195-202.

[168] Poggio, S. L. (2005). Structure of weed communities occurring in monoculture and intercropping of field pea and barley. Agriculture, Ecosystems & Environment, 109(1-2), 48-58.

[169] Poggio, S. L., & Ghersa, C. M. (2011). Species richness and evenness as a function of biomass in arable plant communities. Weed Research, 51(3), 241-249.

[170] Caviglia, O. P., Sadras, V. O., & Andrade, F. H. (2004). Intensification of agriculture in the south-eastern Pampas: I. Capture and efficiency in the use of water and radiation in double-cropped wheat–soybean. Field Crops Research, 87(2-3), 117-129.

[171] Palmer, M. W., & Maurer, T. A. (1997); see above.

[172] Shrestha, B. M. et al. (2000); see above.

[173] Shrestha, B. M. et al. (2000); see above.

[174] Teasdale, J. R. (1996). Contribution of cover crops to weed management in sustainable agricultural systems. Journal of Production Agriculture, 9(4), 475-479.

[175] Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., ... & O'neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. Agronomy Journal, 97(1), 322-332.

[176] Creamer, N. G. et al. (1996); see above.

[177] Davis, A. S., & Liebman, M. (2003). Cropping system effects on giant foxtail (Setaria faberi) demography: I. Green manure and tillage timing. Weed Science, 51(6), 919-929.

[178] Kitajima, K., & Tilman, D. (1996). Seed banks and seedling establishment on an experimental productivity gradient. Oikos, 381-391.

[179] Gomez, P., & Gurevitch, J. (1998); see above.

[180] Molina, G. A. et al. (2014); see above.

[181] De la Fuente, E. B. et al. (2014); see above.

[182] O'Rourke, M. E. et al. (2014); see above.

intercrop than soy alone. Furthermore, de la Fuente et al.[183] found out that herbivores' activity density was 43% higher in the intercrop than the monoculture and of not-herbivores much higher in the monoculture to the intercrop by 108%. The species richness was for both herbivores and not herbivores higher in the monoculture than the intercrop by 11 and 80%.

Molina et al.[184] explained the higher activity density of Arthropoda between soybean monocrop and wheat soybean intercrop with the denser canopy of wheat, which acts as a barrier to higher predators like birds and mammals. Furthermore, after harvest, the remaining wheat crop residues crop offers a dense ground cover, which creates a protected ecosystem for invertebrates. The decrease of *Arthropoda* species richness in the soy-sunflower intercrop compared to soy monocrop is possibly related to the microheterogeneity caused by the crop combination through the variation in canopy structure, weed community characteristics, and pest control.[185] The reason for increased not-herbivore species (predatory species do count to not herbivores) in soy compared to the intercrop may reside in legumes' high availability of herbivore/prey. The authors highlighted soybean as a good protein source for herbivores and, indirectly, for their associated non-herbivores.[186] O´Rourke et al.[187] did not discuss their results regarding biodiversity of soy in comparison to an alfalfa-triticale intercrop.

Management factors

The literature research results for the topics management drivers affecting biodiversity in soybean-based agricultural systems were much more limited than those connected to crop drivers.

Fertilisation

Fertilisation is mainly not a central topic to soybean cultivation since its capacity to fix nitrogen from the air makes nitrogen fertilisation futile.

Plants

The fertilisation of soybean with inorganic compounds (N, P, K) had as a consequence in two of three studies the diminishing of weed biomass as a result (19% and 31%) and in one case a high increase (201%,) (Table A10).[188] [189] [190] Gomes & Gurevitch[191] showed that species richness and Shannon diversity were slightly increased when there was no fertilisation compared to fertilised plots. Legere et al.[192] pointed out that there are findings in which fertilisation increased herbicides' efficiency and, therefore, a decrease in weed biomass followed. Further findings in the literature cited by Legere et al.[193] indicated that fertilisation is one of the management drivers with fewer impacts on accompanying vegetation and that an accompanying plant community gains stability when nutrient

---

[183] De la Fuente, E. B. et al. (2014); see above.
[184] Molina, G. A. et al. (2014); see above.
[185] De la Fuente, E. B. et al. (2014); see above.
[186] Lenardis, A. E. et al. (2011); see above.
[187] O'Rourke, M. E. et al. (2014); see above.
[188] Légère, A. et al. (2008); see above.
[189] Gomez, P., & Gurevitch, J. (1998); see above.
[190] Weil, R. R., & McFadden, M. E. (1991); see above.
[191] Gomez, P., & Gurevitch, J. (1998); see above.
[192] Légère, A. et al. (2008); see above.
[193] Légère, A. et al. (2008); see above.

levels are balanced.[194] [195] [196] On behalf of diversity and species richness, Gomez & Guretvitch[197] cited studies that did observe an improvement of diversity parameters in accompanying vegetation through fertilisation.[198] [199] **Moreover, Tripathi & Singh[200] showed that fertilisation induced a higher increase in crop biomass than in accompanying vegetation.**

Invertebrates

We did not find information about the effect of chemical fertiliser, but one source analyzed the effect of compost added to the soil and its effect on the activity density of herbivore, predator, and foliar spiders.[201] The activity density of herbivores did not react to the addition of compost to the soil, predators were higher when no compost was added (20%), and foliar spiders showed much higher activity densities (134%) when compost was applied (Table A11). Rypstra & Marshall[202] (2005) see in their results the application of compost as attractant *Arthropoda* colonization and therefore increased prey for the spider.

The effect of tillage on plant and invertebrate diversity in soybean cultivation was analyzed in several sources.[203] [204] [205] [206] [207] [208] [209] [210] [211] No-till is the most used tillage practice in soybean cultivation in the Americas.

Plants

Except for the species richness, reduced tillage activity mainly increased biomass, density, diversity, and plant height in soybean. Legere et al.[212] reported 25% higher biomass in no-till than conventional till (Table A12). The average plant density was in no-till 54% higher than conventional tillage.[213] [214] [215] [216] Minimum tillage showed a 59% higher density compared to the conventional one.[217] Only rill tillage had lower density compared to conventional tillage (124%). Shannon diversity was 100% higher in no-tillage than conventional tillage, while 64% in no-tillage compared to minimum tillage. In one study

---

[194] McCloskey, M., Firbank, L. G., Watkinson, A. R., & Webb, D. J. (1996). The dynamics of experimental arable weed communities under different management practices. Journal of Vegetation Science, 7(6), 799-808.

[195] Stevenson, F. C., Légère, A., Simard, R. R., Angers, D. A., Pageau, D., & Lafond, J. (1997). Weed species diversity in spring barley varies with crop rotation and tillage, but not with nutrient source. Weed Science, 798-806.

[196] Yin, L., Cai, Z., & Zhong, W. (2006). Changes in weed community diversity of maize crops due to long-term fertilization. Crop Protection, 25(9), 910-914.

[197] Gomez, P., & Gurevitch, J. (1998); see above.

[198] Huston, M. (1979). A general hypothesis of species diversity. The American Naturalist, 113(1), 81-101.

[199] Tilman, D. (1985). The resource-ratio hypothesis of plant succession. The American Naturalist, 125(6), 827-852.

[200] Tripathi, B., & Singh, C. M. (1983). Weed and fertility management using maize/soyabean intercropping in the north-western Himalayas. International Journal of Pest Management, 29(3), 267-270.

[201] Rypstra, A. L., & Marshall, S. D. (2005). Augmentation of soil detritus affects the spider community and herbivory in a soybean agroecosystem. Entomologia Experimentalis et Applicata, 116(3), 149-157.

[202] Rypstra, A. L., & Marshall, S. D. (2005); see above.

[203] Légère, A. et al. (2008); see above.

[204] Shrestha, B. M. et al. (2000); see above.

[205] Sosnoskie, L. M. et al. (2006); see above.

[206] Sosnoskie, L. M. et al. (2009); see above.

[207] Rypstra, A. L., & Marshall, S. D. (2005); see above.

[208] Murphy, S. D. et al. (2006); see above.

[209] Cardina, J. et al. (1995); see above.

[210] Adams III, P. R. et al. (2017); see above.

[211] House, G. J., & All, J. N. (1981). Carabid beetles in soybean agroecosystems. Environmental Entomology, 10(2), 194-196.

[212] Légère, A. et al. (2008); see above.

[213] Légère, A. et al. (2008); see above.

[214] Shrestha, B. M. et al. (2000); see above.

[215] Sosnoskie, L. M. et al. (2009); see above.

[216] Rypstra, A. L., & Marshall, S. D. (2005); see above.

[217] Sosnoskie, L. M. et al. (2006); see above.

accompanying, vegetation height was increased by 11% in no-till compared to tilled systems. Tillage treatments showed no effect on the parameter species richness. The effect of till in weed seed was assessed in many literature sources.[218] [219] [220] [221] The seed density, seed species richness, and diversity were enhanced when tillage measures were reduced. Only the evenness was slightly reduced. Therefore, species richness was changing in the seed bank but did not express itself in above ground accompanying vegetation.

Some other authors also found higher densities in no-till than conventional tillage.[222] [223] [224] One of these reasons is the increment of perennial weeds.[225] Moreover, different tillage systems offer different soil moisture and aeration regimes. Recently tilled soils dispose of more aeration, porosity, and bulk density; thanks to this, weed seedling emergence is improved.[226] [227] The depth of tillage influences the distribution of weed seeds and, in their capacity to emerge. Conventional tillage holds seeds from deeper soil layer to the surface, promoting weed germination. No-till systems do not have this dynamic, but weed species that survive and germinate at soils surface benefit from this tillage form.[228] [229] Another aspect that explains lower density is the herbicide availability, and efficiency lowered in no-till systems.[230] Most interpretations do also apply for weed seed bank.[231]

It is not definitively clear if these observations apply to other crops than soybean. Shrestha et al.[232] found out that tillage systems did not affect weed community composition in winter wheat. Swanton et al.[233] stated too that management affected wheat, accompanying flora with less intensity than soybean or maize. Moreover accompanying vegetation in smother crops seems non-sensitive to tillage.[234] Concerning other drivers, when there was an increase of weed densities was not in the following of the tillage regime. It was generally because of the reduced use of herbicide and diminished mechanical control.[235] [236] Murphy et al.[237] conclude that reduced tillage combined with a good crop rotation may allow higher diversity, reduce weed density and expenditures on weed management.

---

[218] Sosnoskie, L. M. et al. (2006); see above.
[219] Sosnoskie, L. M. et al. (2009); see above.
[220] Murphy, S. D. et al. (2006); see above.
[221] Cardina, J. et al. (1995); see above.
[222] Buhler, D. D. (1992). Population dynamics and control of annual weeds in maize (Zea mays) as influenced by tillage systems. Weed Science, 241-248.
[223] Murphy, S. D. et al. (2006); see above.
[224] Sims, B. D., & Guethle, D. R. (1992). Herbicide programs in no-tillage and conventional-tillage soybeans (Glycine max) double cropped after wheat (Triticum aestivum). Weed Science, 255-263.
[225] Brandt, S. A. (1992). Zero vs. conventional tillage and their effects on crop yield and soil moisture. Canadian Journal of Plant Science, 72(3), 679-688.
[226] Shrestha, B. M. et al. (2000); see above.
[227] Anderson, R. L. (2009); see above.
[228] Buhler, D. D. (1995). Influence of tillage systems on weed population dynamics and management in maize and soybean in the central USA. Crop Science, 35(5), 1247-1258.
[229] Cardina, J., Regnier, E., & Harrison, K. (1991). Long-term tillage effects on seed banks in three Ohio soils. Weed Science, 186-194.
[230] Sadeghi, A. M., & Isensee, A. R. (1996). Impact of reversing tillage practices on movement and dissipation of atrazine in soil. Soil Science, 161(6), 390-397.
[231] Sosnoskie, L. M. et al. (2009); see above.
[232] Shrestha, B. M. et al. (2000); see above.
[233] Swanton, C. J. et al. (2006); see above.
[234] Légère, A. et al. (2008); see above.
[235] Cardina, J. et al. (1991); see above.
[236] Légère, A. et al. (2008); see above.
[237] Murphy, S. D. et al. (2006); see above.

Invertebrates

Two sources from literature addressed tillage influence in different functional organism groups' activity density.[238] [239] There were marked differences between the different groups in their reaction to this driver. The tilled systems had a higher activity density of total *Arthropoda* and foliar spiders than the no-till system by each 49% and 50% (Table A13).[240] [241] Fungivores and parasitoids showed much higher activity densities in tilled soils compared to no-tilled ones by each 83 and 100%.[242] *Carabidae*'s activity density was 54% higher in no-till systems than tilled ones.[243] The number of detritivores was much higher in no-till systems than tilled ones (317%).[244] Tillage had almost no effect on herbivores and predators' activity density.[245] [246]

Other authors found out that *Arthropoda* fauna was increased in no-till systems for wheat and cotton.[247] [248] So it seems that the effect of the driver tillage does interact with the driver crop identity. Williams et al.[249] mention that conventional tillage negatively affects grounding nesting bees.

Weed control

The effect of mechanical and chemical control in different intensities on accompanying vegetation parameters was analysed in six studies while the effect on invertebrates only in two. [250] [251] [252] [253] [254] [255] [256] [257]

Plants

The weed biomass in soybean was 143% higher when weeds were mechanically controlled compared with chemical control.[258] Weed control had higher weed biomass as a result, namely by 527% compared to no control, while reduced herbicide applications increased weed biomass by 8833% compared to high herbicide usage (Table A14). [259] Low

---

[238] Adams III, P. R. et al. (2017); see above.
[239] Rypstra, A. L., & Marshall, S. D. (2005); see above.
[240] Adams III, P. R. et al. (2017); see above.
[241] Rypstra, A. L., & Marshall, S. D. (2005); see above.
[242] Adams III, P. R. et al. (2017); see above.
[243] House, G. J., & All, J. N. (1981); see above.
[244] Adams III, P. R. et al. (2017); see above.
[245] Rypstra, A. L., & Marshall, S. D. (2005); see above.
[246] Adams III, P. R. et al. (2017); see above.
[247] Brévault, T., Bikay, S., Maldès, J. M., & Naudin, K. (2007). Impact of a no-till with mulch soil management strategy on soil macrofauna communities in a cotton cropping system. Soil and Tillage Research, 97(2), 140-149.
[248] Sapkota, T. B., Mazzoncini, M., Bàrberi, P., Antichi, D., & Silvestri, N. (2012). Fifteen years of no till increase soil organic matter, microbial biomass and arthropod diversity in cover crop-based arable cropping systems. Agronomy for Sustainable Development, 32(4), 853-863.
[249] Williams, N. M., Crone, E. E., T'ai, H. R., Minckley, R. L., Packer, L., & Potts, S. G. (2010). Ecological and life-history traits predict bee species responses to environmental disturbances. Biological Conservation, 143(10), 2280-2291.
[250] Ellsbury, M. M. et al. (1998); see above.
[251] Harasim, E., Gawęda, D., Wesołowski, M., Kwiatkowski, C., & Gocół, M. (2016). Cover cropping influences physico-chemical soil properties under direct drilling soybean. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, 66(1), 85-94.
[252] Kegode, G. O. et al. (1999); see above.
[253] Nord, E. A., Curran, W. S., Mortensen, D. A., Mirsky, S. B., & Jones, B. P. (2011). Integrating multiple tactics for managing weeds in high residue no-till soybean. Agronomy Journal, 103(5), 1542-1551.
[254] Pannacci, E., & Tei, F. (2014); see above.
[255] Shelton, M. D., & Edwards, C. R. (1983). Effects of weeds on the diversity and abundance of insects in soybeans. Environmental Entomology, 12(2), 296-298.
[256] Snyder, E. M., Curran, W. S., Karsten, H. D., Malcolm, G. M., Duiker, S. W., & Hyde, J. A. (2016). Assessment of an integrated weed management system in no-till soybean and maize. Weed Science, 64(4), 712-726.
[257] Swanton, C. J. et al. (2006); see above.
[258] Pannacci, E., & Tei, F. (2014); see above.
[259] Snyder, E. M. (2016); see above.

herbicide use also increased weed density by 1491%. Chemical weed control in soybean resulted in higher weed densities compared with mechanical one (36%). The weed cover also was increased (77%). Interestingly the parameters species richness and diversity in soybean were only slightly affected by control measures. The results on evenness were contradictory; while Harasim et al.[260] showed higher values when herbicides were used, Ellsbury et al.[261] reported an increase in evenness when herbicide doses were reduced. Dominant species were more present when lesser herbicides compared to high herbicide dosages were used, with values ranging between 20 and 38%.

The reason for the differences in accompanying vegetation biomass and density-driven by weed control is apparent and will not be discussed here. An explanation for the low dynamic in the diversity parameter Shannon diversity, evenness, and species richness can be found in the frequent use of glyphosate in soybean systems. It seems that its application independent of the intensity of other drivers determines accompanying flora dynamics at most.[262] [263] Furthermore, it is not surprising; thus, it addresses accompanying vegetation themselves. While maize and soybean reacted similarly to herbicide regimes, wheat did show a different dynamic.[264] [265] [266] Herbicide tolerant soybean got up to two glyphosate applications, while maize and not herbicide tolerant soybean post-emergence treatment is usually a single application of, e.g., atrazine and metolachlor.[267] Unfortunately, we could not find sources concerning differences between herbicide-tolerant soybean and conventional seed in literature. It can be assumed that further differentiation of the vegetation community composition and diversity parameter due to different weed control regimes can occur.

Invertebrates

For the driver pesticide regime, Ellsbury et al.[268] reported higher values for *Carabidae* species richness, evenness, and hierarchical dominance index were when pesticide application was low. Shannon diversity was similar between herbicide intensity. Shelton & Edwards[269] studied the effect of weed-free environments compared to weedy environments. Weedy environments, independent of the weed community composition, always showed higher values of *Arthropoda* species richness and activity density of *Epilachna varivestis* and *Harpalus spec.* by each 79%, 445%, and 156% (Table A15).

Shelton & Edwards[270] emphasize that especially flowering (nectar and pollen providing) weeds can attract predators to soybean habitats and recommend a fair amount of weeds as a part of an integrated pest management approach. Cárcamo et al.[271] showed that chemical fertiliser and herbicide inputs had adverse effects on ground beetles. In another

---

[260] Harasim, E. et al. (2016); see above.

[261] Ellsbury, M. M. et al. (1998); see above.

[262] Sosnoskie, L. M. et al. (2009); see above.

[263] Swanton, C. J. et al. (2006); see above.

[264] Hochol, T., Stupnicka-Rodzynkiewicz, E., Lepiarczyk, A., Hura, T., Dubert, F., & Stoklosa, A. (2004). The influence of date of selected plant species mulch incorporation into the soil on their weed infestation limiting effect. In Annales AFPP, Proceedings of the XII International Conference on Weed Biology, Dijon, France (pp. 187-194).

[265] Swanton, C. J. et al. (2006); see above.

[266] House, G. J., & Brust, G. E. (1989). Ecology of low-input, no-tillage agroecosystems. Agriculture, Ecosystems & Environment, 27(1-4), 331-345.

[267] Qaim, M., & Traxler, G. (2005). Roundup Ready soybeans in Argentina: farm level and aggregate welfare effects. Agricultural Economics, 32(1), 73-86.

[268] Ellsbury, M. M. et al. (1998); see above.

[269] Shelton, M. D., & Edwards, C. R. (1983); see above.

[270] Shelton, M. D., & Edwards, C. R. (1983); see above.

[271] Cárcamo, H. A., Niemalä, J. K., & Spence, J. R. (1995). Farming and ground beetles: effects of agronomic practice on populations and community structure. The Canadian Entomologist, 127(1), 123-140.

study the abundance of *Harpalus pensylvanicus* and the generally higher species richness of invertebrates in low input plots, was explained through the higher amounts of weeds that this low-level input shows.[272] Other authors as Molina et al.[273] stated, contrary to the exposed below, that a low ground cover and less intensive weed control can let arthropods be more exposed to predation and parasitism.

Tscharntke et al.[274] reported that management measures will affect agrobiodiversity only if cropped areas' surrounding landscape show a low proportion of semi-natural habitats. Thus at emergence, the dynamic of both pest organisms of natural enemies is affected through local measures independent of surrounding landscapes.[275]

Landscape

In the following we will present our results to the landscape aspect in soybean cultivation and its biodiversity aspects.

Plants

According to Poggio et al.[276], soy crop accompanying floras alpha and beta diversity were higher when cropland amount in a landscape was lower. The differences amounted up to 50% for alpha diversity and 52% for beta diversity (Table A16). Studies to the differences in plant diversity caused by landscape composition are rarer than those about invertebrate diversity.[277] [278] The processes underlying plant diversity transfer from semi-natural or natural habitats are mostly weed seed transport through mammals, birds, and wind.

Invertebrates

We studied landscapes with high use of soybean in the agricultural production compared to landscapes with a high amount of semi-natural habitats, Le Feón et al.[279] specifically on wild bees, Pacheco et al.[280] on *Formicidae*. Wild bees showed higher activity density, species richness, and taxa richness in semi-natural habitat than soybean-dominated crop areas by 38%, 81%, and 23% (Table A17).[281] *Formicidae* also had higher values for species and taxa richness in semi-natural habitat than cropped area by each 98 and 66%.[282]

---

[272] Ellsbury, M. M. et al. (1998); see above.

[273] Molina, G. A. et al. (2014); see above.

[274] Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecology Letters, 8(8), 857-874.

[275] Sarthou, J. P., Badoz, A., Vaissière, B., Chevallier, A., & Rusch, A. (2014). Local more than landscape parameters structure natural enemy communities during their overwintering in semi-natural habitats. Agriculture, Ecosystems & Environment, 194, 17-28.

[276] Poggio, S. L. et al. (2013); see above

[277] Poggio, S. L. et al. (2013); see above

[278] Rundlöf, M., Nilsson, H., & Smith, H. G. (2008). Interacting effects of farming practice and landscape context on bumble bees. Biological Conservation, 141(2), 417-426.

[279] Le Féon, V., Poggio, S. L., Torretta, J. P., Bertrand, C., Molina, G. A., Burel, F., ... & Ghersa, C. M. (2016). Diversity and life-history traits of wild bees (Insecta: Hymenoptera) in intensive agricultural landscapes in the Rolling Pampa, Argentina. Journal of Natural History, 50(19-20), 1175-1196.

[280] Pacheco, R., Vasconcelos, H. L., Groc, S., Camacho, G. P., & Frizzo, T. L. (2013). The importance of remnants of natural vegetation for maintaining ant diversity in Brazilian agricultural landscapes. Biodiversity and Conservation, 22(4), 983-997.

[281] Le Féon, V. et al. (2016); see above.

[282] Pacheco, R. et al. (2013); see above.

Monasterolo et al.[283] studied both activity densities and species richness of pollinators in forest and soybean fields. Meanwhile Gonzalez et al.[284] observed the same biodiversity parameter for herbivores and predators in landscapes with high forest cover and low forest cover (consequently high soybean cover). As expected, high forest cover or forest itself had always higher activity densities and species richness than landscapes with low forest cover or high amounts of soybean fields. The studies' common trait about landscape composition effect on soybean cultivation was that all of them were carried out in South America.

Surrounding landscape affects invertebrate species in cropped fields.[285] Semi-natural habitat provides hibernation and refuge for several invertebrate species.[286] [287] High forest cover in surrounding areas followed higher invertebrate activity and richness, probably because arthropod communities need a stable habitat and different food sources. [288] Tscharnke et al.[289] suggested that natural habitats can act as a source of pest organisms. Whereas Gonzales et al.[290] stated surrounding forest areas do not act as a pest source; on the contrary, soybean predator activity densities benefit through rich forest cover surrounding. The indiscriminate population growth of pest organisms is given when a tremendous amount of high-quality food is concentrated in an area, which is only the case for the cropped area. A high density of soy fields at the landscape scale has been shown to reduce biodiversity because, compared to semi-natural habitats, only a few arthropod species do adapt to yearly changing crop sequences in the agricultural environment.[291]

Landscape diversity increased the number of beneficial arthropods in maize and soybean fields.[292] [293] [294] [295] Two studies showed that the abundance of natural enemies was higher correlated with the proportion of semi-natural habitat in the landscape rather than with landscape diversity itself.[296] [297] Bianchi et al.[298] indicated that landscape complexity

---

[283] Monasterolo, M., Musicante, M. L., Valladares, G. R., & Salvo, A. (2015). Soybean crops may benefit from forest pollinators. Agriculture, Ecosystems & Environment, 202, 217-222.

[284] González, E., Salvo, A., & Valladares, G. (2017). Arthropod communities and biological control in soybean fields: forest cover at landscape scale is more influential than forest proximity. Agriculture, Ecosystems & Environment, 239, 359-367.

[285] Weibull, A. C., Östman, Ö., & Granqvist, Å. (2003). Species richness in agroecosystems: the effect of landscape, habitat and farm management. Biodiversity & Conservation, 12(7), 1335-1355.

[286] Chiari, W. C., Toledo, V. D. A. A. D., Ruvolo-Takasusuki, M. C. C., Oliveira, A. J. B. D., Sakaguti, E. S., Attencia, V. M., ... & Mitsui, M. H. (2005). Pollination of soybean (Glycine max L. Merril) by honeybees (Apis mellifera L.). Brazilian Archives of Biology and Technology, 48(1), 31-36.

[287] Milfont, M. D. O., Rocha, E. E. M., Lima, A. O. N., & Freitas, B. M. (2013). Higher soybean production using honeybee and wild pollinators, a sustainable alternative to pesticides and autopollination. Environmental Chemistry Letters, 11(4), 335-341.

[288] González, E. et al. (2017); see above.

[289] Tscharntke, T. et al. (2005); see above.

[290] González, E. et al. (2017); see above.

[291] De la Fuente, E. B., Suárez, S. A., & Ghersa, C. M. (2006). Soybean weed community composition and richness between 1995 and 2003 in the Rolling Pampas (Argentina). Agriculture, Ecosystems & Environment, 115(1-4), 229-236.

[292] Bianchi, F. J., Booij, C. J. H., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society B: Biological Sciences, 273(1595), 1715-1727.

[293] Bennett, A. B., & Isaacs, R. (2014). Landscape composition influences pollinators and pollination services in perennial biofuel plantings. Agriculture, Ecosystems & Environment, 193, 1-8.

[294] Gardiner, M. A., Tuell, J. K., Isaacs, R., Gibbs, J., Ascher, J. S., & Landis, D. A. (2010). Implications of three biofuel crops for beneficial arthropods in agricultural landscapes. BioEnergy Research, 3(1), 6-19.

[295] Wheelock, M. J., Rey, K. P., & O'Neal, M. E. (2016). Defining the insect pollinator community found in Iowa maize and soybean fields: Implications for pollinator conservation. Environmental Entomology, 45(5), 1099-1106.

[296] Attwood, S. J., Maron, M., House, A. P. N., & Zammit, C. (2008). Do arthropod assemblages display globally consistent responses to intensified agricultural land use and management?. Global Ecology and Biogeography, 17(5), 585-599.

increased natural enemies in 74% of the cases and reduced pest density in 45%.We found only one source, which, in contrast to the findings counted above, suggested that local factors influenced arthropod diversity and trophic structure the most.[299]

The distribution of non-cropped and cropped areas determined the distribution of ground-dwelling arthropods.[300] The same observation was valid for *Carabidae* whereas the contribution of both farming practices and local environmental conditions was lower than from the landscape.[301] [302] [303] Semi-natural habitats supported bee diversity in agricultural areas.[304] Chiari et al.[305] showed that pollinator visits in soybean were significantly lower with increasing distance to the forest. Others have registered similar effects of simplification of habitat affecting richness, taxonomic composition, and even functional structure of ant assemblages.[306] The conversion of natural forest areas into agricultural use harmed *Formicidae's* diversity.[307]

Summarizing the findings above, the conservation of semi-natural habitats is vital for the general conservation of invertebrate species.[308] [309] Small areas of natural vegetation can help preserve ant and other organism species diversity.[310]

Ecosystem service biocontrol

We found 14 studies about biocontrol concerning soybean cultivation. We found three exclusion experiments in the literature. Gardiner et al.[311] and Woltz et al.[312] analyzed the development of the activity density of aphids. After 1-week exclusion, they reported increased amounts of aphids by 113 and 383% in each experiment (Table A18). After two weeks, exclusion Woltz et al.[313] reported 1883% increased aphid activity density. Vichitbhanda & Wise[314] studied the amount of predator organism groups in an experiment with fences. Unfenced treatments had increased activity densities of all studied groups, *Araneae*, *Linyphiidae*, *Lycosidae*, *Carabidae*, and *Nabidae*, varying between 112 and

---

[297] Woltz, J. M., Isaacs, R., & Landis, D. A. (2012). Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape. Agriculture, Ecosystems & Environment, 152, 40-49.

[298] Bianchi, F. J. et al. (2006); see above.

[299] de la Fuente, E. B., Perelman, S., & Ghersa, C. M. (2010). Weed and arthropod communities in soyabean as related to crop productivity and land use in the Rolling Pampa, Argentina. Weed Research, 50(6), 561-571.

[300] Gardiner, M. A. et al. (2010); see above.

[301] Clark, M. S., Gage, S. H., & Spence, J. R. (1997). Habitats and management associated with common ground beetles (Coleoptera: Carabidae) in a Michigan agricultural landscape. Environmental Entomology, 26(3), 519-527.

[302] Larsen, K. J et al. (2003); see above.

[303] Maisonhaute, J. É., Peres-Neto, P., & Lucas, É. (2010). Influence of agronomic practices, local environment and landscape structure on predatory beetle assemblage. Agriculture, Ecosystems & Environment, 139(4), 500-507.

[304] Garibaldi, L. A., Steffan-Dewenter, I., Kremen, C., Morales, J. M., Bommarco, R., Cunningham, S. A., ... & Holzschuh, A. (2011). Stability of pollination services decreases with isolation from natural areas despite honey bee visits. Ecology Letters, 14(10), 1062-1072.

[305] Chiari, W. C. et al. (2005); see above.

[306] Pacheco, R. et al. (2013); see above.

[307] Perfecto, I., Vandermeer, J., Hanson, P., & Cartín, V. (1997). Arthropod biodiversity loss and the transformation of a tropical agro-ecosystem. Biodiversity & Conservation, 6(7), 935-945.

[308] Larsen, K. J et al. (2003); see above.

[309] Le Féon, V. et al. (2016); see above.

[310] Pacheco, R. et al. (2013); see above.

[311] Gardiner, M. M., Landis, D. A., Gratton, C., Schmidt, N., O'Neal, M., Mueller, E., ... & DiFonzo, C. D. (2009). Landscape composition influences patterns of native and exotic lady beetle abundance. Diversity and Distributions, 15(4), 554-564.

[312] Woltz, J. M. et al. (2012); see above.

[313] Woltz, J. M. et al. (2012); see above.

[314] Vichitbandha, P., & Wise, D. H. (2002). A field experiment on the effectiveness of spiders and carabid beetles as biocontrol agents in soybean. Agricultural and Forest Entomology, 4(1), 31-38.

366% compared to fenced treatments. One study had a focus on the predation of *Helicoverpa zea* eggs. The egg predation was more pronounced in maize than in soybean by around 60%.

Six experiments were about the effect of multicropping strategies. Holmes & Barret[315], Martin et al.[316] and Miklasicz & Hammond[317] reported higher herbivore activity densities in soy monocultures compared with intercropped systems consisting of wheat and sorghum (49%, *Popilia japonica*), soybean and wheat (287%, *Empoasca fabae*) and a soybean maize intercrop (53%, *Ostrinia nubilalis*). The use of cover crops reduced the amount of herbivore organism; in an experiment in the US, 527% lower activity density of soybean aphids than soybean with cover crops.[318] The proportion of plants infested by soybean aphids was 96% higher in systems without cover crops.[319] Michaud et al.[320] studied the effect of trap crops on soybean, the infection through *Dectes texanus* were greater with increasing distance to the trap crop. After a 300 m distance, the infection was 109% higher than a distance up to 200 m from the trap crop.

The effect of different landscapes on biocontrol was showed in the literature in two studies.[321] [322] Gonzalez et al.[323] showed that biological control was 67% higher in landscapes with high forest cover than those with low forest cover. Tabuchi et al.[324] analyzed the activity density of the parasitoid *Ooencyrtus nazarea* and the herbivore *Ryptortus pedestris*, the amounts of *O. nazarea* were considerably higher at the forest edge than the soybean field. The amounts of the herbivore were only 46% higher in the forest edge than the soybean field. Possibly this indicates that there are not tons of herbivores in the forest waiting to invade the fields. Forest can add significant amounts of parasitoids to the agricultural landscapes.

Carter & Rypstra[325] and Rypstra & Marshall[326] examined plant damage, first dependent on spiders' presence, second regarding tillage and soil amendments. The addition of spider to a soybean field has a consequence of 79% reduced plant damage than the control. The removal of spiders had consequently 36% higher plant damage. The tillage intensity did not significantly affect leaves damage, while soils amended with compost had 40% lesser leaves damaged.

---

[315] Holmes, D. M., & Barrett, G. W. (1997). Japanese beetle (Popillia japonica) dispersal behavior in intercropped vs. monoculture soybean agroecosystems. American Midland Naturalist, 312-319.

[316] Martin, R. C., Voldeng, H. D., & Smith, D. L. (1990). Intercropping maize and soybean for silage in a cool-temperature region: yield, protein and economic effects. Field Crops Research, 23(3-4), 295-310.

[317] Miklasiewicz, T. J., & Hammond, R. B. (2001). Density of potato leafhopper (Homoptera: Cicadellidae) in response to soybean-wheat cropping systems. Environmental Entomology, 30(2), 204-214.

[318] Koch, R. L., Sezen, Z., Porter, P. M., Ragsdale, D. W., Wyckhuys, K. A., & Heimpel, G. E. (2015). On-farm evaluation of a fall-seeded rye cover crop for suppression of soybean aphid (H emiptera: A phididae) on soybean. Agricultural and Forest Entomology, 17(3), 239-246.

[319] Koch, R. L. et al. (2015); see above.

[320] Michaud, J. P., Qureshi, J. A., & Grant, A. K. (2007). Sunflowers as a trap crop for reducing soybean losses to the stalk borer Dectes texanus (Coleoptera: Cerambycidae). Pest Management Science: formerly Pesticide Science, 63(9), 903-909.

[321] González, E. et al. (2017); see above.

[322] Tabuchi, K., Taki, H., Iwai, H., Mizutani, N., Nagasaka, K., Moriya, S., & Sasaki, R. (2014). Abundances of a bean bug and its natural enemy in seminatural and cultivated habitats in agricultural landscapes. Environmental Entomology, 43(2), 312-319.

[323] González, E. et al. (2017); see above.

[324] Tabuchi, K. et al. (2014); see above.

[325] Carter, P. E., & Rypstra, A. L. (1995). Top-down effects in soybean agroecosystems: spider density affects herbivore damage. Oikos, 433-439.

[326] Rypstra, A. L., & Marshall, S. D. (2005); see above.

Natural enemies are essential for pest control. Crop rich landscapes caused a reduction of biological control of the soybean aphid.[327] In a review, Bianchi et al.[328] found that increased landscape complexity reduced pest pressure in 45% of the studies; pest density and crop injury were reduced. Noma et al.[329] reported a negative correlation between landscape diversity and aphid density and a positive correlation between landscape diversity and the abundance of aphids enemies.[330] [331] Other authors like Woltz et al.[332] and Gardiner et al.[333] reported a seemingly low predator abundance maintained aphid population constrained even by a low proportion of semi-natural habitats. This suggests that even small amounts of a predator, like, for example, C*occinellidae* provide enough biocontrol. Predation in the early growth phase of soybean is decisive. Hence sources of predators, like semi-natural habitats in the surrounding, are beneficial.

Carter & Rypstra[334] studied spiders in soybean with an adding and removal experimental design. Their results show that spiders do control the pest organism in soybean cropping systems at measurable levels. In their study about egg predation, Pfannenstiel & Yeargan[335] found out that *Nabidae* is the primary predator group in soybean and *Coleomegilla maculata* in maize. The reasons for higher egg predation may reside in the canopy architecture, in which openness in maize permits higher mobility of different trophic groups.

Regarding intercropping systems, Holmes & Barret[336] speak about an "associational resistance" as a reason for reduced herbivore densities. They point out that it is essential to use a non-host crop in mixtures. Miklasievicz & Hammond[337] found out that the non-host crop should be at least present to a 50% of seed density to accomplish the objective of crop protection in soy-wheat intercrops. For the case of cover crops, Koch et al.[338] admitted that the mechanism is not entirely understood why cover crops reduced aphid amounts in such a high manner, but many other authors observed this. One hypothesis is that natural enemies are more abundant in polycultures. Which is not fully supported by the results of this review. The other theory is the so-called "resource concentration," which affirms lower resource concentration for aphids thinning the host crop. According to Koch et al.[339] herbivores have greater chances of getting food resources in high concentrations in monocultures than polycultures. Michaud et al.[340] stated that the spatial aspect of crop protection efficiency through trap crops is limited to a determined area which disposes of enough attraction (possibly through "push phytochemical"). Javaid et

---

[327] Gardiner, M. M. et al. (2009); see above.

[328] Bianchi, F. J. et al. (2006); see above.

[329] Noma, T., Gratton, C., Colunga-Garcia, M., Brewer, M. J., Mueller, E. E., Wyckhuys, K. A., ... & O'Neal, M. E. (2010). Relationship of soybean aphid (Hemiptera: Aphididae) to soybean plant nutrients, landscape structure, and natural enemies. Environmental Entomology, 39(1), 31-41.

[330] Gardiner, M. M. et al. (2009); see above.

[331] Gardiner, M. A. et al. (2010); see above.

[332] Woltz, J. M. et al. (2012); see above.

[333] Gardiner, M. M. et al. (2009); see above.

[334] Carter, P. E., & Rypstra, A. L. (1995); see above.

[335] Pfannenstiel, R. S., & Yeargan, K. V. (2002). Identification and diel activity patterns of predators attacking Helicoverpa zea (Lepidoptera: Noctuidae) eggs in soybean and sweet maize. Environmental Entomology, 31(2), 232-241.

[336] Holmes, D. M., & Barrett, G. W. (1997). Japanese beetle (Popillia japonica) dispersal behavior in intercropped vs. monoculture soybean agroecosystems. American Midland Naturalist, 312-319.

[337] Miklasiewicz, T. J., & Hammond, R. B. (2001); see above.

[338] Koch, R. L., Porter, P. M., Harbur, M. M., Abrahamson, M. D., Wyckhuys, K. A., Ragsdale, D. W., ... & Heimpel, G. E. (2012). Response of soybean insects to an autumn-seeded rye cover crop. Environmental Entomology, 41(4), 750-760.

[339] Koch R. L., et al. (2005); see above.

[340] Michaud, J. P. et al. (2007); see above.

al.[341] showed that Bt-maize acts as a trap crop for the generalist pest organism maize earworm, *Helicoverpa zea*, when planted close enough to soybean fields. The ovipositional activity was focused on one point rather than being distributed in space.

Gonzalez et al.[342], on average, reported biological control by predators and parasitoids were 20% higher in forest-rich landscapes. Tabuchi et al.[343] stated that biocontrol service was more efficient at forest edges than in soybean fields. The relatively high biological control levels found within the forest indicate this habitat's essential role as a reservoir of natural enemies for the crop. Regarding the pest-enemy time dynamic, the pest organism does move first to the field and then increase its population. The movement of natural enemies takes longer. Limiting resources for predators or parasitic organisms are prey species because this food resource is much more ephemeral than the herbivore resource. The pest control in soybean is related to the semi-natural habitats with much higher densities of enemies.

Ecosystem service pollination

The pollination ecosystem service was assessed in two studies of literature. Chiari et al.[344] reported exclusion experiments in Brasil increasing pod amounts when soybean plants were isolated with bees compared with being isolated without bees (81%) and showed higher pod amounts in exclusion with bees than in open parcels (52%) (Table A19). The yield reacted in a similar way and magnitude. Monasterolo et al.[345] reported higher seed weight, pod weights, and reproductive success from open treatments than exclusion experiments by 91, 79, and 114%. The exclusion without bees increased also seed abortion by 26%.

Soybean is a possible pollen and nectar source for bees, and other pollinators not only for bees but also for flies from the *Diptera* genus.[346] [347] The soybean can produce half a million florets in one ha.[348] Flower morphology and the flowering process can have a massive effect on the pollen and nectar accessibility for pollinators. Since the soybean has been bred to be self-pollinating, their flowers are small. In Europe's temperate regions, primarily early-flowering and early-maturing landraces (maturity group 000–00) of soybean are grown. Those varieties strongly tend to produce cleistogamous flowers throughout their blooming period, especially when temperatures are low.[349] Therefore, findings from warm regions in South America and the USA need to be verified in field studies in Europe's temperate regions.

---

[341] Javaid, I., Joshi, J., Dadson, R. B., Hashem, F. M., & Allen, A. L. (2005). The potential of Bt maize as a trap crop for the control of maize earworm, Helicoverpa zea Boddie, in soybean. Journal of Sustainable Agriculture, 26(1), 115-121.

[342] González, E. et al. (2017); see above.

[343] Tabuchi, K. et al. (2014); see above.

[344] Chiari, W. C. et al. (2005); see above.

[345] Monasterolo, M. et al. (2015); see above.

[346] Gill, K. A., & O'neal, M. E. (2015). Survey of soybean insect pollinators: Community identification and sampling method analysis. Environmental Entomology, 44(3), 488-498.

[347] Winfree, R., Bartomeus, I., & Cariveau, D. P. (2011). Native pollinators in anthropogenic habitats. Annual Review of Ecology, Evolution, and Systematics, 42, 1-22.

[348] Gill, K. A., & O'neal, M. E. (2015); see above.

[349] Takahashi, R., Kurosaki, H., Yumoto, S., Han, O. K., & Abe, J. (2001). Genetic and linkage analysis of cleistogamy in soybean. Journal of Heredity, 92(1), 89-92.

Also in some self-pollinating varieties, honeybee pollination can increase yields.[350] [351] [352] Interest in supporting pollinators of soybeans may increase significantly if breeding and seed production of hybrid varieties is developed further because bees will be needed to provide cross-pollination.[353] However, there is evidence that *Apis mellifera* does visit soybean but in a lower abundance than other species like *Melissodes bimaculata* which uses soybean as a forage. Furthermore, soybean pollen was found attached to *Agapostemon texanus*, *Agapostemon virescens*, *Augochlorella aurata*, *Halictus confusus*, *Lassioglossum* (*Dialictus*) *spp*. collected scopa or corbiculae in soybean fields.[354] Milfont et al.[355] in field conditions, reported a 6.34% soybean yield increment in areas where wild pollinators had free access to flowers, and the introduction of honeybee colonies further raised the yield by 18.09%.

The visits of pollinators were significantly lower with increasing distance to the forest. Chiari et al.[356] studied soybean yield increase with exposition to *Apis mellifera*; they and other sourced cited reported yield increases between 5 and 95%. In terms of the provision of ecosystem service pollination soybean, compared to 'mass-flowering crops', such as oilseed rape and sunflower, it is usually not considered.[357] Increased cooperation between farmers and beekeepers can also be a way to increase yields and simultaneously promote wild pollinators and parasitoids, increasing yields.[358]

Biodiversity knowledge from practice

Altogether, we gathered 16 questionnaires coming from the actor groups in Legumes Translated. We group the results according to the work area of the persons who did fill the questionnaires. We differentiated between consultant, practitioner, and scientist. The number of filled questionnaires amounted to each seven, two, and seven for each of the named classes. This work is reported fully in Annex 2.

Tables 4 and 5 show the questionnaires' main results in terms of questions answered for every area of the survey, the disservice-based questions, and the service-based questions by each level of knowledge.

It is clear that most disservices-based questions were answered; for all groups together, the response rate was 85%. In the area of the service-based questions, we registered an answer rate of only 51%. Furthermore, as we assessed the accuracy of the questions, we found out that the accuracy and scope of the responses were also higher in disservices compared to the services.

---

[350] Carvalheiro, L. G., Veldtman, R., Shenkute, A. G., Tesfay, G. B., Pirk, C. W. W., Donaldson, J. S., & Nicolson, S. W. (2011). Natural and within-farmland biodiversity enhances crop productivity. Ecology Letters, 14(3), 251-259.

[351] Chiari, W. C. et al. (2005); see above.

[352] Vanbergen, A. J., & Initiative, T. I. P. (2013). Threats to an ecosystem service: pressures on pollinators. Frontiers in Ecology and the Environment, 11(5), 251-259.

[353] Mader, E., & Hopwood, J. (2013). Pollinator management for organic seed producers. The Xerces Society, Portland.

[354] Gill, K. A., & O'neal, M. E. (2015); see above.

[355] Milfont, M. D. O., Rocha, E. E. M., Lima, A. O. N., & Freitas, B. M. (2013). Higher soybean production using honeybee and wild pollinators, a sustainable alternative to pesticides and autopollination. Environmental Chemistry Letters, 11(4), 335-341.

[356] Chiari, W. C. et al. (2005); see above.

[357] Erickson, E. H. (1975). Effect of Honey Bees on Yield of Three Soybean Cultivars 1. Crop Science, 15(1), 84-86.

[358] Milfont, M. D. O. et al. (2013); see above.

Table 4: Disservice-based biodiversity assessment in the amount of responded questions from the total

	Question topics [answered questions from total]					
	Weed species	Weeds most detrimental	Weed control	Pest organism	Pest control	All [%]
Consultant	7/7	5/7	6/7	7/7	7/7	91.4
Practitioner	2/2	0/2	2/2	2/2	2/2	80.0
Scientist	6/7	4/7	6/7	7/7	6/7	82.9
All	14/16	9/16	14/16	16/16	15/16	85.0

Table 5: Service-based biodiversity assessment in the amount of responded questions from total

	Question topics [answered questions from total]						
	Beneficial organism	Arthropod diversity	Pollinator diversity	Soil organism diversity	Soil services	Inter-cropping	All [%]
Consultant	7/7	0/7	5/7	3/7	6/7	1/7	52.4
Practitioner	2/2	0/2	2/2	1/2	1/2	0/2	50.0
Scientist	6/7	4/7	7/7	0/7	2/7	2/7	50.0
All	15/16	4/16	14/16	4/16	9/16	3/16	51.0

Since only a few pieces of information from the scientific literature regarding service-oriented biodiversity were generated from European trials, these results do not surprise us. We recommend policy to increase efforts in funding studies that analyze community compositions of accompannying vegetation and as well as regulating ecosystems services in Europe.

For disservice-oriented questions, the partners provided precise information regarding main weed species in grain legume cultivation for several geographic regions within Europe. It was observed that the weed community composition varied greatly within geographic locations, having a north-west south-east gradient. All over Europe, the most detrimental weeds were *Fallopia convolvulus*, *Chenopodium album*, and *Echinochla crus-gallis*. Furthermore, the partners listed various methods of mechanical and chemical weed control. Hoeing and harrowing were the primary mechanical control in grain legume cultivation, to the most crucial chemical weed control counted the application of pre-emergence herbicides. Further management aspects that impact weed control were highlighted, such as the importance of site testing for detrimental weed infestation, the use of adequate crop sequence, and choosing a competitive cultivar.

The partners know a lot about pests. The most detrimental pest organisms in grain legume cultivation noted were different aphids, leaf beetle, moths, and butterfly larvae. Damage through mammals and birds also played a role as a detrimental factor. It was remarked that pest occurrence is region-specific and season dependent. The control of pest organisms was not typically needed in the regions the gathered information came. Where necessary, mostly compounds of the family of pyrethroid were used. But also pheromones were used against pests. Management aspects such breaks in crop rotation, alternation of the used grain legumes, and sowing dates do have a preventive function to pest organisms. Other methods of crop protection like catch crops or antagonists were not widely used.

As mentioned above, the service-oriented questions were answered less frequently than disservice-oriented ones. The partners useful organisms were mainly ladybirds and ground beetles and spiders, soldier beetles, mantis, and parasitoids. Concerning pollinators, several taxa such as bumblebees, bees, and hoverflies were mentioned. Partners had relatively little information on the intensity or the value of the ecosystem services, biocontrol (provided by natural enemies), or pollination. The same applies to further quantitative information on the useful organism's biodiversity parameters such as activity densities or species richness. The experiences using grain legumes in intercrop and the effect of grain legume cultivation on soil organisms are limited. This is understandable since there are still few studies on these topics, especially in Europe.

Conclusions

An important finding of those data and expert knowledge compilations is that huge knowledge gaps on biodiversity, ESS and environmental performance exist for legume based cropping systems in the European context. There is by far no enough information, even on the worldwide context, to prove the assumption that all grain legumes do improve biodiversity. In fact only for soybeans enough information was available to make a first statement. By summarizing this practice guide findings, we found reports of slight benefits of soybean cropping on plants, pollinators, parasitoids, and other natural pest control agents compared to the majority of crops present in literature. Only perennial crops or pasture had clearly better influence on biodiversity. Based on these observations, we can conclude that the cultivation and integration of soybeans in European crop rotations does not reduce biodiversity, even though it improved some biodiversity parameters. So we can primarily recommend its integration in European systems.

The knowledge of actor groups about biodiversity is limited and only partly available to disservices oriented questions. To change this situation, a lot has to happen. First the availability of high quality information to biodiversity of grain legumes in European context must increase. For this conducting biodiversity experiments and life-cycle assessments to evaluate the effect of grain legumes on cropping systems will be of vital importance. This applies especially to the other grain legumes such as faba bean, pea, and lupine. Furthermore, the awareness regarding the importance of biodiversity in agroecosystems should increase in many parts of society beginning in agricultural and forestry education, but including agricultural advisers, scientists and further value chain players like corporations and retail. Therefore, we encourage policymakers to cover this necessity.

Annex 1 Biodiversity

Table A1: Effect of crop identity on accompanying vegetation biomass (B), cover (C), density (D), frequency (F), Shannon diversity (H), species richness (S), alpha (α), beta (β) and gamma diversity (γ) given in percent difference for soybean-based cultivation systems (when Δ is positive the values are higher in soy, otherwise in the other crop. Differences up to 10% are marked in grey; differences between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Factor	Crop	Δ[%]	Crop	n	Q	Country	Source
B	Maize	-227	Soy	16	+	US, ITA	2, 15, 25, 37, 38, 54
	Lima bean	-175	Soy	1	+	US	37
	Okra	-181	Soy	1	+	US	37
	Sorghum	-229	Soy	8	+/-	US	54
	Sunflower	-33	Soy	4	+	US, ITA	37, 38
	Wheat	-483	Soy	4	+/-	US	54
	Unplanted	-24	Soy	1	+	US	15
C	Maize	-76	Soy	2	+	US, ITA	37, 38
	Lima bean	-131	Soy	1	+	US	37
	Okra	-121	Soy	1	+	US	37
	Sunflower	-85	Soy	3	+	US, ITA, ARG	10, 37, 38
D	Maize	+65	Soy	22	+	ARG, CAN, US, ITA	2, 12, 25, 38, 40, 49
	*Soy early	+53	Soy late	2	+/-	CAN	49
	Sunflower	-58	Soy	1	+/-	ITA	38
	Wheat	-21	Soy	8	+	CAN	49
F	Maize	+3	Soy	4	+	ARG	41
H	Maize	+216	Soy	7	+	US	15, 25
S	Maize	+21	Soy	9	+	ARG, US	25, 29, 37, 40
	Lima bean	-6	Soy	1	+	US	37
	Okra	-17	Soy	1	+	US	37
	Sunflower	-41	Soy	2	+	US, ARG	10, 37
α	Maize	-22	Soy	2	+	ARG	40, 41
β	Maize	+22	Soy	1	+/-	ARG	40
γ	Maize	-74	Soy	1	+	ARG	41

* early and late is regarding to maturity grades

Table A2: Effect of crop identity on *Aranea* and *Arthropoda* activity density (AD) and species richness (S) as well as *Carabidae* activity density, evenness (E) Shannon diversity (H), hierarchical richness index (HRI), and species richness given in percent difference for soybean-based cultivation systems (when Δ is positive the values are higher in soy, otherwise in the other crop. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Crop	Δ[%]	Crop	n	Q	Country	Source
Aranea	AD	Alfalfa an.	-48	Soy	6	+/-	USA	8, 9
		Alfalfa pe.	-500	Soy	6	+/-	USA	8, 9
		Maize	-3	Soy	2	+/-	USA	11
	S	*Alfalfa a	-22	Soy	6	+	USA	8, 9
		Alfalfa p	-9	Soy	35	+	USA	8, 9, 56
		Maize	+93	Soy	29	+	USA	56
		Cotton	-17	Soy	29	+	USA	56
		Guar	+403	Soy	29	+	USA	56
		Peanuts	+100	Soy	29	+	USA	56
		Rice	+249	Soy	29	+	USA	56
		Sorghum	+197	Soy	29	+	USA	56
		Sugarcane	+91	Soy	29	+	USA	56
Arthropoda	AD	Maize	+26	Soy	9	+/-	USA	1, 11, 33
	S	Maize	+89	Soy	2	+/-	USA	33
Carabidae	AD	Alfalfa	+8	Soy	2	+	USA	35
		Maize	+55	Soy	3	+	USA	13, 35
	E	Alfalfa	+1	Soy	2	+/-	USA	12, 35
		Maize	-38	Soy	3	+/-	USA	12, 35
		Wheat	-15	Soy	1	+/-	USA	12
	H	Alfalfa	-12	Soy	2	+/-	USA	12, 35
		Maize	-28	Soy	3	+/-	USA	12, 35
		Wheat	+11	Soy	1	+/-	USA	12
	HRI	Alfalfa	+213	Soy	1	+/-	USA	12
		Maize	-36	Soy	1	+/-	USA	12
		Wheat	+134	Soy	1	+/-	USA	12
	S	Alfalfa	-3	Soy	2	+/-	USA	12, 35
		Maize	-10	Soy	3	+/-	USA	12, 35
		Wheat	+17	Soy	1	+/-	USA	12

* With an: annual, pe:perennial

Table A3: Effect of crop identity on different organism groups activity density (AD) and species richness (S) given in percent difference for soybean-based cultivation systems (when Δ is positive, the values are higher in soy, otherwise in the other crop. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Crop	Δ[%]	Crop	N	Q	Country	Source
Diplopoda	AD	Maize	-12	Soy	2	+/-	USA	11
Formicidae		Maize	+24	Soy	2	+/-	USA	11
Grillydae		Maize	+39	Soy	2	+/-	USA	11
Lumbricidae		Maize	+14	Soy	4	+	USA, ITA	3
		Cotton	+223	Soy	2	+	ITA	3
Detritivore		Maize	-6	Soy	4	+	USA	1
Fungivore		Maize	-25	Soy	5	+	USA	1
Herbivore		Maize	+3552	Soy	9	+	USA	1
Parasitoids		Maize	-7	Soy	5	+	USA	1
Pollinator		Maize	-17	Soy	1	+/-	USA	53
Predator		Maize	+82	Soy	9	+	USA	1
Parasitoid	S	Alfalfa	-101	Soy	1	+/-	PER	31
		Chickpea	+225	Soy	1	+/-	PER	31
		Maize	+86	Soy	1	+/-	PER	31
		*Maize bean	-115	Soy	1	+/-	PER	31
		Faba bean	-38	Soy	1	+/-	PER	31
		Pea	-8	Soy	1	+/-	PER	31
		Potato	-15	Soy	1	+/-	PER	31
		Vegetable	+86	Soy	1	+/-	PER	31
Pollinator		Maize	-27	Soy	1	+/-	USA	53

*with: Maize: common

Table A4: Effect of crop sequence on accompanying vegetation biomass (B), density (D), Shannon diversity (H) and species richness (S) and plant seed density, evenness (E), Shannon diversity (H), seed production (P) and species richness given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Sequence	Δ [%]	Sequence	n	Q	Country	Source
Plant	B	1a seq	+67	2a seq	1	+/-	US	45
		1a seq	+50	3a seq	1	+/-	US	45
		2a seq	+11	3a seq	1	+/-	US	45
	D	Co-O-H	-29	Co-So	6	+	US	48
	H	1a seq	+56	2a seq	1	+/-	US	45
		1a seq	+94	3a seq	1	+/-	US	45
		2a seq	+24	3a seq	1	+/-	US	45
	S	Co-O-H	-21	Co-So	6	+	US	48
Plant Seed	D	Co mono	-76	Co-So-Co	3	+	US	47
		Co-So-Co	+45	So-Co-So	3	+	US	47
		Co-O-H	-20	Co-So	9	+	US	47, 48
	E	Co mono	0	Co-So-Co	3	+	US	47
		Co-So-Co	+11	So-Co-So	3	+	US	47
		Co-O-H	-28	Co-So	3	+	US	47
	H	Co mono	+5	Co-So-Co	3	+	US	47
		Co-So-Co	+7	So-Co-So	3	+	US	47
		Co-O-H	-75	Co-So	3	+	US	47
	P	Co mono	+150	So-Co-So-Co-So	2	+/-	US	21
	S	Co mono	+3	Co-So-Co	3	+	US	47
		Co-So-Co	-10	So-Co-So	3	+	US	47
		Co-O-H	-51	Co-So	3	+	US	47, 48

[*] a: year, seq: sequence, Co: maize, O: oat, H: hay, W: wheat, A: alfalfa, So: soybean

[*] 1a seq, 2a seq or 3a seq indicates in the study of Smith soybean, maize and wheat mixed in different long sequences but in no specified order.

[*] Sosnoskie et al. (2009) Co-O-H and Co-S sequences, are each three different sequence combinations with the named crops from

Table A5: Effect of crop sequence on different organism groups activity density (AD), evenness (E), Shannon diversity (H) and species richness (S) given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Sequence	Δ[%]	Sequence	n	Q	Country	Source
Araneae	AD	So 2a seq	+7	So 3a seq	1	+/-	US	11
Arthropoda		So 2a seq	+9	So 3a seq	1	+/-	US	11
Carabidae	AD	So 2a seq	+25	So 4a seq	3	+	US	11, 35
	E	So 2a seq	-22	So 4a seq	2	+	US	35
	H	So 2a seq	+14	So 4a seq	2	+	US	35
		Co-Co	-2	Co-So	1	-	US	12
		Co-So	0	Co-So-W-A	1	-	US	12
	S	So 2a seq	+22	So 4a seq	2	+	US	35
		Co-Co	-8	Co-So	1	-	US	12
		Co-So	+23	Co-So-W-A	1	-	US	12
Diplopoda	AD	So 2a seq	+43	So 3a seq	1	+/-	US	11
Formicidae		So 2a seq	+8	So 3a seq	1	+/-	US	11
Grillydae		So 2a seq	+13	So 3a seq	1	+/-	US	11
Lumbricidae		So mono	-11	So 2a seq	2	+	US	3
		W-Co	+97	So-Co	2	+	US	20

[*] a: year, seq: sequence, So: soybean, Co: maize, W: Wheat, A: Alfalfa

[*] So 2a seq, So 3a seq, So 4a seq indicates real comparison between sequences in which soy was specific part of the sequence in every treatment

Table A6: Effect of pre crop on different organism groups activity density given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Sequence	Δ[%]	Sequence	n	Q	Country	Source
Arthropoda	Co after Co	+19	Co after So	8	+	USA	4
Carabidae	Co after Co	+100	Co after So	8	+	USA	4
Lumbricidae	Cott mono	+197	Cott after So	1	+/-	ITA	3
	Cott mono	+43	Cott after Co	2	+	ITA	3

*With Co: maize, So: soybean, Cott: Cotton

Table A7: Effect of different polyculture practices on accompanying vegetation biomass (B), cover grade (C), Shannon diversity (H), alpha (α) and beta (β) diversity given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Factor	Crop	Δ [%]	Crop	n	Q	Country	Source
B	Maize	-49	So/Co IC	2	+/-	US	52
	Soy	-255	So/Co IC	4	+/-	US	15, 52
	Com. bean	-9	MC	1	+	US	37
	Maize	-56	MC	1	+	US	37
	Okra	-17	MC	1	+	US	37
	Soy	+160	MC	1	+	US	37
	Sunflower	-18	MC	1	+	US	37
C	Soy	+200	So/Su IC	1	+	ARG	10
	Sunflower	+4	So/Su IC	1	+	ARG	10
S	Maize	-35	W/So DC	1	+	ARG	29
	Soy	-22	W/So DC	1	+	ARG	29
	Soy	+132	So/Su IC	1	+	ARG	10
	Sunflower	+35	So/Su IC	1	+	ARG	10
	Com. bean	+18	MC	1	+	US	37
	Maize	+5	MC	1	+	US	37
	Okra	+6	MC	1	+	US	37
	Soybean	+24	MC	1	+	US	37
	Sunflower	+12	MC	1	+	US	37
α	Maize	-33	W/So DC	1	+/-	ARG	40
	Soy	-25	W/So DC	1	+/-	ARG	40
β	Maize	-49	W/So DC	1	+/-	ARG	40
	Soy	-38	W/So DC	1	+/-	ARG	40
H	Soy	+28	So/Co IC	2	+	US	15

*With: IC: intercropping, MC: multicroping, DC: Double crop, So: soybean, Co:maize, Su: sunflower, W: wheat

Table A8: Effect of cover crop use on accompanying vegetation biomass (B), density (D) and Shannon diversity (H) species richness (S) given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Factor	Crop	Δ [%]	Crop	n	Q	Country	Source
B	mono	-900	mono 1CC	1	+/-	US	45
	3a seq	-4650	Co-So-W 1CC	1	+/-	US	45
	3a seq	-1800	Co-So-W 2CC	1	+/-	US	45
D	Soy	-57	Soy CC	2	+	CAN	44
	Maize	-57	Maize CC	2	+	CAN	44
H	mono	+5	mono 1CC	1	+/-	US	45
	3a seq	-627	3a seq 1CC	1	+/-	US	45
	3a seq	-7900	3a seq 2CC	1	+/-	US	45
S	mono	-56	mono 1CC	1	+/-	US	45
	Co-So-W	-58	Co-So-W 1CC	1	+/-	US	45
	Co-So-W	-69	Co-So-W 2CC	1	+/-	US	45

* mono: monocrop, a: year, seq: sequence, CC: cover crop, Co: maize, So: soy, W: wheat

* mono indicates in the study of Smith the average of each soybean, maize and wheat monoculture. Single values were not given

Table A9: Effect of intercropping on different organism groups activity density (AD), Shannon diversity (H), evenness (E) and species richness (S) given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Crop	Δ[%]	Crop	n	Q	Country	Source
Arthropoda	AD	So mono	+82	W/So IC	1	+	ARG	29
		So mono	-9	So/Su IC	1	+	ARG	10
	S	So mono	6	W/So IC	1	+	ARG	29
		So mono	-47	So/Su IC	1	+	ARG	10
Carabidae	AD	So mono	-20	Tr/A IC	1	+	US	35
	E	So mono	+44	Tr/A IC	1	+	US	35
	H	So mono	+74	Tr/A IC	1	+	US	35
	S	So mono	+47	Tr/A IC	1	+	US	35
Herbivores	AD	So mono	+43	So/Su IC	1	+	ARG	10
	S	So mono	-11	So/Su IC	1	+	ARG	10
Not herbivores	AD	So mono	-108	So/Su IC	1	+	ARG	10
	S	So mono	-80	So/Su IC	1	+	ARG	10

*with mono: monoculture, IC: Intercropping, So: soybean, W:wheat, Su: sunflower, Tr: Triticale, A: Alfalfa

Table A10: Effect of fertilisation on accompanying vegetation biomass (B), Shannon diversity (H) and species richness (S) given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Factor	Fert	Δ [%]	Fert	n	Q	Country	Source
B	No fert.	-19	Fert.	3	+	US	25
	No fert.	-31	Fert.	1	+	US	15
	No fert.	+201	Fert.	2	+/-	US	52
S	No fert.	-17	Fert.	1	+	US	15
H	No fert.	-26	Fert.	1	+	US	15

Table A11: Effect of application of compost on the activity density (AD) of different invertebrate organism groups given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Fert.	Δ[%]	Fert.	n	Q	Country	Source
Herbivores	-	-2	compost	2	+	US	42
Predators	-	-20	compost	2	+	US	42
Spiders foliar	-	+134	compost	2	+	US	42

Table A12: Effect of tillage on accompanying vegetation biomass (B), density (D), Shannon diversity (H), plant height (He) and species richness (S), and plant seed density (D), evenness (E), Shannon diversity and species richness given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Tillage	Δ [%]	Tillage	n	Q	Country	Source
Plant	B	Till	+25	No till	1	-	US	26
	D	Till	+54	No till	8	+	US, CAN	26, 42, 44, 48
		Till	+59	Min. till	1	+	US	48
		Min. till	+20	No till	1	+	US	48
		Till	-124	Rill till	4	+/-	US	21
	H	Till	+100	No till	2	+	CAN	32
		Min. till	+64	No till	1	+	CAN	32
	He	Till	+11	No till	2	+	US	42
	S	Till	+6	Min. till	1	+	US	48
		Till	+9	No till	1	+	US	48
		Min. till	+3	No till	1	+	US	48
Plant Seed	D	Till	+90	Min. till	1	+	US	48
		Till	+102	No till	2	+	US	32, 48
		Min. till	+50	No till	2	+	US, CAN	32, 48
	E	Till	-4	Min. till	1	+	US	47
		Till	-15	No till	1	+	US	47
		Min. till	-11	No till	1	+	US	47
	H	Till	+4	Min. till	2	+	US	47
		Till	+60	No till	3	+	US, CAN	5, 32, 47
		Min. till	+73	No till	1	+	CAN	32
	S	Till	+20	Min. till	2	+	US	47, 48
		Till	+38	No till	2	+	US	47, 48
		Min. till	+10	No till	2	+	US	47, 48

*With: Min.: minimum

Table A13: Effect of tillage on activity density (AD) of different invertebrate organism groups given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Tillage	Δ[%]	Tillage	n	Q	Country	Source
Arthropoda	Till	-48	No till	2	+	US	1
Carabidae	Till	+54	No till	1	+/-	US	19
Spider foliar	Till	-50	No till	1	+	US	42
Detritivore soil	Till	+317	No till	1	+	US	1
Fungivore soil	Till	-83	No till	1	+	US	1
Herbivores	Till	+7	No till	3	+	US	1, 42
Parasitoid soil	Till	-100	No till	1	+	US	1
Predators	Till	+6	No till	3	+	US	1, 42

Table A14: Effect of weed control measurements on accompanying vegetation biomass (B), density (D), relative abundance (RA), cover (C), species richness (S), Shannon diversity (H), evenness (E), dominance (Do) and hierarchical richness index (HRI) given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Factor	Weed control	Δ [%]	Weed control	n	Q	Country	Source
B	Herb.	143	Mech.	1	+	ITA	38
	No	-527	Yes	8	+	US	34
	Red. herb.	-8833	High herb.	1	+	US	46
C	Herb.	-77	Mech.	2	+		38
D	Low herb.	-1491	High herb.	5	+/-	US	12, 21, 46
	Herb.	-36	Mech.	4	+	ITA	38
Do	No herb.	-38	Herb. 100%	3	+/-	POL	17
	No herb.	-23	Herb. 50%	3	+/-	POL	17
E	No herb.	+17	Herb. 100%	3	+/-	POL	17
	No herb.	+74	Herb. 50%	3	+/-	POL	17
	Low herb.	-13	High herb.	2	+/-	US	12
H	No herb.	+14	Herb. 100%	3	+/-	POL	17
	No herb.	+12	Herb. 50%	3	+/-	POL	17
	Low herb.	-4	High herb.	2	+/-	US	12
HRI	Low herb.	-20	High herb.	2	+/-	US	12
RA	Interrow	-953	Herb.	3	+/-	CAN	49
S	No herb.	-9	Herb. 100%	3	+/-	POL	17
	No herb.	-5	Herb. 50%	3	+/-	POL	17
	Low	-13	High	2	+/-	US	12

*With herb.: herbicide, mech: mechanical weed control, red: reduced herbicide application

*In Harasim study a treatment was a 50% herbicide application maximal applied amount (100%)

Table A15: Effect of weed control measurements on different organism groups and invertebrates species activity density (AD), evenness (E), Shannon diversity (H), hierarchical richness index (HRI) and species richness (S) given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Weed control	Δ[%]	Weed control	n	Q	Country	Source
Arthropoda	S	Mixed w.	-79	No w.	6	+	US	43
Carabidae	E	Low	-13	High	2	+/-	US	12
	H	Low	-4	High	2	+/-	US	12
	HRI	Low	-20	High	2	+/-	US	12
	S	Low	-13	High	2	+/-	US	12
Epilachna varivestis	AD	Mixed w.	-445	No w.	6	+	US	43
Harpalus spec.		Mixed w.	-156	No w.	6	+	US	43

* With: W.: weed

* Sheltons study did work with artificialy created weed or weed free environments

Table A16: Effect of the landscape on accompanying vegetation alpha (ɑ) and beta (β) diversity given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Factor	LC	Δ [%]	LC	n	Q	Country	Source
ɑ	A	-20	B	7	+	ARG	40
	A	-50	D	7	+	ARG	40
	B	-25	D	7	+	ARG	40
β	A	-28	B	7	+	ARG	40
	A	-52	D	7	+	ARG	40
	B	-19	D	7	+	ARG	40

* With LC: Landscape, A: 42% pasture, 50,6% cropland, B: 60% cropland, 20% riparian, D: 86% cropland

Table A17: Effect of the landscape on different invertebrate organism groups activity density (AD), species richness (S) and taxa richness (T) given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Organism	Factor	Habitat	Δ[%]	Habitat	n	Q	Country	Source
Formicidae	S	Sem. nat.	-98	[*]Crop area	6	+	BRA	36
	T	Sem. nat.	-66	Crop area	6	+	BRA	36
Wild bees	AD	Sem. nat.	-38	Crop area	11	+	ARG	24
	S	Sem. nat.	-81	Crop area	11	+	ARG	24
	T	Sem. nat.	-23	Crop area	11	+	ARG	24
Herbivore	AD	High for.	-51	Low for.	4	+	ARG	16
	S	High for.	-14	Low for.	4	+	ARG	16
Pollinators	AD	Forest	-886	Soybean	9	+	ARG	30
	S	Forest	-164	Soybean	9	+	ARG	30
Predator	AD	High for.	-91	Low for.	4	+	ARG	16
	S	High for.	-68	Low for.	4	+	ARG	16

[*] With: Sem. nat.: Semi natural habitat, High for: High forest cover, Low for.: low forest cover

[*] The crop area in Pachecos study is dominated by soybean and maize

Table A18: Overview of experiments investigating the effect of exclusion, adding and removing predators, crop identity, polycropping, tillage and landscapes effects on biocontrol relevant organism or measures given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Experiment	Organism	Treatment	Δ[%]	Treatment	n	Q	Country	Source
Exclusion	*Aphis glycines*	Excl. 1 we.	-113	Open 1 we.	1	+	US	14
		Excl. 2 we.	-383	Open 2 we.	1	+	US	14
		Excl. 2 we.	-1883	Open 2 we.	2	+	US	54
	Araneae	Fenced	+325	Unfenced	1	+	US	51
	Linyphiidae	Fenced	+220	Unfenced	1	+	US	51
	Lycosidae	Fenced	+250	Unfenced	1	+	US	51
	Carabidae	Fenced	+366	Unfenced	1	+	US	51
	Nabidae	Fenced	+112	Unfenced	1	+	US	51
add. rem.	Plant damage	Ad. spider	+79	control	3	+	US	6
		Re. spider	-36	control	3	+	US	6
Crop identity	*Helicoverpa zea* eggs predation	Maize	-60	Soy	2	-	US	39
Inter cropping	*Empoasca fabae*	So mono	-287	So/W IC	4	+/-	US	28
	Popillia japonica	So mono	-49	So/Sor IC	2	+	US	18
	Ostrinia nubilalis in.	Co (tall) mono	-53	So/Co IC	4	+	CAN	26
Cover Crop	*A. glycines*	Rye CC	+527	No CC	6	+	US	22
	infested	Rye CC	+96	No CC	22	+	US	23
Trap Crop	*D. texanus* in.	< 200 m	+109	> 300 m	1	+	US	27
Tillage	Leaves damage	No till	-10	Till	2	+	US	42
		No compost	-40	compost	2	+	US	42
Landscape	Biocontrol	High for. c.	-67	Low for. c.	4	+/-	ARG	16
	Ooencyrtus nazarea	For. edge	-1672	Soy field	11	+	JAP	50
	Riptortus pedestris	For. edge	-46	Soy field	11	+	JAP	50

*Excl.: Exclusion experiment, we.: week, Ad.: added, Re.: removing, in.: infestation, for: forest, c: cover,

Table A19: Overview of experiments investigating the effect of pollinator exclusion on soybean pod amount, seed and pod weight as well as seed abortion, reproductive success, and yield given in percent difference for soybean-based cultivation systems (when Δ is positive, the value right to it in the table is higher, otherwise the left one. Differences up to 10% are marked in grey; between 11 and 35% got a light colour label, between 36 and 75% a medium colour label and besides 76% a dark colour label, each red or blue for negative and positive difference)

Factor	Treatment	Δ [%]	Treatment	n	Q	Country	Source
Pod amount	Excl. no bees	+81	Excl. + bees	1	+	BRA	7
	Excl. + bees	+52	Open	1	+	BRA	7
Seed weight	Excl. no bees	+91	Open	9	+	ARG	30
Pod weight	Excl. + bees	+79	Open	9	+	ARG	30
Seed abortion	Excl. no bees	-26	Open	9	+	ARG	30
Repr. success	Excl. + bees	+114	Open	9	+	ARG	30
Yield	Excl. no bees	+38	Excl. + bees	1	+	BRA	7
	Excl. + bees	+41	Open	1	+	BRA	7

* Excl: Exclusion experiment, Repr: reproductive

Literature

1 Adams III, P. R., Orr, D. B., Arellano, C., & Cardoza, Y. J. (2017). Soil and foliar arthropod abundance and diversity in five cropping systems in the coastal plains of North Carolina. Environmental Entomology, 46(4), 771-783.

2 Anderson, R. L. (2009). A 2-year small grain interval reduces need for herbicides in no-till soybean. Weed Technology, 23(3), 398-403.

3 Ashworth, A. J., Allen, F. L., Tyler, D. D., Pote, D. H., & Shipitalo, M. J. (2017). Earthworm populations are affected from long-term crop sequences and bio-covers under no-tillage. Pedobiologia, 60, 27-33.

4 Brust, G. E., Stinner, B. R., & McCartney, D. A. (1986). Predator activity and predation in maize agroecosystems. Environmental Entomology, 15(5), 1017-1021.

5 Cardina, J., Sparrow, D. H., & McCOY, E. L. (1995). Analysis of spatial distribution of common lambsquarters (Chenopodium album) in no-till soybean (Glycine max). Weed Science, 258-268.

6 Carter, P. E., & Rypstra, A. L. (1995). Top-down effects in soybean agroecosystems: spider density affects herbivore damage. Oikos, 433-439.

7 Chiari, W. C., Toledo, V. D. A. A. D., Ruvolo-Takasusuki, M. C. C., Oliveira, A. J. B. D., Sakaguti, E. S., Attencia, V. M., ... & Mitsui, M. H. (2005). Pollination of soybean (Glycine max L. Merril) by honeybees (Apis mellifera L.). Brazilian Archives of Biology and Technology, 48(1), 31-36.

8 Culin, J. D., & Yeargan, K. V. (1983). Comparative study of spider communities in alfalfa and soybean ecosystems: Foliage-dwelling spiders. Annals of the Entomological Society of America, 76(5), 825-831.

9 Culin, J. D., & Yeargan, K. V. (1983). Comparative study of spider communities in alfalfa and soybean ecosystems: ground-surface spiders. Annals of the Entomological Society of America, 76(5), 832-838.

10 De la Fuente, E. B., Suárez, S. A., Lenardis, A. E., & Poggio, S. L. (2014). Intercropping sunflower and soybean in intensive farming systems: evaluating yield advantage and effect on weed and insect assemblages. NJAS-Wageningen Journal of Life Sciences, 70, 47-52.

11 Dunbar, M. W., O'Neal, M. E., & Gassmann, A. J. (2016). Increased risk of insect injury to maize following rye cover crop. Journal of Economic Entomology, 109(4), 1691-1697.

12 Ellsbury, M. M., Powell, J. E., Forcella, F., Woodson, W. D., Clay, S. A., & Riedell, W. E. (1998). Diversity and dominant species of ground beetle assemblages (Coleoptera: Carabidae) in crop rotation and chemical input systems for the Northern Great Plains. Annals of the Entomological Society of America, 91(5), 619-625.

13 French, B. W., Chandler, L. D., Ellsbury, M. M., Fuller, B. W., & West, M. (2004). Ground beetle (Coleoptera: Carabidae) assemblages in a transgenic maize–soybean cropping system. Environmental Entomology, 33(3), 554-563.

14 Gardiner, M. A., Tuell, J. K., Isaacs, R., Gibbs, J., Ascher, J. S., & Landis, D. A. (2010). Implications of three biofuel crops for beneficial arthropods in agricultural landscapes. BioEnergy Research, 3(1), 6-19.

15 Gomez, P., & Gurevitch, J. (1998). Weed community responses in a maize-soybean intercrop. Applied Vegetation Science, 1(2), 281-288.

16 González, E., Salvo, A., & Valladares, G. (2017). Arthropod communities and biological control in soybean fields: forest cover at landscape scale is more influential than forest proximity. Agriculture, Ecosystems & Environment, 239, 359-367.

17 Harasim, E., Gawęda, D., Wesołowski, M., Kwiatkowski, C., & Gocół, M. (2016). Cover cropping influences physico-chemical soil properties under direct drilling soybean. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, 66(1), 85-94.

18 Holmes, D. M., & Barrett, G. W. (1997). Japanese beetle (Popillia japonica) dispersal behavior in intercropped vs. monoculture soybean agroecosystems. American Midland Naturalist, 312-319.

19 House, G. J., & All, J. N. (1981). Carabid beetles in soybean agroecosystems. Environmental Entomology, 10(2), 194-196.

20 Hubbard, V. C., Jordan, D., & Stecker, J. A. (1999). Earthworm response to rotation and tillage in a Missouri claypan soil. Biology and Fertility of Soils, 29(4), 343-347.

21 Kegode, G. O., Forcella, F., & Clay, S. (1999). Influence of crop rotation, tillage, and management inputs on weed seed production. Weed Science, 175-183.

22 Koch, R. L., Porter, P. M., Harbur, M. M., Abrahamson, M. D., Wyckhuys, K. A., Ragsdale, D. W., ... & Heimpel, G. E. (2012). Response of soybean insects to an autumn-seeded rye cover crop. Environmental Entomology, 41(4), 750-760.

23 Koch, R. L., Sezen, Z., Porter, P. M., Ragsdale, D. W., Wyckhuys, K. A., & Heimpel, G. E. (2015). On-farm evaluation of a fall-seeded rye cover crop for suppression of soybean aphid (H emiptera: A phididae) on soybean. Agricultural and Forest Entomology, 17(3), 239-246.

24 Le Féon, V., Poggio, S. L., Torretta, J. P., Bertrand, C., Molina, G. A., Burel, F., ... & Ghersa, C. M. (2016). Diversity and life-history traits of wild bees (Insecta: Hymenoptera) in intensive agricultural landscapes in the Rolling Pampa, Argentina. Journal of Natural History, 50(19-20), 1175-1196.

25 Légère, A., Stevenson, F. C., & Ziadi, N. (2008). Contrasting responses of weed communities and crops to 12 years of tillage and fertilisation treatments. Weed Technology, 22(2), 309-317.

26 Martin, R. C., Voldeng, H. D., & Smith, D. L. (1990). Intercropping maize and soybean for silage in a cool-temperature region: yield, protein and economic effects. Field Crops Research, 23(3-4), 295-310.

27 Michaud, J. P., Qureshi, J. A., & Grant, A. K. (2007). Sunflowers as a trap crop for reducing soybean losses to the stalk borer Dectes texanus (Coleoptera: Cerambycidae). Pest Management Science: formerly Pesticide Science, 63(9), 903-909.

28 Miklasiewicz, T. J., & Hammond, R. B. (2001). Density of potato leafhopper (Homoptera: Cicadellidae) in response to soybean-wheat cropping systems. Environmental entomology, 30(2), 204-214.

29 Molina, G. A., Poggio, S. L., & Ghersa, C. M. (2014). Epigeal arthropod communities in intensively farmed landscapes: effects of land use mosaics, neighbourhood heterogeneity, and field position. Agriculture, Ecosystems & Environment, 192, 135-143.

30 Monasterolo, M., Musicante, M. L., Valladares, G. R., & Salvo, A. (2015). Soybean crops may benefit from forest pollinators. Agriculture, Ecosystems & Environment, 202, 217-222.

31 Mujica, N., & Kroschel, J. (2011). Leafminer fly (Diptera: Agromyzidae) occurrence, distribution, and parasitoid associations in field and vegetable crops along the Peruvian coast. Environmental Entomology, 40(2), 217-230.

32 Murphy, S. D., Clements, D. R., Belaoussoff, S., Kevan, P. G., & Swanton, C. J. (2006). Promotion of weed species diversity and reduction of weed seedbanks with conservation tillage and crop rotation. Weed Science, 54(1), 69-77.

33 Nelson, J. L., Hunt, L. G., Lewis, M. T., Hamby, K. A., Hooks, C. R., & Dively, G. P. (2018). Arthropod communities in warm and cool grass riparian buffers and their influence on natural enemies in adjacent crops. Agriculture, Ecosystems & Environment, 257, 81-91.

34 Nord, E. A., Curran, W. S., Mortensen, D. A., Mirsky, S. B., & Jones, B. P. (2011). Integrating multiple tactics for managing weeds in high residue no-till soybean. Agronomy Journal, 103(5), 1542-1551.

35 O’Rourke, M. E., Liebman, M., & Rice, M. E. (2014). Ground beetle (Coleoptera: Carabidae) assemblages in conventional and diversified crop rotation systems. Environmental Entomology, 37(1), 121-130.

36 Pacheco, R., Vasconcelos, H. L., Groc, S., Camacho, G. P., & Frizzo, T. L. (2013). The importance of remnants of natural vegetation for maintaining ant diversity in Brazilian agricultural landscapes. Biodiversity and Conservation, 22(4), 983-997.

37 Palmer, M. W., & Maurer, T. A. (1997). Does diversity beget diversity? A case study of crops and weeds. Journal of Vegetation Science, 8(2), 235-240.

38 Pannacci, E., & Tei, F. (2014). Effects of mechanical and chemical methods on weed control, weed seed rain and crop yield in maize, sunflower and soyabean. Crop Protection, 64, 51-59.

39 Pfannenstiel, R. S., & Yeargan, K. V. (2002). Identification and diel activity patterns of predators attacking Helicoverpa zea (Lepidoptera: Noctuidae) eggs in soybean and sweet maize. Environmental Entomology, 31(2), 232-241.

40 Poggio, S. L., Chaneton, E. J., & Ghersa, C. M. (2013). The arable plant diversity of intensively managed farmland: Effects of field position and crop type at local and landscape scales. Agriculture, Ecosystems & Environment, 166, 55-64.

41 Rauber, R. B., Demaría, M. R., Jobbágy, E. G., Arroyo, D. N., & Poggio, S. L. (2018). Weed Communities in semiarid rainfed croplands of Central Argentina: comparison between maize (Zea mays) and soybean (Glycine max) crops. Weed Science, 66(3), 368-378.

42 Rypstra, A. L., & Marshall, S. D. (2005). Augmentation of soil detritus affects the spider community and herbivory in a soybean agroecosystem. Entomologia Experimentalis et Applicata, 116(3), 149-157.

43 Shelton, M. D., & Edwards, C. R. (1983). Effects of weeds on the diversity and abundance of insects in soybeans. Environmental Entomology, 12(2), 296-298.

44 Shrestha, B. M., McConkey, B. G., Smith, W. N., Desjardins, R. L., Campbell, C. A., Grant, B. B., & Miller, P. R. (2013). Effects of crop rotation, crop type and tillage on soil organic carbon in a semiarid climate. Canadian Journal of Soil Science, 93(1), 137-146.

45 Smith, R. G., McSwiney, C. P., Grandy, A. S., Suwanwaree, P., Snider, R. M., & Robertson, G. P. (2008). Diversity and abundance of earthworms across an agricultural land-use intensity gradient. Soil and Tillage Research, 100(1-2), 83-88.

46 Snyder, E. M., Curran, W. S., Karsten, H. D., Malcolm, G. M., Duiker, S. W., & Hyde, J. A. (2016). Assessment of an integrated weed management system in no-till soybean and maize. Weed Science, 64(4), 712-726.

47 Sosnoskie, L. M., Herms, C. P., & Cardina, J. (2006). Weed seedbank community composition in a 35-yr-old tillage and rotation experiment. Weed Science, 54(2), 263-273.

48 Sosnoskie, L. M., Herms, C. P., Cardina, J., & Webster, T. M. (2009). Seedbank and emerged weed communities following adoption of glyphosate-resistant crops in a long-term tillage and rotation study. Weed Science, 57(3), 261-270.

49 Swanton, C. J., Booth, B. D., Chandler, K., Clements, D. R., & Shrestha, A. (2006). Management in a modified no-tillage maize–soybean–wheat rotation influences weed population and community dynamics. Weed Science, 54(1), 47-58.

50 Tabuchi, K., Taki, H., Iwai, H., Mizutani, N., Nagasaka, K., Moriya, S., & Sasaki, R. (2014). Abundances of a bean bug and its natural enemy in seminatural and cultivated habitats in agricultural landscapes. Environmental Entomology, 43(2), 312-319.

51 Vichitbandha, P., & Wise, D. H. (2002). A field experiment on the effectiveness of spiders and carabid beetles as biocontrol agents in soybean. Agricultural and Forest Entomology, 4(1), 31-38.

52 Weil, R. R., & McFadden, M. E. (1991). Fertility and weed stress effects on performance of maize/soybean intercrop. Agronomy Journal, 83(4), 717-721.

53 Wheelock, M. J., Rey, K. P., & O’Neal, M. E. (2016). Defining the insect pollinator community found in Iowa maize and soybean fields: Implications for pollinator conservation. Environmental Entomology, 45(5), 1099-1106.

54 Woltz, J. M., Isaacs, R., & Landis, D. A. (2012). Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape. Agriculture, Ecosystems & Environment, 152, 40-49.

55 Wortman, S. E., Lindquist, J. L., Haar, M. J., & Francis, C. A. (2010). Increased weed diversity, density and above-ground biomass in long-term organic crop rotations. Renewable Agriculture and Food Systems, 281-295.

56 Young, O. P., & Edwards, G. B. (1990). Spiders in United States field crops and their potential effect on crop pests. Journal of Arachnology, 1-27.

Annex 2. Questionnaire about biodiversity effects of legumes

Building on information already provided by actor groups in Deliverable Report 2.2 (Work plan for transition networks), we gathered information about the groups of organisms (plants, soil organisms, arthropods (insects and spiders), small mammals, and birds) associated with grain legume cultivation in Europe. The information needed for our assessments comprised data on the organisms themselves (species richness, number of individuals, density, biomass), data on factors associated with the cultivation of grain legumes known to affect the presence and performance of those species. This document contains the responses in an anonymized form to all questions on biodiversity information collected from the Legumes Translated consortium.

Summary

We classified the questions as related to disservices and services (Table 1). Ecosystem disservices are outcomes of natural processes, in this case of agrobiodiversity, which affects human activities, like farming, negatively. Services are the opposite.

Table 1: Types of requested biodiversity information from the actor groups

Disservices	*Services*
• Weed species in grain legumes	• Beneficial organisms
• Most detrimental weeds in grain legumes	• Arthropod diversity
• Weed management	• Pollinator diversity
• Pest organisms	• Soil organism diversity
• Pest control	• Soil services
	• Intercropping

Altogether, we gathered information in 16 questionnaires provided by partners representing the actor groups. We group the results according to the work area of the persons who completed the questionnaires. We differentiated between consultants, farmers, and scientists. They completed seven, two, and seven questionaires respectively.

Tables 2 and 3 show the questionnaires' main results in terms of questions answered for every area of the survey, the disservice-based questions, and the service-based questions by each level and area of knowledge. From all received questionnaires not all of them were responded entirely, since not every partner got the specifical expertise required to respond all questions. It is clear that most disservices-based questions were answered. The overall response rate was 85%. The response rate for questions about services was around 50 %. Furthermore, in considering the responses, it was evident that the accuracy of the responses were also higher in disservices compared to the services.

The lack of information from respondents about services reflects the literature which is weak in terms of the insights it provides into the services provided by European-grown legume crops.

Table 2. Responses of respondents to requests for information on disservices-based biodiversity

Knowledge group	[total answered questions over total number of received questionnaires]					
	Weed species	Weeds most detrimental	Weed control	Pest organism	Pest control	All [%]
Consultants	7/7	5/7	6/7	7/7	7/7	91,4
Practitioners	2/2	0/2	2/2	2/2	2/2	80,0
Scientists	6/7	4/7	6/7	7/7	6/7	82,9
All	14/16	9/16	14/16	16/16	15/16	85,0

Table 3. Responses of respondents to requests for information on disservices-based biodiversity

Knowledge group	[total answered questions over total number of received questionnaires]						
	Beneficial organism	Arthropod diversity	Pollinator diversity	Soil organism diversity	Soil services	Inter-cropping	All [%]
Consultants	7/7	0/7	5/7	3/7	6/7	1/7	52,4
Practitioners	2/2	0/2	2/2	1/2	1/2	0/2	50,0
Scientists	6/7	4/7	7/7	0/7	2/7	2/7	50,0
All	15/16	4/16	14/16	4/16	9/16	3/16	51,0

For disservice-oriented questions, the partners provided precise information regarding main weed species in grain legume cultivation for several geographic regions within Europe. It was observed that the weed community composition varied greatly within geographic locations, having a north-west south-east gradient. All over Europe, the most detrimental weeds were *Fallopia convolvulus*, *Chenopodium album*, and *Echinochla crus-gallis*. Furthermore, the partners listed various methods of mechanical and chemical weed control. Hoeing and harrowing were the primary mechanical control in grain legume cultivation, to the most crucial chemical weed control counted the application of pre-emergence herbicides. Further management aspects that impact weed control were highlighted, such as the importance of site testing for detrimental weed infestation, the use of adequate crop sequence, and choosing a competitive cultivar.

The partners know a lot about pests.. The most detrimental pest organisms in grain legume cultivation noted were different aphids, leaf beetle, moths, and butterfly larvae. Damage through mammals and birds also played a role as a detrimental factor. It was remarked that pest occurrence is region-specific and season dependent. The control of pest organisms was not typically needed in the regions the gathered information came. Where necessary, mostly compounds of the family of pyrethroid were used. But also pheromones were used against pests. Management aspects such breaks in crop rotation, alternation of the used grain legumes, and sowing dates do have a preventive function to pest organisms. Other methods of crop protection like catch crops or antagonists were not widely used.

As mentioned above, the service-oriented questions were answered less frequently than disservice-oriented ones. The partners useful organisms were mainly ladybirds and ground beetles and spiders, soldier beetles, mantis, and parasitoids. Concerning pollinators, several taxa such as bumblebees, bees, and hoverflies were mentioned. Partners had relatively little information on the intensity or the value of the ecosystem services, biocontrol (provided by natural enemies), or pollination. The same applies to further quantitative information on the useful organism's biodiversity parameters such as activity densities or species richness. The experiences using grain legumes in intercrop and the effect of grain legume cultivation on soil organisms are limited. This is understandable since there are still few studies on these topics, especially in Europe.

Disservice-oriented questions

Request 1:
What types of wild plants/weeds can you find in the legumes grown in your country/region? Please name the plant species. Which of these species are associated with specific grain legume crops? (specify for conventional, organic, or both cultivation systems).

Consultant 1 (Germany)
Conventional: *Fallopia convolvulus*, *Brassica napus*, *Chenopodium album*, *Alopecurus myosuroides*, *Stellaria media*. Organic: *Cirsium arvense*, *Fallopia convolvulus*, *Chenopodium album*.

Consultant 2 (Germany)
For pea, faba bean, lupin, and soybean: warm-season weeds, late weeds; *Chenopodium album, Atriplex spp., Solanum spp..* For early sown grain legume species: *Matricaria chamomilla.*

Consultant 3 (Germany)
Grassy weeds reflect the areas' status, but are less common in grain legumes (summer crops) than in winter crops, e.g., *Bromus spp.*
Other weeds: *Fallopia convolvulus* (problematic even at harvest time), *Chenopodium album.*

Consultant 4 (Austria)
Chenopodium, panics (*Panicum, Setaria, Digitaria*), *Amaranthus*, *Polygonum*, *Convulvulus, Cirsium*, *Solanum nigrum*, *Datura*, *Echinochloa crus-galli*, *Ambrosia*

Consultant 5 (Germany)
Chenopodium, panics (*Panicum, Setaria, Digitaria*), *Amaranthus*, *Polygonum*, *Convulvulus, Cirsium*, *Solanum nigrum*, *Datura*

Consultant 6 (Serbia)
In soybean (in conventional and in organic production): *Ambrosia artemisiifolia*, *Cirsium arvense*, *Amaranthus spp.*, *Solanum nigrum*, *Chenopodium album*, *Chenopodium hybridum*, *Sinapis arvensis*, *Datura stramonium*, *Xanthium strumarium*, *Abutilon theophrasti*, *Convolvulus arvensis*, *Polygonum spp*., *Stachys annua*, *Sonchus arvensis*, *Calystegia sepium*, *Hibiscus trionu*. The grasses *Echinochloa crus-galli*, *Sorghum halepense, Setaria spp*., *Digitaria sanguinalis* and *Panicum spp.*

Consultant 7 (Finland)
All answers concern both cultivation systems, many broad-leaf weeds like *Viola arvensis*, *Stellaria media*, *Chenopodium album*, *Galium spurium*, *Galeopsis spp..*

Farmer 1 (Germany)
Faba bean: *Matricaria chamomilla*, *Atriplex spec*., Aethusa cynapium (because present in sugar beets); *Alopecurus myosuroides* (partly herbicide-resistant)

Farmer 2 (Germany)
Faba bean: *Matricaria chamomilla*, *Chenopodium album*, *Galium aparine*, Convolvulus arvensis

Scientist 1 (Germany)
In pea: *Fallopia convolvulus*, *Cirsium oleraceum*, *Sonchus spec.*, *Centaurea cyanus*, *Tripleurospermum inodorum*; in faba bean: *Chenopodium album*, in both crops: *Cirsium arvense*, almost no grassy weeds

Scientist 2 (Germany)
Fallopia convolvulus (especially in conventional agriculture), *Chenopodium album*, *Atriplex spp.*, *Cirsium arvense*.

Lupine weeds even more than soybean (because soybean are cultivated more intensively due to their higher market value).

In organic farming, it is estimated that there are twice as many weed species as in conventional farming; *Convolvulus arvensis* increases.

Scientist 3 (Finland)
There are many weeds, but the most difficult include quackgrass (it used to be *Elymus repens*, but its name has changed recently) and *Chenopodium album*. *Tripleurospermum* can be problematic in some areas. The spectrum of weeds is similar in both cultivation systems.

Scientist 4 (Finland)
-

Scientist 5 (Bulgaria)
Economically significant weeds for soybean production in North Bulgaria do not influence or slightly affect the herbicides used in conventional BG agro-technology. *Xanthium strumarium* / clotbur, common cocklebu/ plants from *Asteraceae* wild spread *Solanum nigrum* / European black nightshade) is a species in the genus *Solanum*/ *Chenopodium album*. *Chenopodium album* is a fast-growing weedy annual plant in the genus *Chenopodium* (Lambsquarters, melde, goosefoot).

In organic production - in addition to those specified: *Sorghum halepense*, weed from genus *Sorgo*, Johnson grass. *Echinochloa crus galli*, is a type of wild grass, cockspur. *Setaria spp.* are a widespread genus of plants in the grass family, some of them invasive weeds.

Scientist 6 (Bulgaria)
i) For Alfalfa - *Erigeron canadense L.*, *Amaranthus retroflexus L.*, *Amaranthus blitoides*, *Chenopodium album*, *Sinapis alba L.*, *Convolvulus arvensis*, *Sorghum halepense*, *Cursium arvense*, *Setaria glauca*, *Rumex Patientia*, *Capsella bursa-pastoris* both cultivation systems ii) For Peas – *Sinapis alba L.*, *Papaver rhoeas*, *Chenopodium album*, *Amaranthus retroflexus L.*, *Setaria viridis*, *Capsella bursa-pastoris* both cultivation systems iii) For Cicer arietinum - *Sinapis alba L.*, *Chenopodium album*, *Amaranthus retroflexus*, *Setaria viridis*, *Convolvulus arvensis*, *Solanum nigrum*, *Cirsium arvense*, *Sorghum halepense*, *Setaria viridis* both cultivation systems

Scientist 7 (Germany)
Organic farming for narrow-leafed lupin, white lupin, yellow lupin, and soybean: *Chenopodium album*, *Fallopia convolvulus*, *Echinochloa crus-galli*, Polygonum persicaria, Galinsoga, Anchusa arvensis, Solanum nigrum. At the edges also Convolvulus arvensis.
Conventional farming for soybean: *Chenopodium album, Fallopia convolvulus, Echinochloa crus-galli*

Request 2:
Please create a ranking for endangerment by weeds for the grain legumes in your area compared to the main cultivated crops (specify for conventional, organic, or both cultivation systems).

Consultant 1 (Germany)
All mentioned species before are equally estimated in terms of danger for crop development. Less problematic: *Veronica spp., Galeopsis ladanum.*

Consultant 2 (Germany)
-

Consultant 3 (Germany)
Fallopia convolvulus (+++) Chenopodium album (++)

Consultant 4 (Austria)
Weed pressure is in both organic and conventional farming systems similar. General: *Convulvulus spp., chenopodium spp., cirsium spp., amaranthus spp., Polygonum spp., Solanum nigrum, Datura spp.*. High pressure in warm-moist regions in Central Eastern Europe: *Echinochloa crus-galli*. High pressure in warm regions (Pannonian climate region): *Ambrosia spp*.

Consultant 5 (Germany)
Both: *Convulvulus spp., chenopodium spp., cirsium spp., amaranthus spp., Polygonum spp., Solanum nigrum, Datura spp.*.

Consultant 6 (Serbia)
-

Consultant 7 (Finland)
-

Farmer 1 (Germany)
-

Farmer 2 (Germany)
overall manageable hazard potential.

Scientist 1 (Germany)
All mentioned weeds diminish yield. Problematic, because the crop is still green at harvest time, are *Fallopia convolvulus, Chenopodium album, Centaurea cyanus, Matricaria recutita* => harvest difficulty.

Scientist 2 (Germany)

Chenopodium album.

Scientist 3 (Finland)
-

Scientist 4 (Finland)
-

Scientist 5 (Bulgaria)
1. *Solanum nigrum* 2. *Xanthium strumarium* 3. *Chenopodium album* In organic production: 1. *Sorghum halepense*, 2. *Solanum nigrum* 3. *Xanthium strumarium* 4. *Echinochloa crus galli* 5. *Setaria Spp* 6. *Chenopodium album*

Scientist 6 (Bulgaria)
For Alfalfa next years (after the first year) – *Sorghum halepense* conventional systems. For Alfalfa first year – *Amaranthus retroflexus, Sinapis alba L., Setaria viridis,* Dodders; For Alfalfa next years – *Capsella bursa-pastoris, Sorghum halepense, Erigeron canadense L.*, Dodders organic systems. For Peas – no weeds. Conventional systems /when there is weed control. For Peas – *Sinapis alba L., Papaver rhoeas, Chenopodium album, Amaranthus retroflexus, Setaria viridis, Capsella bursa-pastoris*. organic systems. For *Cicer arietinum* - *Sorghum halepense* conventional systems. For *Cicer arietinum* - *Sinapis alba L., Chenopodium album, Cirsium arvense, Sorghum halepense, Amaranthus retroflexus, Setaria viridis, Convolvulus arvensis, Solanum nigrum L..* organic systems.

Scientist 7 (Germany)
The most problematic weeds in organic farming for narrow-leafed lupin, white lupin, yellow lupin, and soybean are *Chenopodium album, Fallopia convolvulus,* and *Echinochloa crus-galli*. The most problematic weeds in conventional farming for soybean are *Chenopodium album, Fallopia convolvulus, Echinochloa crus-galli***.**

Weeds are less problematic in conventional farming than organic farming except when herbicides did not work, e.g., reduced tillage.

Ranking for organic farming (from highest to lowest weed infestation risk): Narrow-leafed lupin > white lupin > yellow lupin > faba bean > soybean > spring cereals > winter cereals.

Request 3:
Please specify the used strategies for chemical and mechanical weed control in grain legume cultivation compared to other crops (e.g., maize, wheat, specify for conventional, organic, or both cultivation systems).
Consultant 1 (Germany)
Faba beans are sown deep; therefore, it is possible to groom the soil before their emergence. They can also be groomed well afterward (better than cereals) (organic).

The lower spectrum of active substances and only in pre-emergence against dicotyledonous species limited weed control (conventional).

Consultant 2 (Germany)
Field beans: choosing long-growing varieties helps against *Raphanus raphanistrum*; mixed cultivation (mainly pea), but also field bean and lupin; mechanical weed control

works quite well, sometimes late weeding is a problem; Faba beans and lupins are hoed more often than peas; the wide planting rows in peas are unstable and make hoeing difficult.

Consultant 3 (Germany)
Pea, faba bean, lupins: only pre-emergence herbicides (with low efficiency); mechanical weed control: faba bean in wide rows can be hoed); system approach: integrate faba bean in crop rotation: Faba bean is a crop that works best with direct sowing (disc colter, cross slot) in mulch/crop residues of previous catch crop or straw, which can be hoed with a rotary hoe.

Consultant 4 (Austria)
Both: Allways start with prevention/choice of the parcel (avoid *convolvulus spp.* and *cirsium spp.*)! When seeded, start early (pre-emergence treatment with herbicides or harrow)! Organic: use harrow during juvenile stages of weeds; complete with how as long as possible.

Consultant 5 (Germany)
Both: Allways start with prevention/choice of the parcel (avoid *convolvulus spp.* and *cirsium spp.*)! When seeded, start early (pre-emergence treatment with herbicides or harrow)! Organic: use harrow during juvenile stages of weeds; complete with how as long as possible.

Consultant 6 (Serbia)
Soybean: i) Chemical control and use registered products in Serbia; ii) Mechanical control – use of inter-row cultivator; iii) Organic production – Striegel, row cultivator with fingers, rotary hoe.

Consultant 7 (Finland)
Chemical weed control can be done before the emergence or when the plant is 5-10 cm. In cereals, the weed control is mainly done at 4-5 leaf-stage.

Farmer 1 (Germany)
Later sowing date in winter cereals against grassy weeds; chemical weed control in faba beans: Pre-emergence soil herbicides, field roller (further work step) provides better soil contact, therefore a higher efficiency of the soil herbicides. On organic fields also harrow use.

Farmer 2 (Germany)
Pre-emergence mainly Bangor and Stomp, (Boxer); slopy areas do not allow hoeing.

Scientist 1 (Germany)
Cultivation of pea with cover crop camelina; faba bean: (1) mechanical hoeing can be carried out for a long segment of the vegetation period (positive), early hoeing promotes N-mineralization; (2) field beans intercropped with oat; (3) undersowing with grasses after the last hoeing of faba bean.

Scientist 2 (Germany)
Chemical control (conventional): soy and lupine only pre-emergence, post-emergence grass herbicide. Mechanical (organic): lupine 2-3 x harrowing, hardly any false seedbed

Soybeans: a lot of false seedbed, a lot of hoeing + harrowing + finger hoeing + ridging (up to 13 transplants counted on one farm); manual work is relatively rare

Scientist 3 (Finland)
Spring drought is often a problem in Finland, and if it hits at the wrong time, herbicides may not dissolve properly, so they do not act effectively. Combine this with the very narrow range of certified herbicides for use on grain legumes (even fewer in Finland than in the rest of Europe), and you end up with a severe weed control problem for conventional farmers. Weed control is one of the top problems, possibly the top, for growing grain legumes in this country. Various Fenix and Basagran formulations are used. I know of one farmer who has success at weed suppression by using a white clover living mulch that he crimps in spring before sowing the grain legume. Reduced and zero tillage have become popular in Finland.

Scientist 4 (Finland)
-

Scientist 5 (Bulgaria)
In conventional production, weed control in soybean is done by two sprayings with herbicides: after sowing, with soil herbicide and vegetative, in FF 1-3 triple leaf of soybean for deciduous and 3-5 triple leaf for wheat weeds. In organic production, our strategy is early sowing - early April; 25 cm, approximately 550,000 - 600,000 p / ha, respectively.

Scientist 6 (Bulgaria)
There is no mechanical weed control after the sowing of the legumes mentioned above. The crop rotation is a crucial element of weed control. The best processors are wheat or barley. Very efficient herbicides (active substances) are: Benthason, Imazetapir, Imazamox. for the conventional systems.

Scientist 7 (Germany)
Organic. Lupin, faba bean: 1x blind harrowing (before emergence), 1-3 x harrowing after emergence. Soybean: 1x blind harrowing (before emergence), 1-2 x harrowing after emergence, 2-3 hoeing between rows when crop established (May/June) Spring/winter cereals: 1x blind harrowing (before emergence), 1-3 x harrowing after emergence. Maize: 1x blind harrowing (before emergence), 1-2 x harrowing after emergence, 2-3 hoeing between rows when crop established (May/June). Conventional: Lupin, faba bean, soybean: 1 x pre-emergence herbicide, 1 x post-emergence herbicide. Could be combined with harrowing and hoeing if the aim is to reduce herbicides

Request 4:
Please name pest organisms (aphids, beetles, etc.) in your country/region that occur in the cultivated legume crop (specify for conventional, organic, or both cultivation systems).

Consultant 1 (Germany)
Faba bean and pea: leaf beetle, aphids, (faba) bean beetle; pea: pea moth

Consultant 2 (Germany)
Faba bean and pea: Aphids, beetles; Pea: Pea moth; Faba bean and pea: leaf beetle, Soy: Painted lady

Consultant 3 (Germany)
Faba bean: leaf beetles (more in direct and mulch sowing), aphids (in "aphid years" there are also many ladybugs)

Consultant 4 (Austria)
Generally, pests are occurring only regionally and not every season. Birds (turtles, crows); *rhizoctonia*, seedcorn maggot until emergence; hares and deers; occasionally painted ladies (*vanessa cardui*), bugs, spider mite. *Tetranychus Urticae Koch*. (two-spotted spider mite). Etiella Zinckenella

Consultant 5 (Germany)
Birds (turtles, crows); rhizoctonia, seedcorn maggot until emergence; hares and deers; occasionally painted ladies (vanessa cardui), bugs, spider mites

Consultant 6 (Serbia)
Pest of underground plant parts: i) Clik beetles (*Elateridae*) - *Agriotes ustulatus* Schalle ii) Scarbs (*Scarabaeidae*) – *Rizotrogus aequinoctialis, Amphimallon solstitialis, Anisophia austriaca, A. segetum, A. lata,* iii) Diptera (*Diptera*) – *Delia platura* Pest of above-ground plant parts:i) Maize leaf weevil (*Tanymecus dilaticollis*) ii) Small leaf weevils (*Sitona spp.*) iii) Leaf aphids (*Aphididae*). Six species of leaf aphids have so far been found in soybean fields in Serbia and the neighboring countries. In Serbia in 1990 and 1995 following species were identified: *Acyrthosipon pisi, Aphis craccivora*, and *Aphis fabae*, *Myzus persicae*. Iv) Trips (*Thysanoptera*) v) Bugs (*Heteroptera*) vi) Southern green stink bug (*Nezara viridula*) Vii) Owlet moths (*Noctudiae*) viii) The painted lady (*Vanessa cardui*) ix) Mites and tickes (*Acarina*) x) The strawberry spider mite (*Tetranicus atlanticus*) Xi) Hamster (*Cricetus cricetus*) Xii) Common vole (*Microtus arvalis*) xiii) The European hare (*Lepus eurepaeus*) (over 83%), the rest are other animal pests. Phytophagous species take place during whole vegetation, from planting to harvest, injuring all parts of plant: root system and root nodules, stem, leaves, flowers, pods, and seed (grain). Economic importance has following species: Germinates seeds and root system, especially in the beginning of the vegetation are injured by *Elateridae, Scarabaeidae, Sitonna spp., Delia platura*, nematodes (*Pratylenchus spp.,* and *Meloidogyne spp.),* various birds (*Aves*), etc. In above parts of the plant, from the beginning to the end of vegetation, various pest occur, but the most important are following: *T. dilatiollis, Sitona spp., Aphididae, Thysanoptera, Heteroptera (Lygus spp.), V. cardui, Autographa gamma, Mamestra brasicacae, Loxostege sticticalis, Etiella zinckenella, Helicoverpa armigera, Scotia spp., Tetranychus spp., C. cricetus, M. arvalis, L. europaeus,* etc. Special economyc importance has *T. atlanticus, V. cardui, C. cricetus,* and *L. europaeu*. The most important soybean pest *Tetranychus urticae*, also occur but in significantly reduced number. The biggest impacts on soybean occur in years with dry summer. Soybean in Serbia is impacted by over 90 various pests. Most of them are insects.

Consultant 7 (Finland)
Quite a few, mainly *Cydia nigricana* requires control and to a lesser extent aphids.

Farmer 1 (Germany)
Field beans: Leaf beetles are increasing; 2018-2020 fewer aphids than in previous years; lupine (for the first time): few pests

Farmer 2 (Germany)
leaf beetles problematic, aphids less problematic

Scientist 1 (Germany)
faba bean and pea: leaf beetle (yield effect), aphids (do grow out); pea moth (only problematic when marketed to freezing plants and seed; pea beetle (no reproduction possible); faba bean beetle

Scientist 2 (Germany)
Soybean: only sporadic painted lady butterflies, no aphids, increasingly bugs; game damage (hares, rabbits, birds after pod-filling). It is recommended to sow more densely and later. Lupine; leaf beetles (very large, larvae eat nodules), hardly any aphids; game damage fallow deer, roe deer; peas: aphids very important, leaf beetles probably not so important. Faba bean: black bean aphid in dry years, green peach aphid as a carrier of nanoviruses.

Scientist 3 (Finland)
The main insect pests are aphids (the black bean aphid *Aphis fabae* and the pea aphid *Acyrthosiphon pisi*), the leaf weevil *Sitona lineatus,* and the pea moth *Cydia nigricana*. While other *Sitona* species are known further south, we don't have them here. The pea moth clearly prefers pea to others, but we have found it on faba bean, narrow-leafed lupin and lentil. So far, we do not have a significant problem with bruchids. Last year we had pressure from the gamma moth *Autographa gamma* that led to special approval of an insecticide to control it.

Scientist 4 (Finland)
Common are aphids (*Acyrtrosiphon pisum, Megoura viciae, Aphis fabae*), pea leaf weevil (*Sitona lineatus*), pea moth (*Cydia nigricana*) in both cultivation systems. In summer 2018, some heavy attacks by the silver Y moth (*Autographa gamma*) larvae were observed locally in Faba bean crops during late summer (but this is not common).

Scientist 5 (Bulgaria)
Soil enemies: Click beetles (fam. *Elateridae*), *Agrotis ipsilon*, *Agrotis* (Scotia) *segetum*. First wire worm /Click beetles / is of economic importance. Spider mites: *Tetranychus atlanticus, Tetranychus urticae*. Weevil: *Tanymecus palliatus, Psalidium maxillosum, Otiorhynchus ligustici*. Green vegetable bug: *Nezara viridula* – has been gaining economic importance in the last 2-3 years

Scientist 6 (Bulgaria)
For Alfalfa – Weevils from *Sitona* genus, *Hypera zoilus, Psalidium maxillosum, Phytodecta fornicata, Chloridea dipsacea L.* conventional systems. For Peas – *Bruchus pisi, Acyrthosiphon pisi*. For *Cicer arietinum* – no

Scientist 7 (Germany)
Organic and conventional: *Sitona spp.* only in narrow-leafed lupin very problematic due to several development cycles during spring/summer, eating on the leaves and the larvae eating on the nodules (**see picture and description**), problematic every year. *Bruchus spp.* in faba bean, large damage to seed quality. Caterpillar of *Vanessa cardui* in soybean but only in 1 out of the last 7 years and only a minor damage (**see here**)

Request 6:
What strategy do you use to fight insect pests? Besides chemical methods, do you use catch crops or antagonists? Please name the catch crop and antagonist strategy for the chosen grain legume (specify for conventional, organic or both cultivation systems).

Consultant 1 (Germany)
No catch crops, no antagonists; but crop rotation (breaks in cultivation, alternation of peas and field beans), soil cultivation, time interval to previous year's harvest

Consultant 2 (Germany)
No catch crops, no antagonists; but mixed cultivation; sowing date (against pea moth) above all for vegetable pea

Consultant 3 (Germany)
No catch crops, no antagonists

Consultant 4 (Austria)
Insecticides are used rarely. Antagonists are not used to my knowledge.

Consultant 5 (Germany)
Against *Vanessa cardui* you may use Karate (Lambda-Cyhalothrine) or *Bacillus thuringiensis* (organic);

Consultant 6 (Serbia)
In conventional production - chemical measures, nets (physical barriers)

Consultant 7 (Finland)
For legumes, insect control is not needed often, only concerning peas for food, no widely used alternative methods exist

Farmer 1 (Germany)
No catch crops, no antagonists; chemical control against leaf beetles; 2x half a single application before and after flowering against faba bean beetles

Farmer 2 (Germany)
No catch crops, no antagonists; pyrethroid against leaf beetles; against bean beetles: one must fight the larvae, lay eggs in beans. In seed propagation with karate as insecticide; Faba bean cultivation only every 5-6 years.

Scientist 1 (Germany)
No catch crops, no antagonists; but the distance between fields are useful, flowering strips that contain field beans or peas in their species composition are very counterproductive.

Scientist 2 (Germany)
No catch crops, no antagonists.

Scientist 3 (Finland)
The only approved control chemical for Sitona is an organic product, so all farmers have access to it. Aphids are often limited by weather conditions but when their population needs control, conventional farmers have access to only one chemical and organics to none. Gamma moth required control last year and farmers were given special permission to use a chemical that is permitted further south. Pea moth populations are monitored with pheromone traps and when they are too high, appropriate insecticides can be used by conventionals. I have suggested that pea trap crops could be used near faba bean or narrow-leafed lupin crops, but so far this has not been necessary.

Scientist 4 (Finland)
On organic Faba bean, pest control actions are not typically needed, but crop rotation is important.

Scientist 5 (Bulgaria)
In the conventional agro-technology in North Bulgaria, is rarely fights enemies /pests/, the seeds are not treated against soil pests. Occasionally, there are spring against mites if there are strong attack. Biological methods and suppliers/substances are not used in production. Preliminary results from experimental ones have no potential practical relevance so far.

Scientist 6 (Bulgaria)
-

Scientist 7 (Germany)
Only against Sitona spp. Organic: Against Sitona spp. Pyrethrum based product (Spruzit Neu) only in experiments not registered for legumes. Conventional: Sitona spp. with insecticides (Karate Zeon).

Table 4: Weed incidence in different grain legumes from the countries we received questionnaires

Country	Legume	Farming system	
		Conventional	Organic
Austria	All	*Amaranthus spp., Ambrosia artemifolia, Chenopodium album, Cirsium arvense, Convolvulus arvensis, Datura stramonium, Digitaria sanguinalis, Echinochloa crus-galli, Galium aparine, Panicum spp., Polygonum spp., Setaria spp., Solanum nigrum*	-
Bulgaria	All	*Arctium spp., Chenopodium album, Solanum nigrum, Xanthium strumarium*	*Arctium spp., Chenopodium album, Echinochloa crus galli, Setaria spp., Solanum nigrum, Sorghum halepense, , Xanthium strumarium*
	Alfalfa	*Amaranthus blitoides*, *Amaranthus retroflexus L.*, *Capsella bursa-pastoris, Chenopodium album*, *Cirsium arvense, Convolvulus arvensis, Erigeron canadense L.*, *Rumex Patientia, Setaria glauca, Sinapis alba L.*, *Sorghum halepense*	
	Peas	*Amaranthus retroflexus L.*, *Capsella bursa-pastoris, Chenopodium album, Papaver rhoeas, Setaria viridis, Sinapis alba L.*,	
	Chickpea	*Amaranthus retroflexus, Chenopodium album, Cirsium arvense, Convolvulus arvensis, Setaria viridis, Sinapis alba L., Solanum nigrum, Sorghum halepense*	
Finland	All	*Chenopodium album*, *Elymus repens*, *Galium spurium*, *Galeopsis spp.. Stellaria media, Tripleurospermum inodorum, Viola arvensis*	
Germany	All	*Alopecurus myosuroides, Amaranthus spp., Ambrosia artemifolia, Atriplex spp., Brassica napus, Bromus spp. Chenopodium album, Cirsium arvense, Convolvulus arvensis, Datura stramonium, Digitaria sanguinalis, Echinochloa crus-galli, Fallopia convolvulus, Matricaria chamomilla, Panicum spp., Setaria spp., Solanum spp., Stellaria media*	*Cirsium arvens, Chenopodium album, Fallopia convolvulus*
	Faba bean	*Aethusa cynapium, Alopecurus myosuroides, Atriplex spec., Chenopodium album, Convolvulus arvensis, Matricaria chamomilla,*	
	Lupin	-	*Anchusa arvensis, Chenopodium album, Convolvulus arvensis, Echinochloa crus-galli, Fallopia convolvulus, Galinsoga spp., Polygonum persicaria, Solanum nigrum*
	Pea	*Centaurea cyanus, Cirsium arvense, Cirsium oleraceum, Fallopia convolvulus, Sonchus spec., Tripleurospermum inodorum*	
Germany	Soybean	*Chenopodium album, Echinochloa crus-galli, Fallopia convolvulus,*	*Anchusa arvensis, Chenopodium album, Convolvulus arvensis, Echinochloa crus-galli, Fallopia convolvulus, Galinsoga spp., Polygonum persicaria, Solanum nigrum*
Serbia	Soybean	*Abutilon theophrasti, Amaranthus spp., Ambrosia artemisiifolia, Calystegia sepium, Chenopodium album, Chenopodium hybridum, Cirsium arvense, Convolvulus arvensis, Datura stramonium, Digitaria sanguinalis, Echinochloa crus-galli, Hibiscus trionum, Panicum spp., Polygonum spp., Setaria spp., Sinapis arvensis, Solanum nigru, Sonchus arvensis, Sorghum halepense, Stachys annua, Xanthium strumarium*	

Table 5: Pest organism in different grain legumes from the countries we received questionnaires

Country	Grain legume	Pest organism
Austria	All	Birds (turtles, crows); *rhizoctonia*, seedcorn maggot until emergence; hares and deers; occasionally painted ladies (*vanessa cardui*), bugs, spider mite. *Tetranychus Urticae Koch*. (two-spotted spider mite). *Etiella Zinckenella*
Bulgaria	All	Soil enemies: Click beetles (fam. *Elateridae*), *Agrotis ipsilon*, *Agrotis* (Scotia) *segetum*. Spider mites: *Tetranychus atlanticus, Tetranychus urticae*. Weevil: *Tanymecus palliatus, Psalidium maxillosum, Otiorhynchus ligustici*. Green vegetable bug: *Nezara viridula*
	Alfalfa	Weevils from *Sitona* genus, *Hypera zoilus, Psalidium maxillosum, Phytodecta fornicata, Chloridea dipsacea L.*
Finland	All	Aphids (Acyrtrosiphon pisum, Megoura viciae, Aphis fabae), pea leaf weevil (Sitona lineatus), pea moth (Cydia nigricana)
Germany	All	Birds (turtles, crows); rhizoctonia, seedcorn maggot until emergence; hares and deers; occasionally painted ladies (vanessa cardui), bugs, spider mites
	Faba bean	leaf beetle, black bean aphid , green peach aphid, bean beetle, *Bruchus spp*.
	Lupin	leaf beetles larva, *sitona spp.*
	Pea	leaf beetle, aphids, pea moth
	Soybean	Painted lady, hares, rabbits, birds after pod-filling
Serbia	Soybean	Pest of underground plant parts: i) Clik beetles (*Elateridae*) - *Agriotes ustulatus* Schalle ii) Scarbs (*Scarabaeidae*) – *Rizotrogus aequinoctialis, Amphimallon solstitialis, Anisophia austriaca, A. segetum, A. lata,* iii) Diptera (*Diptera*) – *Delia platura*. Pest of above-ground plant parts:i) Maize leaf weevil (*Tanymecus dilaticollis*) ii) Small leaf weevils (*Sitona spp.*) iii) Leaf aphids (*Aphididae*). *Acyrthosipon pisi, Aphis craccivora*, and *Aphis fabae*, *Myzus persicae*. Iv) Trips (*Thysanoptera*) v) Bugs (*Heteroptera*) vi) Southern green stink bug (*Nezara viridula*) Vii) Owlet moths (*Noctudiae*) viii) The painted lady (*Vanessa cardui*) ix) Mites and tickes (*Acarina*) x) The strawberry spider mite (*Tetranicus atlanticus*) Xi) Hamster (*Cricetus cricetus*) Xii) Common vole (*Microtus arvalis*) xiii) The European hare (*Lepus eurepaeus*) (over 83%), the rest are other animal pests.

Service-oriented questions

Request 5:

Please name useful organism (predator insects, natural biocontrol agent) in your country/region that occurs in the cultivated legume crop (specify for conventional, organic, or both cultivation systems).

Consultant 1 (Germany)

Ladybugs, hoverflies, ground beetles, spiders.

Consultant 2 (Germany)

Ladybugs, ichneumon flies, hoverflies (AB: Neudosan (50% efficiency?).

Consultant 3 (Germany)

Faba beans have a positive effect on biodiversity and thus on nectar supply; a professional beekeeper visits conventional faba bean field.

Consultant 4 (Austria)

Both: *Bradorhyzobium japonicum* (inoculant for N-fixation). Organic: *Bacillus Thuringiensis* (against Vanessa); dogs and raptors for chasing birds and hares and field mice.

Consultant 5 (Germany)

Both: *Bradorhyzobium japonicum* (inoculant for N-fixation), organic: *Bacillus Thuringiensis* (against Vanessa); dogs and raptors for chasing birds and hares.

Consultant 6 (Serbia)

Coccinellidae (*Coccinella septempunctata* and *Adalia bipunctata*).

Consultant 7 (Finland)

difficult to specify for legumes, but mainly *Coccinella septempunctata* and *Chrysoperla carnea.*

Farmer 1 (Germany)

Faba bean and lupin: bumblebees (no difference between faba bean and lupin); ladybugs.

Farmer 2 (Germany)

Coccinella septempunctata (against aphids).

Scientist 1 (Germany)

Against green pea leaf aphid and black bean aphid: seven-spot ladybird ; against pea beetles, faba bean beetles and pea moth, the beneficial organisms have only developed in the year after cultivation.

Scientist 2 (Germany)

Ladybeetles.

Scientist 3 (Finland)

The only type that I have observed is ladybird beetles of which we have 60 species, the most common being 7-spotted Coccinella septempunctata and 2-spotted Adalia bipunctata. Of course we have spiders, mantids and other predators, but I have not investigated them.

Scientist 4 (Finland)
On organic Faba bean: ground beetles (for example *Pterostichus, Harpalus, Blemus, Anchomenus, Patrobus, Amara, Poecilus, Loricera sp.*), ladybirds (*Coccinellidae*), hymenopteran parasitoids, soldier beetles (*Cantharidae*).

Scientist 5 (Bulgaria)
-

Scientist 6 (Bulgaria)
Bioagents: Nabis genus and Orius horvathi Reuter for organic systems

Scientist 7 (Germany)
None that have a visible/measurable effect. To explore further: Egg parasitoids that parasitise the eggs of *Sitona sp*p. in narrow-leafed lupin, found in 2020 but the effect cannot be assessed yet.

Request 7:
Please provide information about arthropod diversity (e.g. beetles, spiders) in grain legumes compared to other crops? (either qualitative like species names or quantitative information like species richness, number of individuals, density, biomass. Specify for conventional, organic or both cultivation systems).
Consultant 1 (Germany)
-

Consultant 2 (Germany)
-

Consultant 3 (Germany)
-

Consultant 4 (Austria)
-

Consultant 5 (Germany)
-

Consultant 6 (Serbia)
-

Consultant 7 (Finland)
-

Farmer 1 (Germany)
-

Farmer 2 (Germany)
-
Scientist 1 (Germany)

Because summers crops: many ground beetles

Scientist 2 (Germany)
-

Scientist 3 (Finland)
On Faba bean, we have found higher ground beetle and rove beetle activity (i.e. total number of individuals) compared to cabbage, while there was no major difference in spider activity (SUREVEG project). Analyses are currently done to compare the diversity of carabid genera. Also, in Faba bean strips added to a cabbage field, higher number of parasitic wasps and soldier beetles were detected compared to a control cabbage field.

Scientist 4 (Finland)
-

Scientist 5 (Bulgaria)
-

Scientist 6 (Bulgaria)
-

Scientist 7 (Germany)
Ground beetles. Ground beetles are currently assessed in our new landscape experiment with soybean and lupin (compared with wheat, barley, maize, oat). Work across different regions in 2005-2007 on ground beetle has found a great variability of effects. Grain legumes had a higher abundance of ground beetle compared to perennial temporary grass and grass-clover across all case studies. Compared to annual crops the situation is different. In some case studies, grain legumes had a higher abundance then spring cereals and maize (BY, TH) but not in all case studies MV.
Spiders. Work across different regions in 2005-2007 on spiders has found a great variability of effects. Grain legumes had a similar to greater spider abundance than spring and winter cereals and maize in the case studies BY and TH but the smallest abundance in MV.
Hence the agricultural landscape and management seem to affect the role of legumes for arthropod diversity. More details in Willms et al. 2009. Entwicklung und Vergleich von optimierten Anbausystemen für die landwirtschaftliche Produktion von Energiepflanzen unter den verschiedenen Standortbedingungen Deutschlands (EVA), Schlussbericht zu Teilprojekt II:„Ökologische Folgewirkungen des Energiepflanzenanbaus‟ ZALF, Müncheberg.

Request 8:
Please provide information about pollinators like wild bees, bumblebees, and flies in grain legume cultivation compared to other crops (Either qualitative like species names or quantitative information like species richness, number of individuals, density, biomass. Specify for conventional, organic, or both cultivation systems).

Consultant 1 (Germany)
Bumblebees, honey bees.

Consultant 2 (Germany)
Faba beans: Bumblebees; Soybeans: none.

Consultant 3 (Germany)
Bumblebees increasingly observed, and beekeepers go in there on purpose; field beans in a wide row and single grain sowing: Lights Stand: Promotion of ground breeders.

Consultant 4 (Austria)
Not many; occasionally wild bees.

Consultant 5 (Germany)
Not many; occasionally wild bees.

Consultant 6 (Serbia)
-

Consultant 7 (Finland)
-

Farmer 1 (Germany)
Faba bean: compared to other cultures a lot. Also bumblebees: (similar to rape), compared to cereals and sugar beets: much higher activity density

Farmer 2 (Germany)
Bees and bumblebees; flower of the field bean fills "pollen/nectar gap"; coordination with beekeepers.

Scientist 1 (Germany)
Faba bean has extrafloral nectaries and is also a pollen plant; faba beans and peas attract skylarks; partridges like to go into twisted pea fields; peas through many weeds effective, grain legumes generally good for wild bees, faba beans good for bumblebees, pea through dormancy (no hoeing) and field beans (no flaming of weeds) good for the biodiversity of the accompanying flora

Scientist 2 (Germany)
Post-emergence herbicide with a gap in chamomile promotes flowering in field beans.

Scientist 3 (Finland)
My MSc student Tiiu Kyllönen did a nice study (that she wrote in English) on the range of pollinators in faba bean, available from https://helda.helsinki.fi/bitstream/handle/10138/236089/Kyllonen_Tiiu_Pro_Gradu_2018.pdf?sequence=2&isAllowed=y. Honeybees were the most common pollinators and several species of Bombus, mostly short-tongued species that could rob nectar but would visit flowers frontally only when gathering pollen. In her surveys of fields, she found that 100% of faba bean flowers had been robbed. Both white-tailed (B. lucorum group) and red-tailed (B. pascuorum group) bumblebees were seen, along with one long-tongued B. hortorum making a frontal visit. There are plentiful syrphid flies around the fronts of faba bean flowers, but I have seen no evidence that they are strong enough to forage on them. I have photographs of both white-tailed and red-tailed bumblebees on narrow-leafed lupin flowers and their corbiculae were full of orange pollen from the lupins. I have not seen any pollinators on either pea or lentil plots.

Scientist 4 (Finland)
On Faba bean, bumble bees and honeybees are often detected to visit the flowers.

Scientist 5 (Bulgaria)
Except honey bees the other important pollinators for legumes are wide bees from genera Osmia and Bombus, earth bees and flies from family *Syrphidae*.

Scientist 6 (Bulgaria)
For Alfalfa - *Megachile rotundata*, *Bombus spp.*

Scientist 7 (Germany)
Bumble bees regularly in soybean flowers (July) in both organic & conventional but no quantification done, compared to cereals and maize. Less pollinators in lupin, we did not check faba bean carefully yet. Lupin, soybean etc. are mainly self-pollinated and faba bean is partially cross-pollinated.

Request 9:
Please provide information about soil fauna such as earthworms and collembolan in grain legume cultivation compared to other crops (Either qualitative like species names or quantitative information like species richness, number of individuals, density, biomass. Specify for conventional, organic or both cultivation systems).
Consultant 1 (Germany)
-

Consultant 2 (Germany)
-

Consultant 3 (Germany)
a question of the cultivation system (crop rotation, tillage), e.g. field beans in the no-tillage system; wheat after faba bean copes better with a dry spring than wheat after wheat; in contrast, wheat after maize is problematic.

Consultant 4 (Austria)
Both: Earthworms might appreciate the dense litter of fallen leaves a few weeks before harvest.

Consultant 5 (Germany)
Both: Earthworms might appreciate the dense litter of fallen leaves a few weeks before harvest.

Consultant 6 (Serbia)
-

Consultant 7 (Finland)
-

Farmer 1 (Germany)
Crop rotation with field beans in a no-till system: straw remains (promotes soil microorganisms); the pre-crop value of field beans is better than that of grain; beans in this respect also better than rapeseed, poppy, hemp; corn, however, similarly good.

Farmer 2 (Germany)
-
Scientist 1 (Germany)

-

Scientist 2 (Germany)
-

Scientist 3 (Finland)
-

Scientist 4 (Finland)
-

Scientist 5 (Bulgaria)
-

Scientist 6 (Bulgaria)
-

Scientist 7 (Germany)
Work has started in 2020 in our new landscape experiment with soybean and lupin (compared with wheat, barley, maize, oat).

Request 10:
Please provide information about improvements in soil fertility, such as soil structure and carbon balance through the cultivation of grain legumes? (Specify for conventional, organic or both cultivation systems).

Consultant 1 (Germany)
Better soil conditions after faba beans than after grain (as a result, less effort for soil tillage than after grain).

Consultant 2 (Germany)
Usually good soil structure after grain legumes; humus effect: unclear

Consultant 3 (Germany)
Previous crop effect (before winter barley): rapeseed the better previous crop than pea, but field bean the better previous crop than rapeseed (rapeseed has problems in "snail years", which then also influence its previous crop effect); with mulch and no-tillage the previous crop advantage of faba bean over rapeseed is even greater.

Consultant 4 (Austria)
Both: soil fertility is improved by a perfect structure which enables to seed winter wheat by mulch till as well as by 30-40 kgs Nmin/ha residual nitrogen.

Consultant 5 (Germany)
Both: soil fertility is improved by a perfect structure that enables to seed winter wheat by mulch till and by 30-40 kgs Nmin/ha residual nitrogen.
Consultant 6 (Serbia)
-

Consultant 7 (Finland)
legumes are regarded good in crop rotation because of N-fixing and cutting the disease pressure of cereals, new information on carbon binding is just about to gain.

Farmer 1 (Germany)
Faba bean improves soil structure directly; this effect remains in subsequent crops; the legume effect in terms of N input for soil life of field bean also counts; reduced tillage systems have a positive effect on soil structure (with total herbicide).

Farmer 2 (Germany)
-

Scientist 1 (Germany)
-

Scientist 2 (Germany)
-

Scientist 3 (Finland)
-

Scientist 4 (Finland)
-

Scientist 5 (Bulgaria)
-

Scientist 6 (Bulgaria)
Alfalfa (Medicago sativa L.) can be considered as "soil building" legume crop. It enriches the soil with nitrogen and organic substances. The amount of root mass which alfalfa accumulates in the soil during a four-year growing period was for alfalfa with direction of use for forage 4017 - 4714 kg/ha and for alfalfa with direction of use for seeds - 2792-2828 kg/ha, respectively.

Scientist 7 (Germany)
Difficult because we have no experiments investigating this specifically. It depends on the amounts and quality of the crop residues (C:N ratio) and roots see e.g. our review Watson et al. 2017.

In Germany we assume an addition of SOM for calculating SOM balances (see VDLUFA standard factors) of 160 kg C ha^{-1} a^{-1} compared to -280 kg for cereals and - 560 kg for maize. Some studies found a decline in SOM with grain legumes see e.g. Plaza-Bonilla 2018

Request 11:
What experience have you had in intercropping of grain legumes with other crops in relation to the diversity of plants, arthropods, small mammals and birds? (Specify for conventional, organic or both cultivation systems).

Consultant 1 (Germany)
-

Consultant 2 (Germany)
-

Consultant 3 (Germany)
-

Consultant 4 (Austria)
-

Consultant 5 (Germany)
-

Consultant 6 (Serbia)
Please find information in - Models, Developments, and Perspectives of Mutual Legume Intercropping (this is attached as part of this data request). In our experiments we started with use of cover crops in soybean production. If this is interested, we can elaborate more on this topic.

Consultant 7 (Finland)
-

Farmer 1 (Germany)
-

Farmer 2 (Germany)
-

Scientist 1 (Germany)
-

Scientist 2 (Germany)
-

Scientist 3 (Finland)
My experiments on cereal-legume intercrops have generally been unsuccessful because of poor weed control. A few years ago, we grew 10 ha of white lupin – wheat intercrop for a ruminant feeding trial. The price of white lupin seed had multiplied nearly 10-fold between planning and ordering. First, barnacle geese on their spring migration consumed the lupin seedlings from a quarter of the field, then during the late autumn rats moved into the bales of silage and spoiled every last one of them. Final score, vertebrate biodiversity 2, crop mixture 0. One-litre micro-silos showed the silage quality to be very high. I think that the problem in this area is validity of data. Experimental plots are usually too small to deliver good data about biodiversity of mobile animals whereas fields are unreplicated.

Scientist 4 (Finland)
-

Scientist 5 (Bulgaria)
-

Scientist 6 (Bulgaria)

-

Scientist 7 (Germany)
None – sorry! We will start with intercropping soon (wheat-soybean and maize-soybean).

Table 6: Useful organism in different grain legumes from the countries we received questionnaires

Country	Grain legume	Useful organism
Austria	All	*Bradorhyzobium japonicum* (inoculant for N-fixation). Organic: *Bacillus Thuringiensis* (against *Vanessa*)
Bulgaria	All	Nabis genus and Orius horvathi Reuter
Finland	All	Spiders, ground beetles (for example *Pterostichus, Harpalus, Blemus, Anchomenus, Patrobus, Amara, Poecilus, Loricera* sp.), ladybirds (*Coccinellidae* e.g. *Coccinella septempunctata* and *Chrysoperla carnea*), hymenopteran parasitoids, soldier beetles (*Cantharidae*).
Germany	All	Ladybugs, Ichneumonidae, hoverflies, spiders. *Bradorhyzobium japonicum* (inoculant for N-fixation), organic: *Bacillus thuringiensis* (against Vanessa); bumblebees, eggs parasitoids
Serbia	Soybean	*Coccinellidae* (*Coccinella septempunctata and Adalia bipunctata*).

About this report

Authors: Leoanardo Amthauer Gallardo, Georg Everwand and Jens Dauber Thünen-Institut: Biodiversity (thuenen.de) and Thünen-Institut: Agricultural Technology (thuenen.de)

Contact: Leonardo Amthauer Gallardo leonardo.amthauer@thuenen.de,

Georg Everwand georg.everwand@thuenen.de

and Jens Dauber jens.dauber@thuenen.de

Production: Donau Soja

Permalink: www.zenodo.org/record/6538485

Cover photograph: Bumblebee. Photograph: Seed Technology Ltd.

Citation: Amthauer Gallardo, L., Everwand, G. and Dauber, J., 2022. Effects of legume crops on biodiversity. Legumes Translated Report 2. Available from www.legumehub.eu

This report was prepared within the Legumes Translated project funded by the European Union through Horizon 2020, Project Grant Number 817634