SINGLE-IMPACT FICHE
INTERCROPPING

IMPACT: CROP YIELD

Data extracted in May 2021
Fiche created in December 2023

Note to the reader: This fiche summarises the effects of Intercropping on CROP YIELD. It is based on 19 synthesis papers[1], including from 17 to 180 primary studies.

1. WEIGHT OF THE EVIDENCE

CONSISTENCY OF THE IMPACT

Intercropping of either multiple crop species (i.e., crop mixture cropping) or genotypes (i.e., cultivar mixture cropping), as compared to monoculture or pure stands, resulted in an overall positive effect on crop yield (table 1).

The table below shows the number of synthesis papers with statistical tests reporting i) a significant difference between the Intervention and the Comparator, that is to say, a significant statistical effect, which can be positive or negative; or ii) a non-statistically significant difference between the Intervention and the Comparator. In addition, we include, if any, the number of synthesis papers reporting relevant results but without statistical test of the effects. Details on the quality assessment of the synthesis papers can be found in the methodology section of this WIKI.

- crop mixture cropping: from a total of 18 results, 14 were positive, 2 were negative and 2 showed non-significant effects. The two negative effects on crop yield are reported from two studies (Letourneau et al. 2011; Iverson et al. 2014) that measured the effect of intercropping considering only the yield from the main crop. The authors of both studies concluded that considering total yield would have probably resulted in a positive overall effect of intercropping on crop yield, as compared to monoculture.
- cultivar mixture cropping: from a total of 4 results, 3 were positive (increase in crop yield) and 1 showed a non-significant effect.

Out of the 19 selected synthesis papers, 14 included studies conducted in Europe (see **Table 2**).

Table 1: Summary of effects. Number of synthesis papers reporting positive, negative or non-statistically significant effects on environmental and climate impacts. The number of synthesis papers reporting relevant results but without statistical test of the effects are also provided. When not all the synthesis papers reporting an effect are of high quality, the number of synthesis papers with a quality score of at least 50% is indicated in parentheses. The reference numbers of the synthesis papers reporting each of the effects are provided in **Table 3**. Some synthesis papers may report effects for more than one impact or more than one effect for the same impact.

				Statistically tested			Non-statistically tested
Impact	Metric	Intervention	Comparator	Significantly positive	Significantly negative	Non-significant	
Increase crop yield	Crop yield	Crop mixture cropping	monoculture	14	2	2	0
		Cultivar mixture cropping	monoculture	3	0	1	0

QUALITY OF THE SYNTHESIS PAPERS

The quality of each synthesis paper was assessed based on 16 criteria regarding three main aspects: 1) the literature search strategy and primary studies selection; 2) the statistical analysis conducted; and 3) the evaluation of potential bias. We assessed whether authors addressed and reported these criteria. Then, a quality score was calculated as the percentage of these 16 criteria properly addressed and reported in each synthesis paper. Details on quality criteria can be found in the methodology section of this WIKI.

2. IMPACTS

The main characteristics and results of the 19 synthesis papers are reported in **Table 2** with the terminology used in those papers, while **Table 3** shows the reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**. Comprehensive information about the results reported in each synthesis paper, in particular about the modulation of effects by factors related to soil, climate and management practices, are provided in the **summaries of the synthesis papers** available in this WIKI.

Table 2: Main characteristics of the synthesis papers reporting effects on crop yield. The references are ordered chronologically with the most recent publication date first.

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Ref2	Cereals and legumes	Global	17	Intercropping	Monoculture	Crop yield and biomass (Land equivalent ratio, LERY and LERB; net effect NEY and NEB)	Results indicate substantial improvements in land use efficiency are obtained by cereal/legume intercropping.	75%

[1] Synthesis research papers include either meta-analysis or systematic reviews with quantitative results. Details can be found in the methodology section of the WIKI.

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Ref3	Grain legumes and cereals	Africa	180	Grain legume and cereal intercropping	Monoculture	Land equivalent ratio (LER)	Compared to sole crop, intercropping legumes to cereals resulted in an elevated LER, hence adding legumes into cereal cultivation increased resource-use efficiency.	62%
Ref5	Multiple crops	China	69	Intercropping	Monoculture	Overall yield gain (NE, difference between the observed yield and the expected yield)	Total yield in intercrops exceeded the expected yield, estimated on the basis of sole crop yields, by 2.14 ± 0.16 Mg ha−1 (mean ± standard error). The study highlights that net effects of Chinese intercropping on yield are highly dependent on the presence of maize. The results confirm that intercropping is a promising pathway for ecological intensification of agriculture which demands for design of optimized cropping systems that are highly productive and resource use efficient	81%
Ref4	Multiple crops	Global	132	Intercropping	Monoculture	Overall yield gain (NE, difference between the observed yield and the expected yield), land equivalent ratio (LER)	Intercropping offers opportunities for the sustainable intensification of both high- and low-input agriculture.	81%
Ref7	Maize and soybean	Global	100	Intercropping	Monoculture	Land equivalent ratio (LER)	Maize/soybean intercropping is a promising practice to meet the challenge of sustainable development and food security. It is important not only for smallholder agriculture in developing countries, e.g. in Africa, to meet demands for calories and protein, but also for organic farming and land sparing in developing countries.	94%
Ref9	Agro-grasslands	Global	48	Intercropping	Monoculture	Total aboveground production (net primary productivity)	Legume intercropping may be one component of the management portfolio that reduces greenhouse gas emissions and chemical inputs, while maintaining NPP and fodder quality to the largest agricultural land base: agro-grasslands.	81%
Ref10	Wheat	Global	32	Cultivar mixtures	Pure stand	Overyielding (the difference in productivity of a variety mixture compared with the weighted mean of its component varieties in pure stand)	Cultivar mixtures increase yield relatively to pure varieties.	94%
Ref12	Multiple crops	Global	126	Intercropping	Monoculture	Land equivalent ratio (LER), relative land output (RLO) based upon gross energy and RLO based upon gross incomes	Intercropping offers a great opportunity for intensification of existing agricultural lands. Irrigation and the aridity index in non-irrigated intercrops did not affect land equivalent ratio, thereby indicating that intercropping remains beneficial, both under stressful and non-stressful contexts concerning moisture availability.	94%
Ref13	Multiple crops	Global	91	Cultivar mixtures	Pure stand	Relative yield (RY, it compares the productivity of plants grown as monocultures and those grown in combination with others) and yield stability (it compares the average monoculture coefficient of variation to that of the mixtures)	Cultivar mixtures are a viable strategy to increase diversity in agroecosystems, promoting increased yield and yield stability, with minimal environmental impact.	81%
Ref14	Cover crops: hairy vetch (Vicia villosa Roth)–cereal rye (Secale cereale L.)	United States	21	Intercropping	Monoculture	Aboveground biomass	Hairy vetch–cereal rye mixtures can produce equivalent or more biomass than both monocultures.	75%
Ref16	Multiple crops	Africa	58	Intercropping	Monoculture	Total LER (land equivalent ratio) and gross income (USD)	Intercropping can increase gross income and yield in Africa.	75%
Ref17	Multiple crops	Global	33	Intercropping	Monoculture	Yield stability (Coefficient of variation - %CV)	Increasing crop diversification through intercropping of cereals and grain legumes can enhance yield stability and food security, making an important contribution to eco-functional, ecological or sustainable intensification of global food production.	56%
Ref18	Cereals and legumes	Global	77	Intercropping	Monoculture	Partial land equivalent ratio (PLER: the relative yield of an intercropped speciescompared to its yield in a sole crop)	The performance of cereals and legumes in an intercrop is affected by sowing densities, relative sowing times, and nitrogen fertilizer. These findings can be used to enhance species complementarity, total productivity and economic profit of intercropping.	81%
Ref19	Multiple crops	Global	100	Intercropping	Monoculture	Land equivalent ratio (LER)	Substantial improvements in land use efficiency in agriculture may be obtained by using mixtures, par-ticularly C_3/C_4 mixtures. Thus, enhanced within-field crop diversity can make an important contributionto sustainable increases in food production.	88%
Ref20	Multiple crops	Global	26	Intercropping	Monoculture	Per-plant crop yield from only the main crop	Intercropping that maintains overall plant density constant compared to monoculture (substitutive design) increased per-plant yield from only the main crop over monocultures. Intercropping that increases overall plant density compared to monoculture (additive design) had a negative effect on per-plant yield from only the main crop over monocultures. Well-designed polycultures can produce win-win outcomes between per-plant, and potentially per-unit area, primary crop yield and biocontrol.	88%
Ref21	Cereals and legumes	Global	17	Intercropping	Monoculture	Land equivalent ration (LER; partial and total LER), yield ratio, and proportion of legume in the mixture of crop grains.	Intercrops are more efficient than sole crops for grain yield production.	75%
Ref22	Multiple crops	Global	140	Intercropping	Monoculture	Energy conversion efficiency (εc, the efficiency with which intercepted or absorbed energy is converted into biomass and is based on the photochemical efficiency of the entire plant canopy)	Optimizing management strategies such as intercropping can enhance energy conversion efficiency	62%
Ref24	Multiple crops	Global	45	Intercropping	Monoculture	Crop yield from only the main crop	A relatively small, but significantly negative, mean effect size for crop yield indicated that pest-suppressive diversification schemes interfered with production, in part because of reducing densities of the main crop by replacing it with intercrops. Especially for additive designs of intercrops, pooling the yields of all crops to calculate the land-equivalent ratios or relative yield total probably would have resulted in a more positive overall yield for the diversification scheme than for a	88%

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
							monoculture crop.	
Ref25	Wheat and barley	Global	26	Varietal mixtures	Pure stand	Grain yield difference	The results obtained through meta-analysis confirm the potential of cereal variety mixtures as a means of obtaining higher grain yields, on average, compared to growing the crop in pure stand.	88%

Table 3: Reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**.

				Statistically tested			Non-statistically tested
Impact	Metric	Intervention	Comparator	Significantly positive	Significantly negative	Non-significant	
Increase crop yield	Crop yield	Crop mixture cropping	monoculture	Ref2, Ref3, Ref4, Ref5, Ref7, Ref9, Ref12, Ref14, Ref16, Ref17, Ref18, Ref19, Ref20 and Ref21	Ref20 and Ref24	Ref14 and Ref22	
		Cultivar mixture cropping	monoculture	Ref10, Ref13 and Ref25		Ref13	

3. FACTORS INFLUENCING THE EFFECTS ON CROP YIELD

Table 4: List of factors reported to significantly affect the size and/or direction of the effects on crop yield, according to the synthesis papers reviewed.

Factor	Reference number
Climate	Ref9
Crop density	Ref18 and Ref19
Crop spatial arrangement	Ref4, Ref19 and Ref17
Crop type	Ref10, Ref3, Ref13, Ref25, Ref18 and Ref9
Crop/cultivar combinations	Ref16, Ref13, Ref12, Ref4, Ref5, Ref20, Ref25, Ref19, Ref17, Ref2, Ref21 and Ref9
Disease severity	Ref10 and Ref13
Fertiliser application	Ref16, Ref13, Ref4, Ref5, Ref18, Ref19, Ref2 and Ref9
Geographical area	Ref19 and Ref7
Growing degree days	Ref14
Herbicide use	Ref16
Latitude	Ref13 and Ref25
Pesticide use	Ref16
Previous crop	Ref14
Row distance	Ref9
Soil organic matter	Ref13 and Ref7
Soil pH	Ref13
Soil texture	Ref14 and Ref9
Sowing time	Ref18 and Ref7
Temporal treatment establishment	Ref9
Tillage	Ref16
Trait heterogeneity	Ref10

4. KNOWLEDGE GAPS

Table 5: Knowledge gap(s) reported by the authors of the synthesis papers included in this review.

Ref Num	Gap
Ref3	Studies that focus on indigenous African grain legumes or cereals should be encouraged because, with the exception of cowpea and teff, most past studies have focused on non-native species.
Ref5	Further work is needed to elucidate the role of different plant traits in the complementarity in maize/legume systems with temporal niche differentiation.

Ref Num	Gap
Ref7	Further research is needed to identify optimal combinations of planting configuration, sowing dates and fertilizer to achieve high yields and high N use efficiency in intercropping, and exploit biological N fixation without driving the system to very resource poor low yielding conditions.
Ref10	Knowledge regarding the causal links between variety traits and beneficial ecological mechanisms. Studies exploring the effects of diversity in various traits and mixture performance through both experimental and modelling approaches
Ref13	Studies exploring how soil and climate conditions and management practices influence cultivar mixtures effect on yields. More research demonstrating the viability of cultivar mixtures for a range of end uses would be helpful. Studies exploring increased diversity effects on nutrient retention and use efficiency, soil organic matter accumulation, weed suppression, and crop pollination.
Ref14	Future studies evaluating cover crop mixtures over monocultures should take into account of the multiple factors that influence mixtures productivity, including soil N availability and precipitation during cover crop growth period. Future studies should also prioritize research on belowground biomass and N accumulation with cover crop mixtures relative to monocultures.
Ref16	There is a need for additional studies across a range of environments and situations in order to more quantitatively describe the relationships between intercropping outcomes and moderating factors (e.g. soil type, temperature, season, crop combinations, and others) in Africa.
Ref18	Further analyses are necessaryto fully understand total productivity in intercrops, including the possibility of transgressive over yielding, i.e. a total yield exceeding the yield of both monocultures in absolute rather than relative terms.
Ref20	There is the need for a greater investment in researching the underlying relationships between multiple agroecosystem services so we can better achieve agroecosystem multifunctionality.
Ref22	Further experimentation could determine beneficial relationships in mixed stands containing plants of varying heights and shade tolerances to maximize εc on a land area basis. Further tests with mixes of legumes and non-legumes on nutrient poor soils would be useful to determine the potential for nutrient sharing between legumes and non-legumes. Further experimentation to determine optimal practices is warranted, but growth condition analyses emphasize the importance of obtaining estimates of εc in field conditions for reliable results.
Ref24	More research is needed to better discern which schemes deliver the desired results for biological control, and what underlying mechanisms can be used to predict the ''right kind of diversity'' for providing these ecosystem services for pest regulation while maintaining crop yield.
Ref25	(1) further work should try to separate the effects of the potential mechanisms and interactions acting in variety mixtures; (2) more information on the growing conditions of varieties and mixtures should be collected and reported from original field trials; and (3) retrievable measures of trial variation should be reported to a larger extent in order to facilitate more substantial overall (meta-)analyses of mixing effects.

5. SYNTHESIS PAPERS INCLUDED IN THE REVIEW

Table 6: List of synthesis papers included in this review. More details can be found in the summaries of the meta-analyses.

Ref Num	Author(s)	Year	Title	Journal	DOI
Ref2	Tang, XY; Zhang, CC; Yu, Y; Shen, JB; van der Werf, W; Zhang, FS	2021	Intercropping legumes and cereals increases phosphorus use efficiency; a meta-analysis	Plant Soil 460, 89–104	10.1007/s11104-020-04768-x
Ref3	Daryanto, S; Fu, BJ; Zhao, WW; Wang, S; Jacinthe, PA; Wang, LX	2020	Ecosystem service provision of grain legume and cereal intercropping in Africa	Agric Syst 178, 102761	10.1016/j.agsy.2019.102761
Ref4	Li, CJ; Hoffland, E; Kuyper, TW; Yu, Y; Zhang, CC; Li, HG; Zhang, FS; van der Werf, W	2020	Syndromes of production in intercropping impact yield gains	Nat Plants 6, 653–660	10.1038/s41477-020-0680-9
Ref5	Li, CJ; Hoffland, E; Kuyper, TW; Yu, Y; Li, HG; Zhang, CC; Zhang, FS; van der Werf, W	2020	Yield gain, complementarity and competitive dominance in intercropping in China: A meta-analysis of drivers of yield gain using additive partitioning	Eur J Agron 113, 125987	10.1016/j.eja.2019.125987
Ref7	Xu, Z; Li, CJ; Zhang, CC; Yu, Y; van der Werf, W; Zhang, FS	2020	Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use; A meta-analysis	Field Crops Res 246, 107661	10.1016/j.fcr.2019.107661
Ref9	Ashworth, AJ; Toler, HD; Allen, FL; Auge, RM	2018	Global meta-analysis reveals agro-grassland productivity varies based on species diversity over time	PloS One 13, e0200274.	10.1371/journal.pone.0200274
Ref10	Borg, J; Kiaer, LP; Lecarpentier, C; Goldringer, I; Gauffreteau, A; Saint-Jean, S; Barot, S; Enjalbert, J	2018	Unfolding the potential of wheat cultivar mixtures: A meta-analysis perspective and identification of knowledge gaps	Field Crops Res 221, 298-313	10.1016/j.fcr.2017.09.006
Ref12	Martin-Guay, MO; Paquette, A; Dupras, J; Rivest, D	2018	The new Green Revolution: Sustainable intensification of agriculture by intercropping	Sci Total Environ. 615, 767–772	10.1016/j.scitotenv.2017.10.024
Ref13	Reiss, ER; Drinkwater, LE	2018	Cultivar mixtures: a meta-analysis of the effect of intraspecific diversity on crop yield	Ecol Appl 28, 62–77	10.1002/eap.1629
Ref14	Thapa, R; Poffenbarger, H; Tully, KL; Ackroyd, VJ; Kramer, M; Mirsky, SB	2018	Biomass Production and Nitrogen Accumulation by Hairy Vetch-Cereal Rye Mixtures: A Meta-Analysis	J Agron 91, 25–33	10.2134/agronj2017.09.0544
Ref16	Himmelstein, J; Ares, A; Gallagher, D; Myers, J	2017	A meta-analysis of intercropping in Africa: impacts on crop yield, farmer income, and integrated pest management effects	Int J Sustain Agric Res 15, 1-10	10.1080/14735903.2016.1242332
Ref17	Raseduzzaman, M; Jensen, ES	2017	Does intercropping enhance yield stability in arable crop production ? A meta-analysis	Eur J Agron 91, 25–33	10.1016/j.eja.2017.09.009
Ref18	Yu, Y; Stomph, TJ; Makowski, D; Zhang, LZ; van der Werf, W	2016	A meta-analysis of relative crop yields in cereal/legume mixtures suggests options for management	Field Crops Res 198, 269–279	10.1016/j.fcr.2016.08.001
Ref19	Yu, Y; Stomph, TJ; Makowski, D; van der Werf, W	2015	Temporal niche differentiation increases the land equivalent ratio of annual intercrops: A meta-analysis	Field Crops Res 184, 133–144	10.1016/j.fcr.2015.09.010
Ref20	Iverson, AL; Marin, LE; Ennis, KK; Gonthier, DJ; Connor-Barrie, BT; Remfert, JL; Cardinale, BJ; Perfecto, I	2014	Do polycultures promote win-wins or trade-offs in agricultural ecosystem services? A meta-analysis	J Appl Ecol 51, 1593–1602	10.1111/1365-2664.12334
Ref21	Pelzer, E; Hombert, N; Jeuffroy, MH; Makowski, D	2014	Meta-Analysis of the Effect of Nitrogen Fertilization on Annual Cereal-Legume Intercrop Production	Agron J 106, 1775–1786	10.2134/agronj13.0590

Ref Num	Author(s)	Year	Title	Journal	DOI
Ref22	Slattery, RA; Ainsworth, EA; Ort, DR	2013	A meta-analysis of responses of canopy photosynthetic conversion efficiency to environmental factors reveals major causes of yield gap	J Exp Bot 12, 3723–3733	10.1093/jxb/ert207
Ref24	Letourneau, DK; Armbrecht, I; Rivera, BS; Lerma, JM; Carmona, EJ; Daza, MC; Escobar, S; Galindo, V; Gutierrez, C; Lopez, SD; Mejia, JL; Rangel, AMA; Rangel, JH; Rivera, L; Saavedra, CA; Torres, AM; Trujillo, AR	2011	Does plant diversity benefit agroecosystems? A synthetic review	Ecol Appl 21, 9-21.	10.1890/09-2026.1
Ref25	Kiaer, LP; Skovgaard, IM; Ostergard, H	2009	Grain yield increase in cereal variety mixtures: A meta-analysis of field trials	Field Crops Res 114, 361–373	10.1016/j.fcr.2009.09.006

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