SINGLE-IMPACT FICHE
INTERCROPPING

IMPACT: CROP YIELD

Data extracted in May 2021

Note to the reader: This fiche summarises the impact of intercropping on CROP YIELD. It is based on 19 peer-reviewed synthesis research papers[1], each of them including from 17 to 180 individual 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 (i.e., increase in crop yield).
    - crop mixture cropping: from a total of 18 results, 14 were positive, 2 were negative and 2 showed no-effect (see **Table 1**). 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 (see Table 2).
    - cultivar mixture cropping: from a total of 4 results, 3 were positive (increase in crop yield) and 1 showed no-effect (see **Table 1**).

  The results are affected by several factors, in particular the type of crops/cultivars included in the mixture.

  Note: Nine out of 19 studies measured crop yield as land equivalent ratio (LER), i.e., the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level[2]. LER is generally calculated as the sum of the fractions of the intercropped yields divided by the sole-crop yields. The LER can be taken as a measure of the relative yield advantage, e.g., a LER of 1.2 indicates a yield advantage of 20% (i.e., 20% more land would be required as sole crops to produce the same yields as intercropping). This, however, might not necessarily indicate an economic advantage for the farmer as the yield of the most valuable crop in the intercrop might decrease compared to monoculture[3].

  Among the 19 reviewed synthesis papers, 14 include data collected in Europe (see **Tables 1 and 2**).

[1] Research synthesis papers include a formal meta-analysis or systematic reviews with some quantitative results. Details can be found in the methodology section of the WIKI.
[2] *Guidelines: land evaluation for irrigated agriculture*. FAO. Glossary. ISBN 92-5-102243-7.
[3] Mead, R., & Willey, R. (1980). The concept of a 'land equivalent ratio' and advantages in yields from intercropping. Experimental Agriculture, 16(3), 217-228

Table 1. Summary of effects. The numbers between parenthesis indicate the number of synthesis papers with a quality score of at least 50%. Details on quality criteria can be found in the next section.

		All studies				Only studies including EU			
Impact	**Intervention**	**Positive**	**Negative**	**No effect**	**Uncertain**	**Positive**	**Negative**	**No effect**	**Uncertain**
Increase Crop yield	Crop mixture	14 (14)	2 (2) *	2 (2)	0	9 (9)	1(1) *	1 (1)	0
	Cultivar mixture	3 (3)	0	1 (1)	0	3 (3)	0	1 (1)	0

* These studies considered crop yield from only the main crop.

QUALITY OF THE SYNTHESIS PAPERS: *The quality score summarises 16 criteria assessing the quality of three main aspects of the synthesis papers: 1) the literature search strategy and studies selection; 2) the statistical analysis; 3) the potential bias. Details on quality criteria can be found in in the methodology section of this WIKI.*

2. IMPACTS

The main characteristics and results of the synthesis papers are summarized in **Table 2**. Summaries of the meta-analyses provide fuller 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.

Table 2. Main characteristics of the synthesis papers reporting impacts of intercropping on crop yield.

Reference	Population	Geographical scale	Num. papers	Intervention	Comparator	Metrics	Conclusion	Quality score
Tang, XY; Zhang, CC; Yu, Y; Shen, JB; van der Werf, W; Zhang, FS 2021	Cereals and legumes	Global	17	Crop mixture cropping	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%
Daryanto, S; Fu, BJ; Zhao, WW; Wang, S; Jacinthe, PA; Wang, LX 2020	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%
Li, CJ; Hoffland, E; Kuyper, TW; Yu, Y; Li, HG; Zhang, CC; Zhang, FS; van der Werf, W 2020	Multiple crops	China	69	Crop mixture cropping	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 tons 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	81%

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							intensification of agriculture which demands for design of optimized cropping systems that are highly productive and resource use efficient.	
Li, CJ; Hoffland, E; Kuyper, TW; Yu, Y; Zhang, CC; Li, HG; Zhang, FS; van der Werf, W 2020	Multiple crops	Global	132	Crop mixture cropping	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%
Xu, Z; Li, CJ; Zhang, CC; Yu, Y; van der Werf, W; Zhang, FS 2020	Maize and soybean	Global	100	Crop mixture cropping	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%
Ashworth, AJ; Toler, HD; Allen, FL; Auge, RM 2018	Agro-grasslands	Global	48	Crop mixture cropping	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%
Borg, J; Kiaer, LP; Lecarpentier, C; Goldringer, I; Gauffreteau, A; Saint-Jean, S; Barot, S; Enjalbert, J 2018	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%
Martin-Guay, MO; Paquette, A; Dupras, J; Rivest, D 2018	Multiple crops	Global	126	Crop mixture cropping	Monoculture	Land equivalent ratio (LER), relative land output (RLO) based upon gross energy and RLO based upon gross	Intercropping offers a great opportunity for intensification of existing agricultural lands. Since, the irrigation and the aridity index in non-irrigated intercrops did not affect	94%

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						incomes	land equivalent ratio, thereby indicating that intercropping remains beneficial, both under stressful and non-stressful contexts concerning moisture availability.	
Reiss, ER; Drinkwater, LE 2018	Multiple crops	Global	91	Cultivar mixtures	Pure stand	Relative yield and yield stability (coefficient of variation)	Cultivar mixtures are a viable strategy to increase diversity in agroecosystems, promoting increased yield and yield stability, with minimal environmental impact.	81%
Thapa, R; Poffenbarger, H; Tully, KL; Ackroyd, VJ; Kramer, M; Mirsky, SB 2018	Cover crops: hairy vetch (Vicia villosa Roth)–cereal rye (Secale cereale L.)	United States	21	Crop mixture cropping	Monoculture	Aboveground biomass	Hairy vetch–cereal rye mixtures can produce equivalent or more biomass than both monocultures.	75%
Himmelstein, J; Ares, A; Gallagher, D; Myers, J 2017	Multiple crops	Africa	58	Crop mixture cropping	Monoculture	Total LER (land equivalent ratio) and gross income (USD)	Intercropping can increase gross income and yield in Africa.	75%
Raseduzzaman, M; Jensen, ES 2017	Multiple crops	Global	33	Crop mixture cropping	Monoculture	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%
Yu, Y; Stomph, TJ; Makowski, D; Zhang, LZ; van der Werf, W 2016	Cereals and legumes	Global	77	Crop mixture cropping	Monoculture	Partial land equivalent ratio (PLER: the relative yield of an intercropped species compared 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%
Yu, Y; Stomph, TJ; Makowski, D; van der Werf, W 2015	Multiple crops	Global	100	Crop mixture cropping	Monoculture	Land equivalent ratio (LER)	Substantial improvements in land use efficiency in agriculture may be obtained by using mixtures, particularly C_3/C_4 mixtures. Thus, enhanced within-field crop diversity can make an important contribution to	88%

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							sustainable increases in food production.	
Iverson, AL; Marin, LE; Ennis, KK; Gonthier, DJ; Connor-Barrie, BT; Remfert, JL; Cardinale, BJ; Perfecto, I 2014	Multiple crops	Global	26	Crop mixture cropping	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%
Pelzer, E; Hombert, N; Jeuffroy, MH; Makowski, D 2014	Cereals and legumes	Global	17	Crop mixture cropping	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%
Slattery, RA; Ainsworth, EA; Ort, DR 2013	Multiple crops	Global	140	Crop mixture cropping	Monoculture	Energy conversion efficiency (ε_c, the efficiency with which intercepted or absorbed energy is converted into biomass; based on the photochemical efficiency of the entire plant canopy)	Optimizing management strategies such as intercropping can enhance energy conversion efficiency. Improving plant energy conversion efficiency (ε_c) is crucial for increasing food and bioenergy crop production and yields."	62%
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,	Multiple crops	Global	45	Crop mixture cropping	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	88%

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AR 2011							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 monoculture crop.	
Kiaer, LP; Skovgaard, IM; Ostergard, H 2009	Wheat and barley	Global	26	Cultivar mixtures	Pure stand	Grain yield difference	The results obtained through meta-analysis confirm the potential of cereal variety mixtures as a mean of obtaining higher grain yields, on average, compared to growing the crop in pure stand.	88%

3. KNOWLEDGE GAPS

Daryanto et al., 2020	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.
Li et al., 2020	Further work is needed to elucidate the role of different plant traits in the complementarity in maize/legume systems with temporal niche differentiation.
Xu et al., 2020	Further research is needed to identify optimal combinations of planting configuration, sowing dates and fertilizer to achieve high yields and high Nitrogen use efficiency in intercropping, and exploit biological Nitrogen fixation without driving the system to very resource poor low yielding conditions.
Borg et al., 2018	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.
Reiss and Drinkwater, 2018	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.
Thapa et al., 2018	Future studies evaluating cover crop mixtures over monocultures should consider 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.

Himmelstein et al., 2017	There is a need for additional studies across a range of environments and situations in order to describe more quantitatively the relationships between intercropping outcomes and moderating factors (e.g., soil type, temperature, season, crop combinations, and others) in Africa.
Yu et al., 2016	Further analyses are necessary to 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.
Iverson et al., 2014	There is the need for a greater investment in researching the underlying relationships between multiple agroecosystem services so we can better achieve agroecosystem multifunctionality.
Slattery et al., 2013	Further experimentation could determine beneficial relationships in mixed stands containing plants of varying heights and shade tolerances to maximize Energy conversion efficiency (ε_c) 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 ε_c in field conditions for reliable results.
Letourneau et al., 2011	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.
Kiaer et al., 2009	Further work should try to separate the effects of the potential mechanisms and interactions acting in variety mixtures; more information on the growing conditions of varieties and mixtures should be collected and reported from original field trials; retrievable measures of trial variation should be reported to a larger extent in order to facilitate more substantial overall (meta-)analyses of mixing effects.