SINGLE-IMPACT FICHE
COVER AND CATCH CROPS

IMPACT: NUTRIENT LEACHING AND RUN-OFF

Data extracted in January 2022
Fiche created in February 2024

Note to the reader: This fiche summarises the effects of Cover and catch crops on NUTRIENT LEACHING AND RUN-OFF. It is based on 10 synthesis papers[1], including from 4 to 269 primary studies.

1. WEIGHT OF THE EVIDENCE

CONSISTENCY OF THE IMPACT

The effect of cover/catch crops, as compared to bare soil, on NUTRIENT LEACHING AND RUNOFF is reported in **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.

- The effect of cover/catch crops, as compared to bare soil, on NUTRIENT LEACHING AND RUNOFF is generally positive, with 6 results out of 8 indicating a significant decrease in nutrient leaching and runoff (mainly nitrogen leaching to groundwater).
- The positive effect is particularly evident for non-legume cover crops, with a consensus of 7 results reporting a significant decrease in nitrogen loss.
- On the other hand, the effect is generally neutral for leguminous cover crops, with 5 out of 7 results reporting non-significant change in nitrogen leaching and runoff.
- For cover crops (and natural vegetation cover) applied to orchards/tree plantations, the effect was positive (decrease in nitrogen leaching and runoff), either for legume or non-legume cover crops.
- Phosphorous loss resulted in positive effect for cover crops, either leguminous or non-leguminous).

Out of the 10 selected synthesis papers, 7 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	
Decrease nutrient leaching and run-off	N loss	Cover crops	Bare soil	6	0	2	0
		Legume cover crops	Bare soil	2	0	5	0
		Non-legume cover crops	Bare soil	7	0	0	0
Decrease nutrient leaching and run-off	P loss	Cover crops	Bare soil	1	0	0	0
		Legume cover crops	Bare soil	1	0	0	0
		Non-legume cover crops	Bare soil	1	0	0	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

[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.

The main characteristics and results of the 10 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 nutrient leaching and run-off. The references are ordered chronologically with the most recent publication date first.

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Ref3	Tree crops (orchards)	Global	85	1) Cover crops; 2) Legume cover crops; 3) Non-legume cover crops	Clean tillage management	1) Total nitrogen loss reduction; 2) Nitrate nitrogen loss reduction; 3) Ammonium nitrogen loss reduction; 4) Total phosphorus loss reduction; 5) Dissolved phosphorus loss reduction;	Cover cropping (either legumes or non-legumes) showed significant efficiency in reducing nutrient (Total nitrogen, inorganic nitrogen, total phosphorous and dissolved phosphorous) losses from tree-crops fields.	81%
Ref8	solar greenhouse and open-field vegetable production systems in China. The distribution of the selected articles was as follows: greenhouse vegetables 14 (58.3%) and open-field vegetables 14 (41.7%)	China	4	Catch crops	no catch crops	Total nitrate leaching	The use of catch crops significantly reduced nitrate leaching by 35% (n=4).	69%
Ref10	Data from North America, Europe, Africa, and Asia, specifically eastern China; Cash crop type: corn, soybean, wheat, vegetable, corn-soybean rotation, corn-soybean-wheat rotation, and other	Global	269	Cover and catch crops (legume, grass, multi-species mixture, and other)	No cover/catch crop	Nutrient (N,P,K, …) leaching/runoff	Cover crops significantly decreased nutrients surface-runoff and leaching.	62%
Ref24	Arable crops in Mediterranean area	Global (Mediterranean climate). The authors analysed data from 57 publications that included data from 326 experiments and 1062 comparisons (Table 2): 26 publications from a wider review of Mediterranean farming practices (Shackelford et al., 2017) and 31 publications from our new searches (see File S3 for a list of included publications and a modified PRISMA flow diagram). The data came from approximately 50 species or mixtures of cover crops, 12 food crops, and 5 countries: Italy (24 publications), the United States of America (20 publications), Spain (9 publications), France (2 publications), and Greece (2 publications).	57	Winter cover crops (legumes, non legumes, mixtures).	Bare soil	Soil nitrate leaching	Soil nitrate leaching was 53% lower (R = 0.47) in plots with non-legume cover crops, compared to plots without cover crops, but soil nitrate leaching were not significantly different between plots with legume cover crops and plots without cover crops.	88%
Ref28	Arable fields with cereal crops	US and EU	28	Cover crop (nonleguminous, leguminous, and nonlegume–legume cover crop mixtures). Nonleguminous cover crops included both grasses and broadleaves.	No cover crops	Soil nitrate leaching	There is a clear indication that nonleguminous cover crops can substantially reduce NO_3^- leaching into freshwater systems, on average by 56%. Legumes alone or in combination with nonlegumes had no significant effect on NO_3^- leaching.	88%
Ref36	Arable fields	Global. Not specified.	17	Winter weedy fallow; Cover crops (legumes, non-legumes)	Bare fallows; weedy fallow	Leachate nitrogen and inorganic soil nitrogen are undoubtedly different measures of potential nitrogen loss. The former estimates nitrogen concentrations in soil water beneath or near the bottom of the crop rooting zone via lysimeter, while the latter typically estimates inorganic nitrogen in bulk soil within the crop rooting zone via soil sampling and chemical extraction. Because elevated concentrations of inorganic soil nitrogen in the rooting zone precludes nitrogen leaching deeper in the profile, we elected to use the former as a proxy for future leaching potential given the lack of leachate data available within this literature search (7 of 17 studies eligible for data extraction).	Results of this meta-analysis suggest that weeds are effective nitrogen scavengers during fallow periods, but not as effective as nonlegume cover crops.	69%

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Ref37	Spring cereals	EU Nordic countries. Denmark, Sweden, Finland and Norway	35	Winter catch crops undersown to spring cereal. The catch crops were four non-legume species (Italian ryegrass (Lolium multiflorum Lam.), perennial ryegrass (Lolium perenne L.), Westerwolds ryegrass (L. multiflorum Lam. var westerwoldicum) and rapeseed (Brassica napus L.)) and two legume species (white clover (Trifolium repens L.) and red clover (Trifolium pratense L.)).	Bare fallows	Nitrate and ammmonium leaching	Non-legumes, mainly ryegrasses, reduced N leaching loss by 50%. Legumes did not diminish the risk for N leaching. In spring cereal production, non-legume catch crops represent a universal and effective method for reducing N leaching across the varieties of soils and weather conditions in the Nordic countries.	81%
Ref38	Arable crops	Global (including EU)	26	Cover crops (legume/non-legume; incorporated/surface)	Bare soil with the same treatments than in the intervention	Soil nitrate leaching	NO_3 loss with a cover crop was significantly lower than with bare soil.	81%
Ref39	Irrigated agricultural cropping system	Global. Irrigated land is present in many regions of the world, and the scientific literature selected represented a global data-set. The geographical distribution of the selected articles was as follows: North America (44%), Europe (38%), Asia (14%) and South America (4%). Most data came from the European Mediterranean basin (35%) and from the Midwest of the United States (30%).	44	Replacing winter fallow by a non-legume CC (39 experiments); Replacing winter fallow by a legume CC (20 experiments)	No cover crops	Soil nitrate leaching	The (statistically significant) effect of Use of cover crops on nitrate leaching was of -35%.	69%
Ref40	Arable crops	USA and Brazil	35	Fertilization using cover crops as green manure (with distinction between legume and non-legume)	Bare soil with mineral-N fertilization	Soil nitrogen leaching	The potential for reduced N leaching from green manure fertilized systems due to greater retention of organic N is supported by short-term isotopic experiments, long-term systems comparisons, and this meta-analysis.	50%

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	
Decrease nutrient leaching and run-off	N loss	Cover crops	Bare soil	Ref3, Ref8, Ref10, Ref36, Ref38 and Ref39		Ref24 and Ref28	
		Legume cover crops	Bare soil	Ref3 and Ref40		Ref24, Ref28, Ref36, Ref37 and Ref39	
		Non-legume cover crops	Bare soil	Ref3, Ref24, Ref28, Ref36, Ref37, Ref39 and Ref40			
Decrease nutrient leaching and run-off	P loss	Cover crops	Bare soil	Ref3			
		Legume cover crops	Bare soil	Ref3			
		Non-legume cover crops	Bare soil	Ref3			

3. FACTORS INFLUENCING THE EFFECTS ON NUTRIENT LEACHING AND RUN-OFF

Table 4: List of factors reported to significantly affect the size and/or direction of the effects on nutrient leaching and run-off, according to the synthesis papers reviewed.

Factor	Reference number
Cover crop biomass production	Ref28
Cover crop species	Ref28
Mean annual precipitation	Ref3 and Ref28
Mean annual temperature	Ref3
N cover crop input to soil	Ref40
No factor reported	Ref38
Planting dates	Ref28

Factor	Reference number
Slope gradient	Ref3
Soil texture	Ref28

4. KNOWLEDGE GAPS

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

Ref Num	Gap
Ref8	First, most of the data included in our meta-analysis were from temperate zones; data from tropical and cold zones were under-represented. Second, the nitrate leaching data were obtained over the entire growing season, while fallow season nitrate leaching was neglected. Third, nitrate leaching was greatly affected by the type of vegetable crop and tillage practices. However, the effects of vegetable type and tillage practice on the efficacy of strategies to control nitrate leaching are not well documented due to a lack of data.
Ref24	The results for soil nitrogen content could also be sensitive to publication bias, since the fail-safe number was relatively low (File S2). Thus, the results for soil nitrogen content should be seen as inconclusive, and so should the results for soil nitrate leaching (plots with cover crops had significantly less nitrate leaching than plots without cover crops in 50% of the sensitivity analyses.
Ref40	Further mechanistic research is necessary to follow the fate of N in alternative systems, and to develop viable, regional, optimal management strategies.

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
Ref3	Liu, R; Thomas, B; Shi, XJ; Zhang, XL; Wang, ZC; Zhang, YT	2021	Effects of ground cover management on improving water and soil conservation in tree crop systems: A meta-analysis	CATENA 199, 105085	10.1016/j.catena.2020.105085
Ref8	Bai, XL; Zhang, ZB; Cui, JJ; Liu, ZJ; Chen, ZJ; Zhou, JB	2020	Strategies to mitigate nitrate leaching in vegetable production in China: a meta-analysis	Environmental Science and Pollution Research 27, 18382–18391	10.1007/s11356-020-08322-1
Ref10	Jian, Jinshi; Lester, Brandon J.; Du, Xuan; Reiter, Mark S.; Stewart, Ryan D.	2020	A calculator to quantify cover crop effects on soil health and productivity	Soil and Tillage Research 199, 104575	10.1016/j.still.2020.104575
Ref24	Shackelford, GE; Kelsey, R; Dicks, LV	2019	Effects of cover crops on multiple ecosystem services: Ten meta-analyses of data from arable farmland in California and the Mediterranean	LAND USE POLICY, 88, 104204.	10.1016/j.landusepol.2019.104204
Ref28	Thapa R, Mirsky SB, Tully KL	2018	Cover Crops Reduce Nitrate Leaching in Agroecosystems:A Global Meta-Analysis	Journal of Environmental Quality 47, 6, 1400-1411	10.2134/jeq2018.03.0107
Ref36	Wortman, Sam E.	2016	Weedy fallow as an alternative strategy for reducing nitrogen loss from annual cropping systems	Agronomy for Sustainable Development 61	10.1007/s13593-016-0397-3
Ref37	Valkama E, Lemola R, Känkänen H, Turtola E	2015	Meta-analysis of the effects of undersown catch crops on nitrogen leaching loss and grain yields in the Nordic countries	Agriculture, Ecosystems & Environment 203, 93-101	10.1016/j.agee.2015.01.023
Ref38	Basche, AD; Miguez, FE; Kaspar, TC; Castellano, MJ;	2014	Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis	JOURNAL OF SOIL AND WATER CONSERVATION, 69, 471-482.	10.2489/jswc.69.6.471
Ref39	Quemada, M.; Baranski, M.; Nobel-de Lange, M. N. J.; Vallejo, A.; Cooper, J. M.	2013	Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	10.1016/j.agee.2013.04.018
Ref40	Tonitto, C; David, MB; Drinkwater, LE	2006	Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics	AGRICULTURE ECOSYSTEMS & ENVIRONMENT, 112, 58–72.	10.1016/j.agee.2005.07.003