Agricultural Beneficial Management Practices: A Synthesis of Co-benefits, Tradeoffs, and Co-costs between Crop Yield and Non-provisioning Ecosystem Services

Andrew N. Kadykalo[a*], **Kris A. Johnson**[b], **Scott McFatridge**[c], **C. Scott Findlay**[a,d,e]

[a]Institute of the Environment, University of Ottawa, 1 Stewart St, Ottawa, ON, K1N 7M9
[b]The Nature Conservancy - North America Agriculture Program, 1101 West River Parkway, Suite 200 Minneapolis, MN, 55415
[c]Smart Prosperity Institute, Institute of Environment, University of Ottawa,1 Stewart St (3rd Floor), Ottawa, ON, K1N 6N5
[d]Department of Biology, Marie-Curie Private, Ottawa, ON, K1N 9A7
[e]Institute for Science, Society and Policy, 120 University Private Social Sciences Building 15th Floor Ottawa, ON, K1N 6N5

*Corresponding author: andriy.kadykalo@gmail.com

Abstract

Although agricultural “best (or beneficial) management practices” (BMPs) first emerged to mitigate agro-environmental resource challenges, they may also enhance ‘non-provisioning’ ecosystem services. The enthusiasm for adopting BMPs partially depends on evidence that doing so will lead to agro-environmental benefits while not substantially reducing crop productivity or farmer income. We survey and synthesize evidence in the existing literature to document the joint effects on agricultural crop yield and 12 ecosystem service (ES) associated with implementation of 5 agricultural BMPs (crop rotations, cover crops, nutrient management, perennial vegetated buffers, reduced or no tillage). We also analyze the prevalence of co-benefits (‘win-win’), tradeoffs, and co-costs (‘lose-lose’) outcomes. On the basis of a set of contextual variables we then develop empirical models that predict the likelihood of co-benefits relative to tradeoffs, and co-costs. We found thirty-six studies investigating 141 combinations of crop yields and non-provisioning ES outcomes (YESs) in the relevant literatures covering the period 1983-2016. The scope of the review is global, but included studies are geographically concentrated in the U.S. Corn Belt (Midwestern United States). In the literature sample, reporting of co-benefits (26%) was much more prevalent than reporting of co-costs (4%) between yields and ES. Tradeoffs most often resulted in a reduction in crop yields and an increase in ES (28%); this was marginally greater than studies reporting a neutral influence on crop yields and an increase in ES (26%). Other Y/ES combinations were uncommon. Mixed-effects models indicated reduced tillage and crop rotations had generally positive associations with YESs. Temporal scale was an informative predictor suggesting studies with longer time scales resulted in greater positive outcomes on YESs, on average. Our results are a step towards identifying those contexts where co-benefits or partial improvement outcomes of BMPs are more likely to be realized, as well as the impact of particular practices on specific ES.

Keywords: conservation agriculture, diversified farming, best management practices, beneficial management practices, sustainable agriculture, cropping systems, agroecology, meta-analysis, nature’s contributions to people, NCP, land sparing, land sharing

1. Introduction

Agricultural “best (or alternative or beneficial) management practices” (BMP or BMPs) (also commonly referred to as “diversified farming” practices or in combinations, “conservation agriculture”) have emerged to mitigate soil loss, deteriorating water quality, and other agro-environmental resource challenges. Most BMPs have been designed with the objective of reducing nutrient, chemical and/or soil losses (Logan et al. 1991), whereas less attention has been paid to the impact of these practices on regulating and supporting ecosystem services (i.e. regulating ‘nature’s contributions to people’ - Díaz et al. (2018) such as climate regulation and carbon sequestration, soil fertility, habitat provisioning). The value of these ‘non-provisioning’ (and often ‘non-marketed’) ecosystem services to agriculture is potentially enormous and often underappreciated (Power 2010; Bommarco et al. 2013; Shackelford et al. 2019b). Core BMP practices such as soil tillage, crop residue management, nutrient management and pest management (Stavi et al. 2016) are intended to conserve a farm’s agro-environmental resources (water, soil, nutrients) without sacrificing agricultural productivity.

While the evidence base on benefits of BMPs across different agroecosystems is fragmented (Palm et al. 2014; Duru et al. 2015; Rosa-Schleich et al. 2019), there is some evidence that the adoption of one or more BMPs does indeed enhance other on-farm ecosystem services besides food production, relative to conventional farming practices (see, for example, Kremen and Miles 2012; Daryanto et al. 2018; Shackelford et al. 2019a; Tamburini et al. 2020). On the other hand, there is also some evidence that certain BMP(s) do not enhance ecosystem service delivery (e.g. Palm et al. 2014; Stavi et al. 2016; Garbach et al. 2017), and in rare cases may even reduce certain ecosystem service levels relative to conventional agricultural systems.

These debates notwithstanding, two important questions remain concerning the contribution of BMPs to broader sustainable development objectives (i.e. United Nations Sustainable Development Goals: 2. Zero Hunger, 12. Responsible Consumption and Production, 13. Climate Action, 14. Life with Water, among others). The first question concerns the *scalability* of BMPs and their ability to secure regulating and supporting ecosystem services when moving beyond the scale of the farm (e.g. to regional or global scales). BMPs enhance on-farm ecosystem services through measures such as reducing input use, residue retention, and establishing vegetative buffers – many of which have the potential to reduce agricultural yields. If a sufficiently large number of producers adopt these BMPs, this could lead to a substantial reduction in yields. All other things being equal, this tends to increase prices, which encourages non-adopters to increase their production – potentially by expanding the area under cultivation, or by increasing input use (Seufert et al. 2012; Simpson 2014). Under such a scenario, it is not clear that BMPs are enhancing aggregate ecosystem services at broader spatial scales (Gockowski et al. 2013; Simpson 2014; Luskin et al. 2018). The issue becomes even more pressing in light of the long-term objective of safeguarding biodiversity and ecosystem services while meeting a two-fold increase in global crop demand (relative to 2005 levels, Tilman et al. 2011) arising from a population that is projected to surpass 9 billion people by 2050 (Godfray et al. 2010; United Nations 2015). Meeting this challenge will require some combination of increasing agricultural intensification, expanding the area under cultivation, dietary substitution (e.g. from grain-fed to grass-fed beef, or from animal protein to vegetable protein), or reducing food loss and food waste (Foley 2011; Foley et al. 2011; Seufert et al. 2012; Gaba et al. 2014; Firbank et al. 2018).

The second question concerns the implications of BMPs for agricultural yields and on-farm incomes. BMP adoption by farmers remains limited (Singer et al. 2007; Muñoz et al. 2014; Rosa-Schleich et al. 2019). One potential explanation is that implementing BMPs is perceived to reduce agricultural yields or profits to unacceptable levels. Although there is some evidence that farmers care about on-farm environmental benefits (Ridley 2004; Greiner et al. 2009; Smith and Sullivan 2014), most farmers are either concerned with maximizing their expected profits (while allowing for slight deviations to reduce risk) (Gedikoglu et al. 2010; Pannell 2017)[1] and/or their agricultural yields (Pedersen et al. 2012). Hence, if BMPs do indeed reduce yield (or are perceived to do so), this will discourage adoption for many farmers. On the other hand, if some BMPs, in certain contexts, either do not significantly affect agricultural yields – or perhaps even increase them (see, for example, Pretty et al. 2006; Ponisio et al. 2015; Rosa-Schleich et al. 2019; Tamburini et al. 2020), this may render BMPs more attractive compared to conventional farming practices.

Here we review the literature to document the prevalence of agricultural crop yield and regulating/supporting ecosystem service co-benefits, partial improvements, tradeoffs, and co-costs associated with agricultural BMP implementation. On the basis of a set of contextual variables and information, we then develop empirical models that predict the likelihood of co-benefits relative to partial improvements, tradeoffs, and co-costs. Our analysis contributes to the debates on the optimal strategy for securing ecosystem services at broader spatial scales (‘land sparing’ versus ‘land sharing’ strategies), as well as the literature on the social acceptability of

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[1] The relationship between yield and farmers’ profits is not straightforward and depends on a number of factors including the shape of the agricultural “production function” (relationship between input applications and expected crop yield), as well as crop prices, input costs, and labor costs Pannell D.J. (2017) Economic perspectives on nitrogen in farming systems: managing trade-offs between production, risk and the environment. *Soil Research* **55**, 473-378.. However, in cases where depressed yields also lead to a reduction in farmers’ profits, profit-maximizing farmers will also be reluctant to adopt these BMPs.

BMPs due to their risk of lower yields (whether real or perceived). Integrating knowledge of ecosystem service values other than food production associated with BMP implementation can help address these questions, thereby increasing the potential for 'win-win' synergistic scenarios (Dale and Polasky 2007; Power 2010; Seufert et al. 2012; Garbach et al. 2017; Rosa-Schleich et al. 2019) between agricultural yield productivity, profitability, and ecosystem services delivery (i.e. reduced production costs, reduced environmental impacts, increased crop productivity and improved agro-environmental resources), and for making informed tradeoffs among different objectives (e.g. farmer income, yield, and regulating/supporting ecosystem services).

2. Methods

Using an institutional repository of 454 published studies examining the impact of agricultural BMPs on i) provisioning (i.e. crop yield: gains in physical yield (biomass) obtained in the short-term) or ii) regulating and supporting ecosystem services (i.e. 'non-provisioning' ecosystem services, hereafter simply "ecosystem services") developed and organized by *The Nature Conservancy's* North America Agriculture Program (https://www.nature.org, hereafter "TNC"). See Appendix A for the literature search strategy and resources used in developing the TNC repository. We explore patterns of association between candidate predictor variables and the likelihood of co-benefits between crop yield and ecosystem services after BMP(s) adoption relative to tradeoffs, partial improvements, and co-costs. Due to resource and time restrictions we performed a rapid meta-analytic quantitative review, not a true systematic and comprehensive meta-analysis of weighted statistical effect sizes and variability.

2.1 *Study Inclusion Criteria*

Since the majority of studies within TNC repository do not investigate joint outcomes of BMPs on both yield *and* ecosystem services we screened studies for eligibility based on a set of inclusion criteria. To be included in the analysis, studies must include (i) explicit statements (or some estimate of the effect) of implementing an agricultural BMP (or combination of BMPs) (Table 1) on at least: (a) one measure of crop productivity (i.e. food production, excluding livestock and harvested animal production) *and* (b) at least one measure associated with the delivery of one of 12 ecosystem services (Table 2) found in the TNC repository which formed the basis of our outcome variable, **YESs**: the joint effects on crop yield (Y) and ecosystem services (ES) (see Table 3), and (c) at least one factor (candidate predictor variable) for which estimates were available for a sufficient number (sample size) of **YESs** so as to have some confidence in fitted empirical models (Table 4); (ii) were published in a peer-reviewed scientific journal or a government/institutional report (i.e. relevant grey literature was eligible for inclusion); and (iii) reported results from crop agroecosystems where agriculture was the prevalent land use, with a particular emphasis on temperate climate zones.

Table 1. BMP typology based on BMP(s) implemented in in original texts of sources retrieved from literature sources which met study inclusion criteria.

Best Management Practice(s) Category	**Best Management Practice(s) Code**	**Best Management Practice(s)**
Edge of Field (*Off-farm*)	VB	Perennial Vegetated Buffers (Buffer and Filter Strips/Hedgerows/Riparian Buffers)
In-Field (*On-farm*)	CC	Cover Crops
	CR	Crop Rotations
	NM	Nutrient Management
	TI	Reduced (or no) Tillage

Table 2. Ecosystem services typology based on ecosystem service outcomes estimated or measured in original texts of the TNC repository.

Ecosystem Service Category	**Ecosystem Service**
Cultural	Cultural Services – e.g. fishing, boating/floating, swimming (CS)
Provisioning	Food Production (**reference tradeoff outcome**) (FP)
Regulating	Air Quality Regulation (AR)
	Climate Regulation and Carbon Sequestration (CR)
	Erosion Regulation (ER)
	Water Purification and Waste Treatment (WPWT)
	Water Regulation and Soil Moisture Retention (WRSR)
	Pest Regulation (PR)
Supporting	Biodiversity Conservation (BIO)
	Biomass Production/Primary Productivity (BPPP)
	Habitat Provisioning (HA)
	Nutrient Cycling and Supply (NC)
	Soil Formation (SF)

2.2 *Record Screening and Selection of Included Studies*

Records in the TNC repository were screened in two distinct stages: (i) title and abstract and (ii) full text. We identified 439 unique records (after the removal of duplicates) for screening of titles and abstracts (Fig. 1). After the screening of titles and abstracts, we excluded 402 records based on failure to satisfy one or more inclusion criteria. Specifically, these records were excluded for lacking (a) a BMP intervention, or a (b) measure (i.e. explicit statement or estimate of effect) for both crop yield, ecosystem services, or both. Many reviews were excluded based on the latter criteria. Thus, 37 records were selected for full-text review. Only one record (Kremen and Miles 2012) was removed after assessment at full-text for failing to report independent and direct (i.e. co-occurring) joint effects on crop yield (Y) and ecosystem services (ES) (after BMP implementation). A list of the 36 eligible (included) records which serve as data sources in this quantitative review is presented in Appendix D.

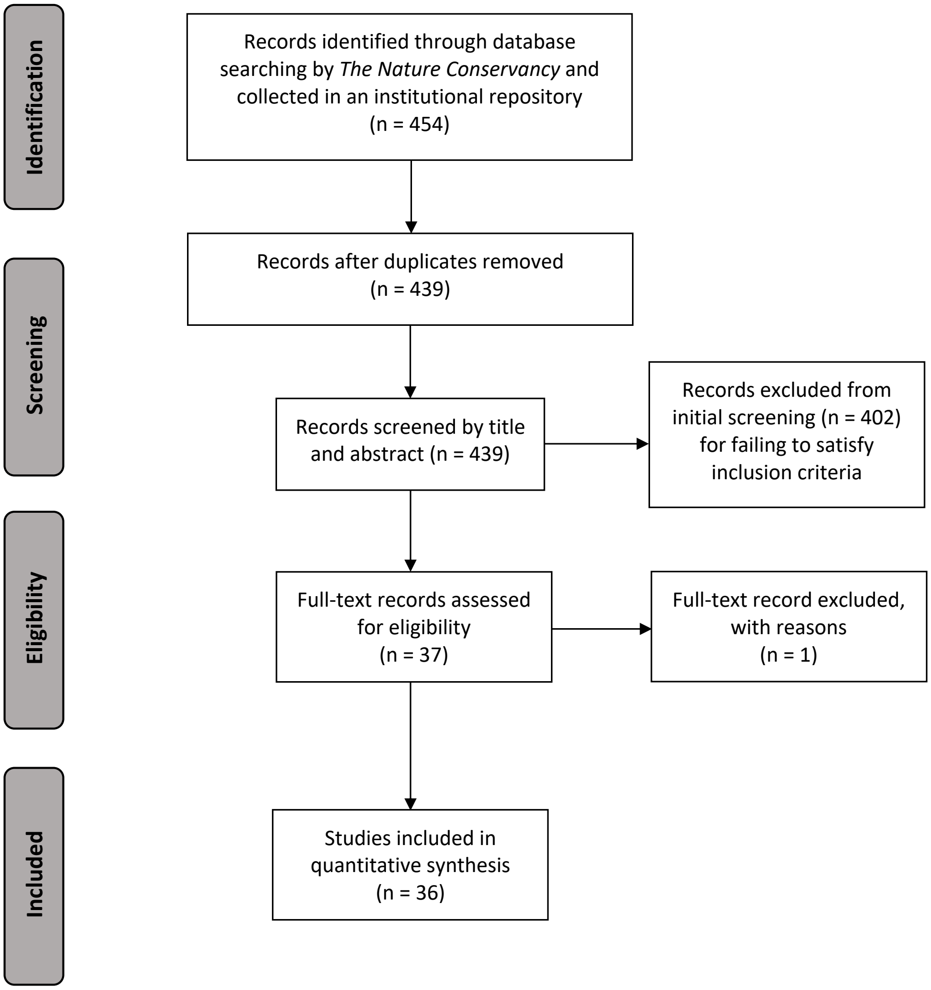

Figure 1. Flow diagram of the record selection process in which records were screened for eligibility and included or excluded based on defined eligibility criteria.

2.3 *Data Extraction*

From each included record, two different types of information were extracted and inputted into an electronic database: YESs – our outcome variable, and candidate moderating factors – explanatory variables explored in empirical models that predict the likelihood of co-benefits relative to partial improvements, tradeoffs, and co-costs.

2.3.1 YESs

In our analysis, the outcomes of interest were **YESs**, the joint effects on crop yield (Y) and ecosystem services (ES) from studies that reported outcomes on both Y and ES, with **YES** values ranging from negative effects on both (-/-) (i.e. diminishment of both) to positive effects on both (+/+) (i.e. enhancement of both). We characterized this relationship in several ways. The first was based on explicit qualitative statements about the impact of BMP implementation on Y and ES (summaries/conclusions) appearing in the original text, (e.g. Y: "Long-term average corn yields were greater under ridge-tillage compared with conventional tillage"; ES: "Sediment loss was lower under ridge-tillage compared with conventional tillage"). A second was based on explicit statements in the original text that provided quantitative estimates of the impact of BMP implementation on Y and ES (e.g. Y: "Max. Hedgerows reduce yield by 8% in reference to Tomatoes only"; ES: Max. "Hedgerows increase carbon storage by 3% in reference to Tomatoes only"). Each combination of effect on Y and ES (referred to as a **YES**) was treated as an observation in the analysis. Consequently, studies investigating the effect of multiple different BMPs and/or the effect on multiple different crops or ES produced multiple observations per study. For example, a study that examined the effect of implementing a BMP (e.g. reduced tillage) on the production of two different crops (e.g. corn, soybean) and on two different ES (e.g. climate regulation, water regulation and soil moisture retention) would contribute four observations to the analysis.

YESs were classified into nine possible outcome groups according to whether the textual account of the effects indicated that Y and ES were negatively or positively affected, or if there was a neutral or non-existent effect on Y or on an ES (Table 3).

Table 3. YESs based on explicit statements or quantitative results between agricultural crop yield (Y) and ecosystem services (ES).

YES Category	YES Definition	Co-occurrence Outcome
-/-	Y reduced; ES reduced (co-costs)	lose-lose
-/•	Y reduced; No apparent effect on ES (Y tradeoff)	lose-neutral
-/+	Y reduced; ES increased (Y tradeoff)	lose-win
•/-	No apparent effect on Y; ES reduced (ES tradeoff)	neutral-lose
•/•	No apparent effect on Y; No apparent effect on ES	neutral-neutral

•/+	No apparent effect on Y; ES increases (partial improvement/no-regrets)	neutral-win
+/-	Y increased; ES reduced (ES tradeoff)	win-lose
+/•	Y increased; No apparent effect on ES (partial improvement/no-regrets)	win-neutral
+/+	Y increased; ES increased (co-benefits)	win-win

2.3.2 *Candidate Moderating Factors*

We also sought to explain variability among studies in estimated **YESs** by identifying a set of candidate predictor variables for which information was available for most of the studies in our sample. Candidate predictor variables (Table 4, see Appendix B for meta-data) are those which: (a) characterize BMP(s) by type, location of implementation, and number deployed; (b) are study context variables, i.e. variables that might be expected to affect either crop yield or ecosystem service independently of, or in interaction with BMPs, such as temperature and precipitation; and (c) study design variables that might be expected to affect the strength of any inferences drawn by study authors on the causal effects of BMP implementation on crop yield and/or ecosystem services.

Table 4. Candidate **YES** predictor variables and associated levels.

Predictor variables	**Levels**
Study design variables	
Temporal Scale	Short (1); Medium (2); Long (3); Very Long (4)
Spatial Scale	Local (LO); Regional (REG); National (NAT); International (INT)
Study Type	Empirical (E); Empirical Modelled (EM)
Study Design	Correlative Design (CD); Control-Impact (CI)
Crop Endpoint	Multiple Crop Yields Measured/Estimated (0); Single Crop Yield Measured/Estimated (1)
Study context variables	
Precipitation	Average Annual Rainfall (mm)
Temperature	Average Annual Temperature (°C)
Corn	No (0)/Yes (1)
Soybean	No (0)/Yes (1)
Wheat	No (0)/Yes (1)
BMP characterization variables	
BMP Category	Edge of Field (*Off-farm*) (0); In-Field (*On-farm*) (1)
BMP Intervention	Single BMP (0); Multiple BMPs (1)
BMP	Cover Crops (CC); Crop Rotations (CR); Nutrient Management (NM); Reduced (or no) Tillage (TI); Perennial Vegetated Buffers (VB)
Ecosystem service characterization variables	
Ecosystem Service Category	Cultural, Provisioning, Regulating, Supporting

2.4 *Statistical Analysis*

For the set of studies that satisfied study selection criteria, linear regression models were used to model associations between **YESs (**Table 3) as the dependent variable and candidate predictor variables (Table 4) that serve as independent variables. Because **YESs** had some degree of order (e.g. in this context, co-costs are worse than co-benefits) multinomial (non-ordered) logistic regression was inappropriate. On the other hand, ordinal (ordered) logistic regression is also inappropriate as it would have required us to make subjective decisions on the ordering of **YES** categories (i.e. crop yield or ecosystem services tradeoffs – Table 3). Therefore, **YESs** were scored on an ordinal scale and the **YES** categories were stratified by five different 'agriculture weights' (w_A). These weights model the relative importance attached to crop yield versus ecosystem services in decisions about BMP implementation: the greater is w_A, the larger weighting for any positive outcome on crop yield after BMP adoption, independent of the effect on ecosystem service. By contrast, the smaller the w_A, the more heavily positive outcomes on ecosystem services are weighted. Co-benefits received a score of 1, co-costs a score of -1. **YES** categories were weighted by five different w_A values: 0.9, 0.75, 0.5, 0.25, 0.1, which resulted in stratified **YES** scores between [1] and [-1]. For example, a crop yield tradeoff (-/+) under a w_A of 0.25 would be scored as: $1 – (2 \times 0.25) = 0.5$, while an ecosystem services tradeoff (+/-) under a w_A of 0.25 would be scored as the inverse: $(2 \times -0.25)) – 1 = -0.5$. Thus, outcome combinations between crop yield and ecosystem services were parameterized to explore payoffs or costs related to outcome possibilities.

To address the potential bias associated with within-study correlations among **YESs**, we calculated the intra-class correlation (ICC) based on the within- and between-study variances in **YESs** for all studies with multiple **YESs** to check for a study effect. ICC values were moderate-high (Appendix C: Table C1, Fig. C1); when stratified by w_A, they ranged from 0.59 to 0.62 providing a strong rationale to explore the random-effects of 'study' in mixed-effects models. Mixed-effects models were fit using the "lmer" function from the "lme4" package in R (R Core Team 2018). The effect of study was treated as a random-effect and predictor variables were treated as fixed-effects. Fitted models were evaluated on the basis of second order-Akaike Information Criterion (AIC_c) and pseudo R^2 (Nakagawa and Schielzeth 2013). Since we were interested in comparing models with different fixed-effects via information-theoretic criteria (AIC_c) we estimated variance components using maximum-likelihood (ML), with final models fit using restricted maximum likelihood (REML). We restricted the number of fitted parameters (*p*) in any candidate model such that the sample size (*N*) to parameters (*N/p)* ratio was greater than 5, sufficient – at least in principle – to ensure reasonable model stability and/or sufficient precision of estimated coefficients (Vittinghoff et al. 2005). The **YES** co-costs (-/-) was always used as the reference outcome in all fitted models.

3. Results

3.1 *Overview*

One hundred and forty-one **YESs** were extracted from 36 studies (see Appendix D for a list of the eligible (included) articles and their extracted data; https://doi.org/10.5683/SP2/SNQWJV for the open source data in electronic (.csv) format; Appendix E for additional descriptive results) spanning four countries (Australia, Canada, Norway, and USA) and various geographical scales including international, national, regional (e.g. Upper Mississippi River Basin) and local (12 U.S. states, 1 Canadian province−Québec); but is dominated by studies within the Upper Mississippi River Basin of Midwestern United States. Annual average precipitation ranged from 325mm (Australia) to 1252mm (Illinois), average annual temperature from 4.4°C (Minnesota) to 18.6°C (Georgia).

The studies included in the analysis covered a rather comprehensive set of anemophilous (wind-pollinated) grain (cereal) and leguminous (with the exception of Cotton and Tomato) cash crops in North America. This analysis covers studies which have investigated BMP **YESs** in the following crops: Barley, Cotton, Oats, Sorghum, Tomato, Wheat, but most predominantly, Corn, which was a target crop in 71% of **YESs** and Soybean, which was a target crop in 57% of **YESs**.

In our sample, the prevalence of positive effects on ecosystem services exceeds that for crop yield (Fig. 2). Fully, 26% of **YESs** indicated BMP implementation resulted in co-benefits between yield and ecosystem services, and a further 26% indicated an increase in ecosystem services but no significant reduction in yield. A reduction in yield and increase in ecosystem services (28%) was slightly the most outcome and indeed the most common tradeoff. Co-costs were rare, representing only 4% of outcomes.

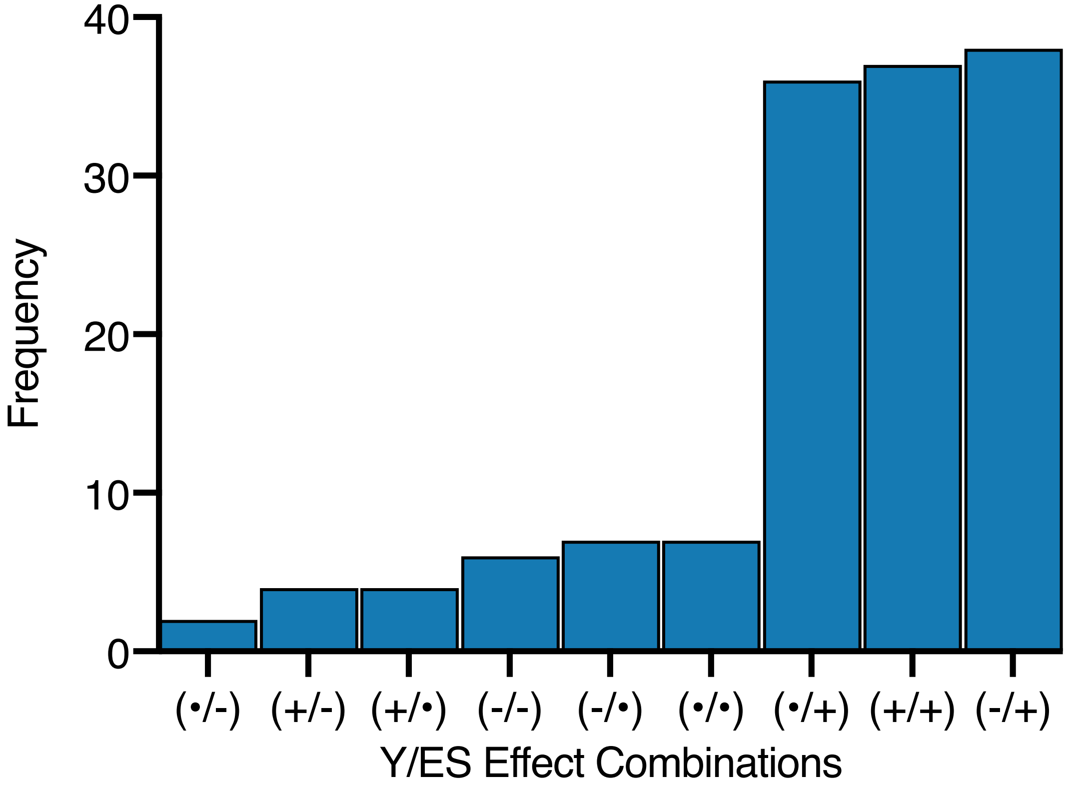

Figure 2. Histogram of **YES** counts across 9 possible Y/ES outcome combinations between yield and ecosystem services on whether yield or ecosystem services were reduced (-), increased (+), or unaffected (•) by BMP implementation.

Twelve ecosystem services were investigated in **YESs** with food production (i.e. crop yield) after BMP intervention (Fig. 3). Of these 12 ecosystem services, water purification and waste treatment – most often measured/estimated by nitrate (NO_3) leaching and phosphorus load reduction – was investigated most frequently (21%). Climate regulation and carbon sequestration (as measured/estimated by soil organic carbon and carbon dioxide equivalents) (14%), water regulation and soil moisture retention (as measured/estimated by drainage and soil moisture) (13%) as well as pest regulation (as measured/estimated by weed suppression, plant damage, number of pests, predator activity) (12%) were also frequent ecosystem services observed to be investigated in combination with crop yield after BMP adoption. Erosion regulation (6%) and supporting services associated with agro-environmental resources such as nutrient cycling (9%) and soil formation (8%) surprisingly received less attention. In our sample, BMP implementation resulted in relatively positive (+) effects on climate (CR = +19, •1) and erosion regulating (ER = +5, •3), and soil (SF = +10, -1) and biodiversity (BIO = +9, •2) supporting services; but had more varied effects on nutrient supporting (NC = +10, -2), pest regulating (PR = +11, •4, -2), and hydrological services (WPWT = +27, •2, -1; WRSR = +11, •5, -3).

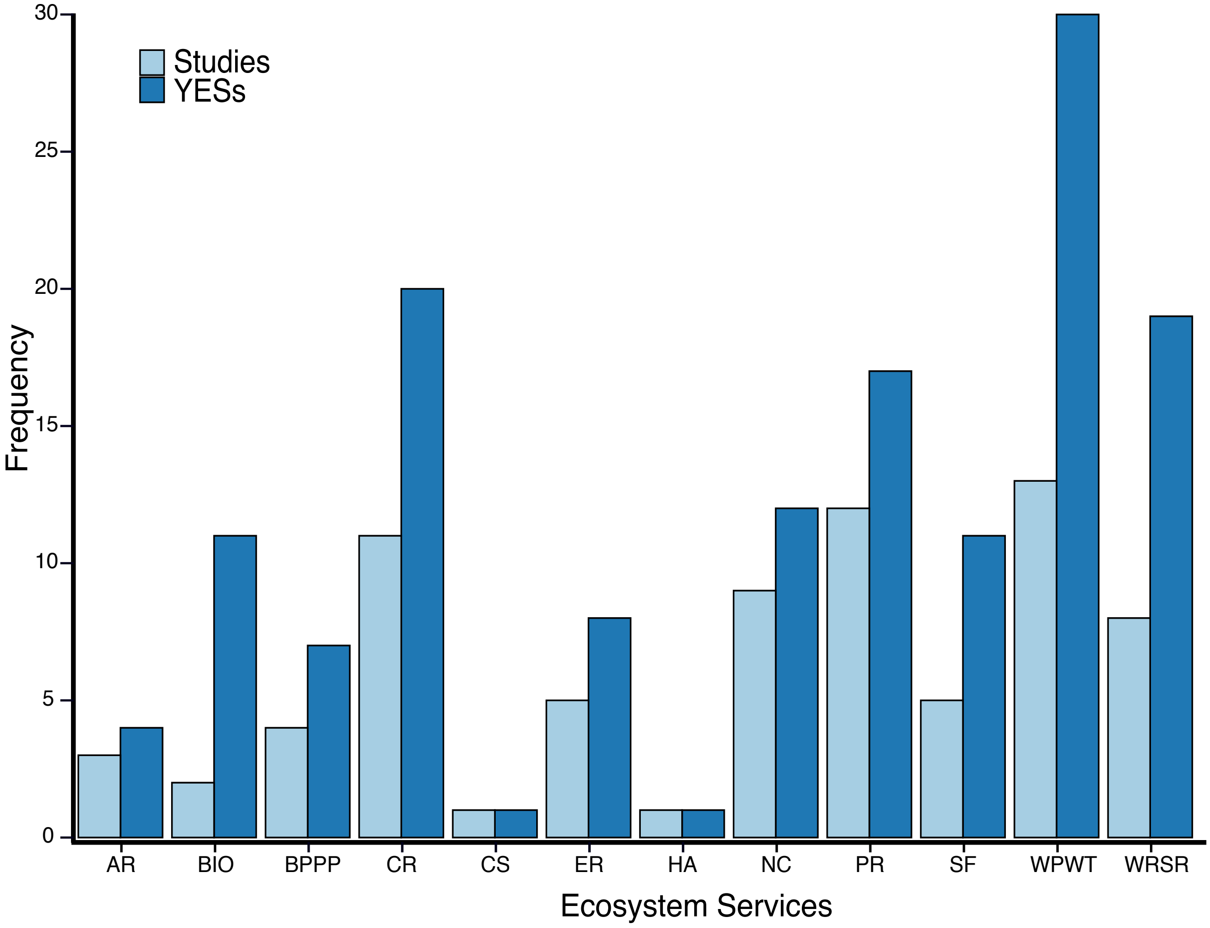

Figure 3. The relative attention dedicated to twelve ecosystem services (air quality regulation, biodiversity conservation, biomass production/primary productivity, climate regulation and carbon sequestration, cultural services, erosion regulation, habitat provisioning, nutrient cycling, pest regulation, soil formation, water purification and waste treatment, water regulation and soil moisture retention) in (*k* = 36) studies and (*n* = 141) **YESs**.

3.2 *Effects of moderators*

In order to improve model accuracy, mixed-effects models were performed on a reduced data set (*n* = 135, *k* = 34) which removed **YES** entries which had low sample sizes for BMP combinations (i.e. CR + NM = 2, NM + TI = 1, CC + CR + NM = 3). In mixed-effects models (which incorporated the random-effect of 'study') only 'cover crops', 'reduced tillage' and 'temporal scale' showed informative associations with **YESs**. For agriculture weights w_A 0.9, 0.75, 0.5, and 0.25 'cover crops' was an informative predictor, resulting, on average, in negative associations with **YESs** (Table 5). While the addition of the informative bivariate predictor 'reduced tillage' did not improve multivariate model fit, it and the other BMPs (for which we were not able to detect informative associations) demonstrated different associations with (i.e. effects on) **YESs**: 'reduced tillage' and 'crop rotations', generally positive, and 'nutrient management' and 'perennial vegetative buffers', generally negative (Fig. 4). In mixed-effects models the effect of BMPs (i.e. cover crops, reduced tillage) declines with decreasing w_A, while the effect of temporal scale increases (Fig. 5). Across agriculture weights w_A 0.75, 0.5, 0.25, and 0.1 temporal scale was an informative predictor, with studies with longer time scales resulting in higher **YES** scores (Fig. 6, Table 5). We did not detect an effect of crop type, climate, spatial scale, study type, or study design.

Table 5. The most informative mixed-effects models (*k* = 34, *n* = 135). CC = cover crops, log Lik = log likelihood, k = number of parameters.

Agriculture Weight (w_A) Data Set	Top Model and Model Coefficients	Marginal R^2	Conditional R^2	AIC_c	ΔAIC_c	k	log Lik
w_A 0.9	0.2438 – 0.6479CC + (1|Study Effect)	0.17	0.60	252.70	57.12	3	-112.27
w_A 0.75	-0.3527 – 0.5649CC + 0.2118Temporal Scale + (1|Study Effect)	0.17	0.59	211.87	58.52	4	-100.80
w_A 0.5	-0.3091 – 0.3693CC + 0.2366Temporal Scale + (1|Study Effect)	0.16	0.53	165.63	51.68	4	-77.68
w_A 0.25	-0.2845 – 0.1954CC + 0.2677Temporal Scale + (1|Study Effect)	0.14	0.43	179.14	33.01	4	-84.44
w_A 0.1	-0.2722 + 0.2783Temporal Scale + (1|Study Effect)	0.12	0.41	211.66	24.92	3	-101.75

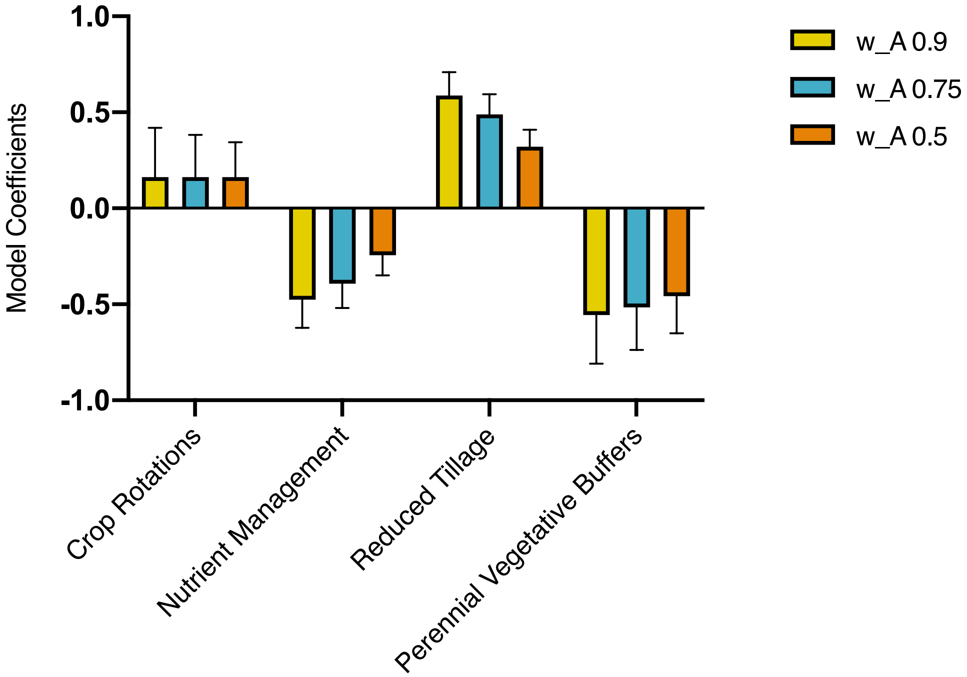

Figure 4. The effect of individual BMPs on **YESs** as estimated from model coefficients (+SE) in mixed-effects bivariate models (*k* = 34, *n* = 135) for agriculture weights w_A 0.9, 0.75, and 0.5 which were more strongly associated with BMPs.

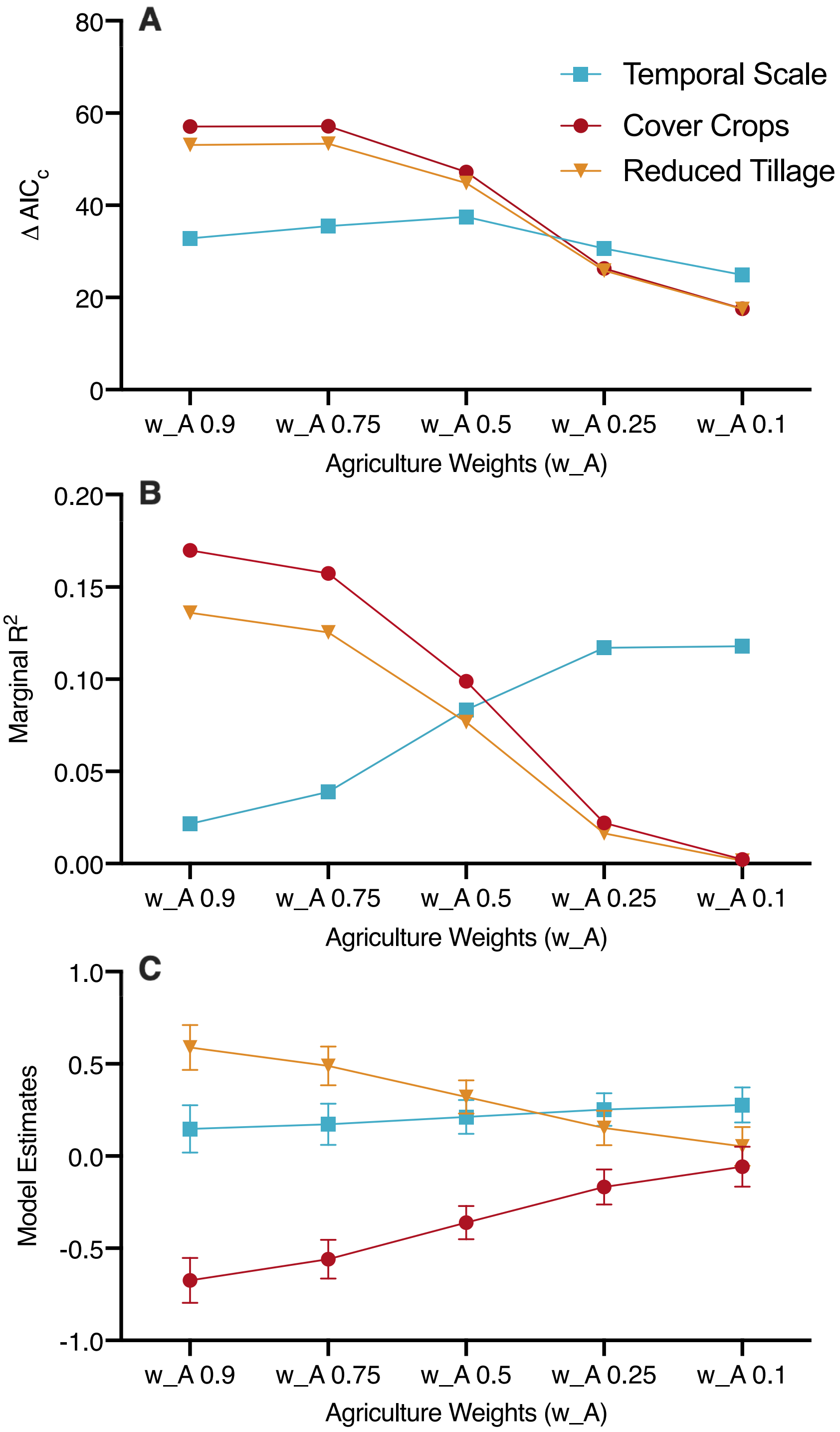

Figure 5. The results of mixed-effects bivariate models between **YESs** and temporal scale, cover crops, and reduced tillage as estimated by a) AIC$_c$, b) marginal pseudo R^2, and c) model coefficients (+/- SE) for each agricultural weight (w_A).

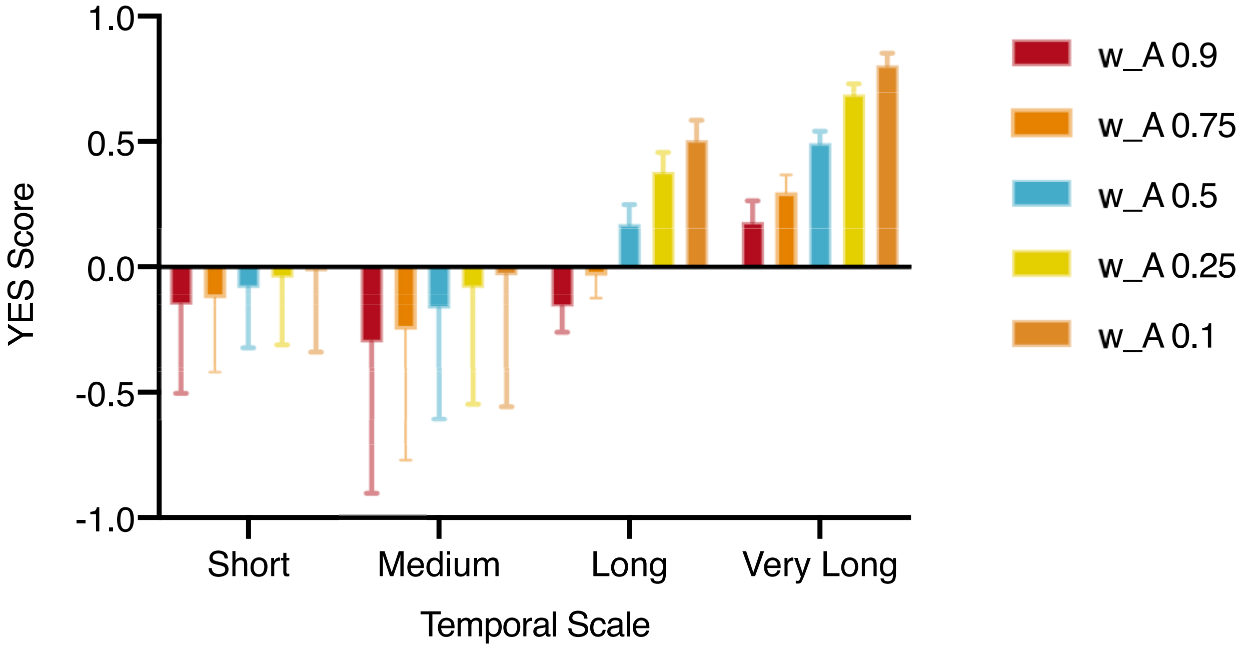

Figure 6. Average **YES** score (+SE) as a function of temporal scale for each agricultural weight (w_A) (*k* = 34, *n* = 135).

Because outcomes with positive effects on ecosystem services are more prevalent in the **YES** distribution (Fig. 1), average **YES** scores decline with increasing agricultural weight (Fig. 7), although mean **YES** score is still positive for any agricultural weight (w_A).

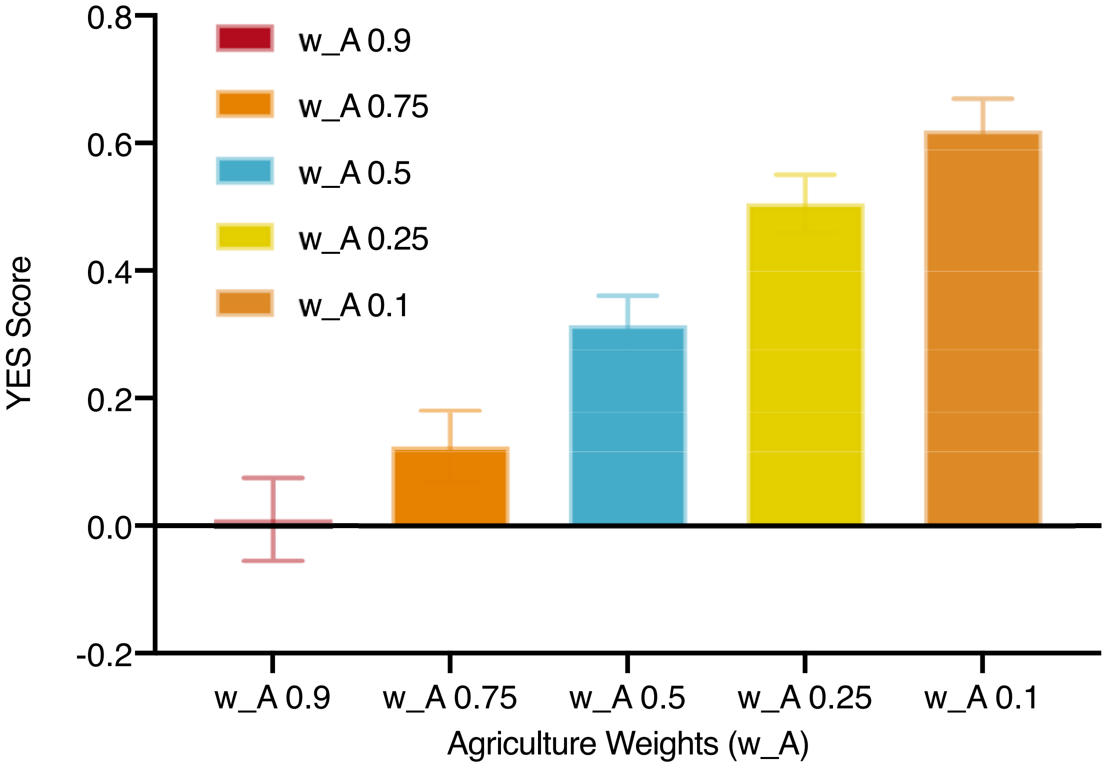

Figure 7. Average **YES** score (+/- SE) for each class of agricultural weight (w_A) (*k* = 34, *n* = 135).

4. Discussion

The TNC repository turned up (*k* = 36) studies to investigate (*n* = 141) **YES** outcomes between crop yield and ecosystem services. Our results provide evidence that the implementation of agricultural BMPs does indeed impact the prevalence of crop yield and ecosystem services co-benefits, partial improvements, tradeoffs, and co-costs. More often, a BMP intervention resulted in co-benefits and least often in co-costs between yield and ecosystem services. This provides evidence that – at least for the geographies and commodities captured in this review – "land sharing'' practices in the form of agricultural BMPs are scalable, since in many instances they are beneficial for (or at least not harmful to) both crop yield and ecosystem service delivery. This being said, the co-benefits are practice-specific, and the risk of tradeoffs persists, since on average, implementing a BMP more often resulted in a crop yield tradeoff compared to an ecosystem services tradeoff, a pattern which has been reported elsewhere (e.g. Pilgrim et al. 2010; Seufert et al. 2012; Schipanski et al. 2014; Reganold and Wachter 2016; Lee et al. 2019). However, given that BMPs are designed to reduce negative impacts of agriculture on ecosystem services, this is somewhat expected. This may nonetheless also serve as a possible deterrent for BMP adoption by farmers in the absence of certainty and precision concerning the impacts of BMPs on yields.

Linear regression (prediction) analysis explains a moderate degree of variation (41-60%) and indicates that the likelihood of yield and ecosystem service co-benefits versus tradeoffs depends, in part, on the type of BMP implemented, and temporal scale.

Whether agricultural BMPs result in co-benefits is highly contextual (cf. Power 2010; Seufert et al. 2012; Palm et al. 2014; Duru et al. 2015; Garbach et al. 2017) and depends on the BMP, crop, geographical location, and biophysical attributes. While we were not able to detect informative associations of all BMPs with **YESs**, likely due to low sample sizes, overall, BMPs were more predictive of significant associations with crop yield outcomes than with ecosystem service outcomes. Conservation (i.e. reduced) tillage practices (reducing conventional tillage or increasing crop residue retention) were most likely to result in co-benefits versus partial improvements, tradeoffs, or co-costs, as there is evidence that these practices can produce equivalent or greater yields than conventional tillage especially when combined with other practices (see Kragt and Robertson 2014; Pittelkow et al. 2015a; Zhao et al. 2017). Crop rotations also hold promise as BMPs that were more likely to result in co-benefits or tradeoffs versus co-costs. On the other hand, in our sample, cover crops, nutrient management (i.e. applying nitrification inhibitors or reducing fertilizer rate), and perennial vegetative buffers were less likely to result in co-benefits in comparison to conventional agriculture, and more likely to result in tradeoffs. Nutrient management may reduce crop yields by reducing overall nutrient inputs[2], while cover crops and perennial vegetative buffers may take productive agricultural land out of use (through time, or space, respectively) and thereby decrease yields (e.g. Agus et al. 1998; Kragt and Robertson 2014; Rosa-Schleich et al. 2019). As Rosa-Schleich et al. (2019) describe, "[diversified farming] practices may lead to increased opportunity costs if some lands are temporarily or permanently retired from production". In the case of cover crops and perennial vegetative buffers, there may be a mismatch between where ecosystem services are measured and where the benefits are actually realized (i.e. measuring or estimating ecosystem services within-fields while ecosystem service benefits may be at the 'edge of field' (*off-farm*) or 'downstream').

Studies which investigated the effects of BMP implementation over longer temporal scales were more likely to result in co-benefits, although the effect was more pronounced when ecosystem services were weighted more heavily. Given this result, a possible hypothesis for the effect of temporal scale is that the (positive) ecosystem service effects tend to accumulate over time, indicating a possible time lag, delaying benefits until years or even decades later, while (negative) yield effects are felt more immediately. The association between temporal scale and delayed benefits has been found for cover crops on ecosystem services (e.g. Olson et al. 2014; Schipanski et al. 2014) and for no-till on crop yields (Pittelkow et al. 2015b). Alternatively, the strong effect of temporal scale on **YESs** may potentially suggest that the implementation of a BMP and the likelihood of attaining co-benefits may be dependent on cumulative effects which

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[2] Although as mentioned previously, depending on the shape of the payoff function for nutrient application rates, this may increase farmers' profits despite reducing overall yields, in which case farmers might still prefer to reduce application rates (Pannell 2017).

incrementally accumulate through time to ‘realizing’ positive outcomes on crop yields and ecosystem services. However, this result could also be due to all sorts of confounding factors.

Unsurprisingly, in our sample of studies, more attention was paid to regulating than supporting ecosystem services. Garbach et al. (2017) also found that studies on BMPs focus on a subset of ecosystem services, namely those expected to be most influenced by BMP adoption. Authors in our review focused heavily on hydrological (e.g. nitrate leaching, soil moisture and drainage) and climate regulating services (e.g. soil organic carbon), although hydrological services demonstrated rather mixed effects after BMP adoption. Pest regulation received a relatively large amount of attention but also resulted in mixed effects. Others have found that pest abundances, predation rates, crop damage and yields show little overall consistent or conclusive trend with landscape configuration (Kremen and Miles 2012; Karp et al. 2018). Despite demonstrating positive effects after BMP adoption, erosion regulation was surprisingly not a large focus for study authors. Supporting services like nutrient cycling and soil formation also received less attention despite demonstrating increased benefits after BMP adoption. Erosion regulation and nutrient cycling were found to be the only two ecosystem services shown to enhance agricultural production (Pilgrim et al. 2010), and will therefore require more attention and protection.

4.1 Limitations

Geographically, the dataset is dominated by 28 studies from the United States. This distribution reflects a likely research bias towards BMP enquiry (and/or higher levels of investment in BMP promotion programs) in North America compared to other regions of the world. It could also be due to regional differences in practices and terminology.

BMPs encompass a wide variety of practices and combinations thereof. As a result, BMPs appear to be inconsistently characterized and there is some overlap between them (e.g. reduced input practices as defined by study authors can also include modified tillage practices which other study authors investigate these practices in isolation). This poses challenges for comparing authors' terminology and categorization for agricultural BMPs. Moreover, many candidate BMPs promoted by governments, farming organizations/associations, non-profits (e.g. biosolids, diversion terraces, drainage, fencing and exclusion) and 'Edge of Field' (*off-farm*) practices seemed absent or limited in our sample of literature and therefore this dataset.

The set of studies that satisfied our inclusion criteria may comprise a small proportion of studies that would satisfy selection criteria if one were to conduct a comprehensive systematic literature search including screening bibliographies for articles that satisfy inclusion criteria. This small sample may limit our ability to transfer our study results to broader contexts. However, our eligibility criteria restricted studies to the joint effects on crop yield and ecosystem services. This excluded the majority of studies retrieved in searches, suggesting that the total number of studies satisfying this criterion may be few. In fact, a similar review by Garbach et al. (2017) identified the paucity of studies which conjointly examine effects on crop yields and ecosystem services as a major knowledge gap — which becomes more acute for meta-analyzing the effects of multiple practices on a diverse set of ecosystem services. On the other hand, our analysis indicated patterns and associations between different sample-sized datasets, so we are optimistic that these associations will be reproducible and robust. We recommend future reviews and syntheses to undertake meta-analysis where possible and appropriate. In doing so, they should follow systematic review protocols developed by the Collaboration of Environmental Evidence (https://www.environmentalevidence.org/), including having multiple reviewers independently applying eligibility criteria, cross-checking extracted data, and critically appraising studies.

4.2 Implications

The evidence presented in this research has several implications. First, in comparison to conventional agriculture, conservation agriculture (i.e. implementing BMPs) changes biophysical properties and processes in a manner that can positively affect the delivery of regulating and supporting ecosystem services, some of which underpin provisioning services like crop yield. Second, the results of a given BMP on yield and ecosystem service delivery are expected to change depending on study context (i.e. location and site characteristics). The type of BMP, and temporal scale of the study are likely candidates for affecting the likelihood of co-benefits and tradeoffs between crop yield and other ecosystem services. Therefore, generalized and simplified estimates of BMP performance are discouraged because they demonstrably have little practical value in the absence of context.

Based on the study results, we suggest three areas for extending the research (both in the primary literature as well as in future review studies). The first would be to review (and further design and implement) experimental or quasi-experimental studies which compellingly identify the biophysical and socio-economic *mechanisms* through which the selected BMPs realize co-benefits between crop yields and ecosystem services. Depending on the BMP these might include, *inter alia*, enhancing yield stability due to e.g. enhanced soil organic carbon stocks (Cong et al. 2014), optimizing input application rates (e.g. fertilizers, pesticides) (Pannell 2017), improved knowledge of farm conditions (e.g. soil nutrient profiles) as a result of BMP adoption, or the ability for certain regulating ecosystem services (e.g. pollination or biological pest control) to serve as either complementary, substitute or synergistic inputs to crop production (c.f.

Simpson 2014). Identifying these mechanisms could potentially uncover important intervening variables which complement the candidate predictor variables identified in this study. Clearly communicating the mechanisms through which BMPs could positively impact yield and profitability to farmers might also increase their attractiveness and increase the likelihood of adoption.

The second area would be to extend this review to a systematic meta-analysis which quantitatively assesses agronomic and ecosystem service outcomes in monetary terms – either in terms of the impacts of BMPs on the monetary value of on-farm ecosystem services, or on farmers' profits (ideally, both outcomes would be quantified). Designing and implementing BMP programs entails costs for both farmers and for the broader society (in the form of transaction and implementation costs associated with the program, as well as input, labor and opportunity costs for the farmer). Integrating data on monetary costs and benefits would enable policymakers to better assess whether the expected benefits of these on-farm ecosystem services exceed the expected costs. At a minimum, incorporating data on economic costs of BMP adoption would enable policymakers to better assess the *cost-effectiveness* of BMPs (especially those associated with tradeoffs or no-regrets outcomes) for securing specific regulating and supporting ecosystem services. This information is an essential input to policymakers who are deciding where to allocate scarce dollars for agro-environmental and on-farm conservation programs.

In the event that an insufficient number of high-quality primary studies are available to conduct a meta-analysis, policymakers could also consider using benefit transfer techniques (Schmidt et al. 2016) to provide preliminary estimates of the value of these on-farm ecosystem services (as a complement to primary data collection). This information could provide an approximate estimate (e.g. in terms of conservative upper and lower bounds) as to whether the ecosystem services delivered by BMPs are likely to exceed the costs. Moreover, given that much of the value of regulating and supporting ecosystem services in agroecosystems derives from their direct or indirect contributions to crop production over sufficiently broad time scales, policymakers need to be careful to avoid double-counting.

The third extension would ideally build on the second, by systematically identifying the appropriate policy instruments for promoting these BMPs, such as extension and information programs versus cost share or other payment schemes (e.g. price premiums from ecologically certified crop production). Choosing the optimal policy instruments for encouraging BMP adoption depends in part on the ratio of public and private costs and benefits realized by these practices (Pannell 2008). One plausible hypothesis is that BMPs entailing yield benefits for the farmer and ecosystem service co-benefits for the public are more likely to be suitable targets for extension programs, whereas the BMPs entailing tradeoffs between off-farm ecosystem service benefits and crop yields are more likely to be suitable for incentive payment schemes (since the costs of BMP adoption are borne by the farmer) (Pannell 2008). However, such estimates would need to be corroborated by statistically estimating the relationship between the implementation of a particular BMP and associated changes in farmers' profits (which can be due to a number of other factors besides increased yields, such as reduced input costs).

In order to provide sufficient food for the world's growing population, agriculture will need to adopt sustainable practices that increase productivity without negatively impacting ecosystem services. This will involve taking an ecological approach, and focusing on long-term sustainability versus short-term production of food at the expense of underpinning regulating and supporting ecosystem services (Robertson and Swinton 2005; Stallman 2011). This research makes clear that, in the appropriate contexts, "land sharing" strategies can indeed be beneficial for delivering landscape-scale ecosystem services – certain agricultural BMPs can maintain or even increase crop yields while also augmenting the supply and delivery of critical regulating and supporting ecosystem services. While this does not guarantee in and of itself that these practices will be adopted, the importance of demonstrating that BMPs do in fact satisfy some of the necessary conditions for long-term sustainability in the agricultural sector should not be discounted.

In conclusion, this review confirms that agricultural BMPs impact the likelihood of co-benefits between crop yield and ecosystem services as well as the likelihood of tradeoffs and partial improvement scenarios. It strengthens the view that agricultural BMPs must be an important part of modern sustainable agriculture to satisfy both the global growing demand in food production and improving agro-environmental resources and environmental outcomes (i.e. regulating and supporting ecosystem services delivery) (see Bommarco et al. 2013; Gaba et al. 2014; Reganold and Wachter 2016). Successful agricultural management requires knowledge of the extent to which agricultural BMPs affect both crop yield and other ecosystem services. Since it is not feasible to study every BMP in every geographical context in detail, rapid assessments and syntheses such as this can help identify which BMPs may potentially result in 'win-win' or 'no-regrets' scenarios.

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Appendix A

The Nature Conservancy institutional repository: literature search strategy and resources used.

A repository of peer-reviewed and grey (organizational, government) literature in the reference manager *Mendeley* developed by *The Nature Conservancy* (North America Agriculture Program) was used as the initial data source for this review. The database contains 454 references on the impacts of BMPs on yield and agro-environmental resources, including regulating and supporting ecosystem services. Included studies in the database are particularly biased towards agricultural BMPs in the Upper Mississippi River Basin-Midwestern United States in corn and soy agroecosystems. For this database, literature searches were conducted in Google Scholar and ISI Web of Science from 2013-2016 (last update September 2016) using the terms "agricultur* best management practice*", "agricultur* BMP", "ecosystem service*", and the combination of (individual BMP: "till*" OR "cover crop*" OR "crop residue" OR "crop rotation*" OR "nutrient management" OR "pest management" OR "residue retention" OR "riparian buffer*" OR "hedgerow*" OR "buffer strip*" OR "buffers" OR "filter strip*") AND (individual 'provisioning' or 'non-provisioning' service: "food" OR "water supply" OR "fresh water" OR "air quality" OR "climate regulation" OR "water regulation" OR "water quality" OR "water quantity" OR "nitrogen" OR "phosphorous" OR "waste treatment" OR "water purification" OR "erosion regulation" OR "sediment retention" OR "soil formation" OR "soil fertility" OR "pollination" OR "biological control" OR "pest control" OR "pest regulation" OR "nutrient cycling" OR "biodiversity" OR "habitat"). Google scholar captured potentially relevant grey literature. No date restrictions were placed on database searches, resulting in studies spanning a 43-year period from 1973 to 2016. No language restrictions were placed on database searches.

Appendix B

Meta-data for candidate predictor variables.

Bibliographic information

- ***Reference ID**: a unique ID assigned to each piece of evidence in the database. An alphanumeric code, such as ANK001, with ANK the initials of the study authors or subject topic.*

- ***Authors**: The authors of the article, listed in sequence, e.g. "Kadykalo, A.; Findlay, C.S.".*

- ***Date**: the year of publication of the article.*

- ***Title**: the title of the article, e.g. "Organic agriculture and the global food supply".*

- ***Volume**: the volume number of the journal in which the article was published.*

- ***Start Page, End Page**: the beginning and end pages of the article.*

- ***DOI**: the corresponding digital object identifier, if it has been assigned.*

- ***PDF**: score 1 if a pdf version of the article is available, 0 if it is not.*

Experimental Design Variables

- ***Study type**: is the study an empirical study (E) or a simulation modelling study (M) or both (EM – corresponding to a case where a model is built, but modelled parameters are estimated from empirical data as part of the study).*

- ***Study design**: Control-Impact (CI); Correlative Design (CD)*

- ***Temporal scale**: short (days to weeks) (1); medium (months to a year) (2); long (several years to <10 years) (3); very long (decades) (4).*

- ***Spatial scale**: local (LO); regional (REG); national (NAT); international (INT).*

Context-Specific Variables

- ***Country, or US State/Canadian Province or Territories**: Country/Location of study*

- ***Precipitation**: average annual rainfall (mm)*

- ***Temperature**: average annual temperature (°C)*

- ***Corn**: Binary – Corn was a crop estimated in the agricultural system? Yes/No*

- ***Soybean**: Binary – Soybean was a crop estimated in the agricultural system? Yes/No*

- ***Wheat:*** Binary – Wheat was a crop estimated in the agricultural system? Yes/No

- ***BMP Category****:* Edge of Field (*Off-farm*), In-Field (*On-farm*)

  Edge of Field (*off-farm*) practices include BMPs that typically take land out of production, occurring at field margins/edges or between fields and water courses. These practices use permanent vegetation typically bordering a road, field, or water course. They are most often focused on reducing erosion and improving water quality by intercepting and slowing runoff or groundwater (e.g. buffer and filter strips, hedgerows, grassed waterways, riparian buffers) (ecosystem focused)

  In-Field (*on-farm*) practices are the most common BMPs and include the management of nutrients, tillage, cover crops, pesticides, crop rotations. In-Field practices are not likely to take agricultural land out of production but are rather focused on how crop land is managed (resource/production-focused)

- ***BMP(s)*** *Populated from BMP(s) implemented, and terms used in original texts of the literature repository database:*

Code	BMP(s)	Definition/Examples
CC	Cover Crops	Crops grown as cover over soil to maintain soil quality and productivity: red clover, oat, most often rye
CR	Crop Rotations	Crop rotation to reduce soil erosion and increase soil fertility by changing nutrient regimes; including perennial pastures (like alfalfa) into the crop rotation increasing the length of pasture phases in annual crop rotation; increasing the complexity of the cropping system (several different crops in planned succession or different times on the same field)
NM	Nutrient Management	Applying nitrification inhibitors – chemical compounds that slow the nitrification of ammonia, ammonium-containing, or urea-containing fertilizers, which are applied to soil as fertilizer; reducing the fertilizer rate; using natural/organic fertilizers (manure)
TI	Reduced (or no) Tillage	No-till, ridge-till, or reduced tillage compared to conventional (i.e. chisel, disk harrow, plow/plough) tillage – minimal mechanical soil disturbance through non-turning soil cultivation; increasing the proportion of crop residues retained (i.e. practice involved removing the crop residues (stubble) being removed from the soil surface after crop harvest)
MP	Multiple Practices	YESs based on two or more of the BMP categories
VB	Perennial Vegetative Buffers	Permanent vegetative buffers of woody or herbaceous species that border a road, field or water body/course – buffer and filter strips; grass strips, hedgerows, riparian buffers, wetland buffers, living fences

- ***Ecosystem Services Category****:* Provisioning, Regulating, Cultural, Supporting

Based on common ecosystem services typologies and classifications – see (Value of Nature to Canadians Study Taskforce 2017)

- ***Ecosystem Service Measure*** *Populated from ecosystem service outcomes and terms used in original texts of the literature repository database:*

Code	**Ecosystem Service**	**Definition/Examples**
AR	Air Quality Regulation	The capacity of an ecosystem to exchange chemicals with the atmosphere through bio-geochemical cycles
BIO	Biodiversity Conservation	The variability of life among and within species and ecosystems—underpins ecosystem resilience, integrity, and functioning
BPPP	Biomass Production/Primary Productivity	The formation of biomass through the conversion of solar energy (photosynthesis) and nutrient uptake by plants, contributing to plant growth
CR	Climate Regulation and Carbon Sequestration	The capacity of ecosystems, and particularly the plants and soils within them, to store (remove and sequester) carbon dioxide and other greenhouse gases and regulate local, regional and global climate
CS	Cultural Services	Water-based recreation benefits: fishing, boating/floating, and swimming
ER	Erosion Regulation	The capacity of vegetative cover and, in particular, the structure of vegetation both above and below ground, to retain soil and stabilize slopes
FP	Food Production ***(reference tradeoff outcome)***	Edible products derived from plants (e.g. fruits, grains, nuts, seeds, vegetables, tubers/roots, herbs, oils)
HA	Habitat Provisioning	Habitats that can be essential for a species' lifecycle (food, water, shelter)
NC	Nutrient Cycling and Supply	The capacity of an ecosystem to decompose and recycle nutrients, changing forms and making them available to plants for redistribution within the system
PR	Pest Regulation	The capacity of an ecosystem to reduce impacts of unwanted predation, for example, on crops, and the monetary and (in the case of pesticide use) health costs associated with implementing engineered controls
SF	Soil Formation	The capacity of an ecosystem to form soil through long-term processes of rock weathering and the accumulation of organic matter; a substrate for plant growth (i.e. soil fertility and quality)
WPWT	Water Purification and Waste Treatment	The capacity of an ecosystem to filter out and sequester or decompose organic wastes, including those introduced in production landscapes

WRSR	Water Regulation and Soil Moisture Retention	The capacity of an ecosystem to maintain natural water-flow regimes in a watershed, providing natural irrigation and water storage (i.e. soil moisture retention)

- ***Metric****:* indicator and metric used (e.g. Corn Yield for Food Production (kg/ha); Nitrate Leaching for Water Purification and Waste Treatment (kg of NO_3−N/ha/year))

- ***Summary ecosystem service statement****:* Explicit ecosystem service statements (summaries/conclusions) extracted directly, or in paraphrased form from the original text; or quantitative responses/results (%/magnitude of change) published in the original text regarding the impact of BMP implementation on yield and ecosystem services. These statements were scored next to their respective ecosystem service measures:
    - "+" signifies for the study under consideration, the conclusion reached by the authors was the implementation of the BMP(s) in question increased the level of ecosystem service delivery relative to conventional practices without the implementation of the BMP(s);
    - "-" signifies for the study under consideration, the conclusion reached by the authors was the implementation of the BMP(s) in question reduced the level of ecosystem service delivery relative to conventional practices without the implementation of the BMP(s);
    - "•" signifies for the study under consideration, the conclusion reached by the authors was the implementation of the BMP(s) in question resulted in a neutral influence (i.e. neutral/non-existent effect) regarding the level of ecosystem service delivery relative to conventional practices without the implementation of the BMP(s).

Literature Cited

Value of Nature to Canadians Study Taskforce. 2017. Completing and using ecosystem service assessment for decision-making: An interdisciplinary toolkit for managers and analysts [Online]. Ottawa, ON: Federal, Provincial, and Territorial Governments of Canada. Available: http://biodivcanada.ca/default.asp?lang=En&n=B443A05E-1.

Appendix C

Intra-class correlation (ICC) based on the within- and between-study variances in YESs to check for a study effect.

Table C1. Intra-class correlation coefficients (ICC) calculated from the within- and between-study variances in **YESs** for each Agriculture weight 'w_A' (*k* = 36, *n* = 141).

Agriculture weight (w_A)	ICC
0.9	0.5885
0.75	0.6070
0.5	0.6200
0.25	0.5720
0.1	0.5245

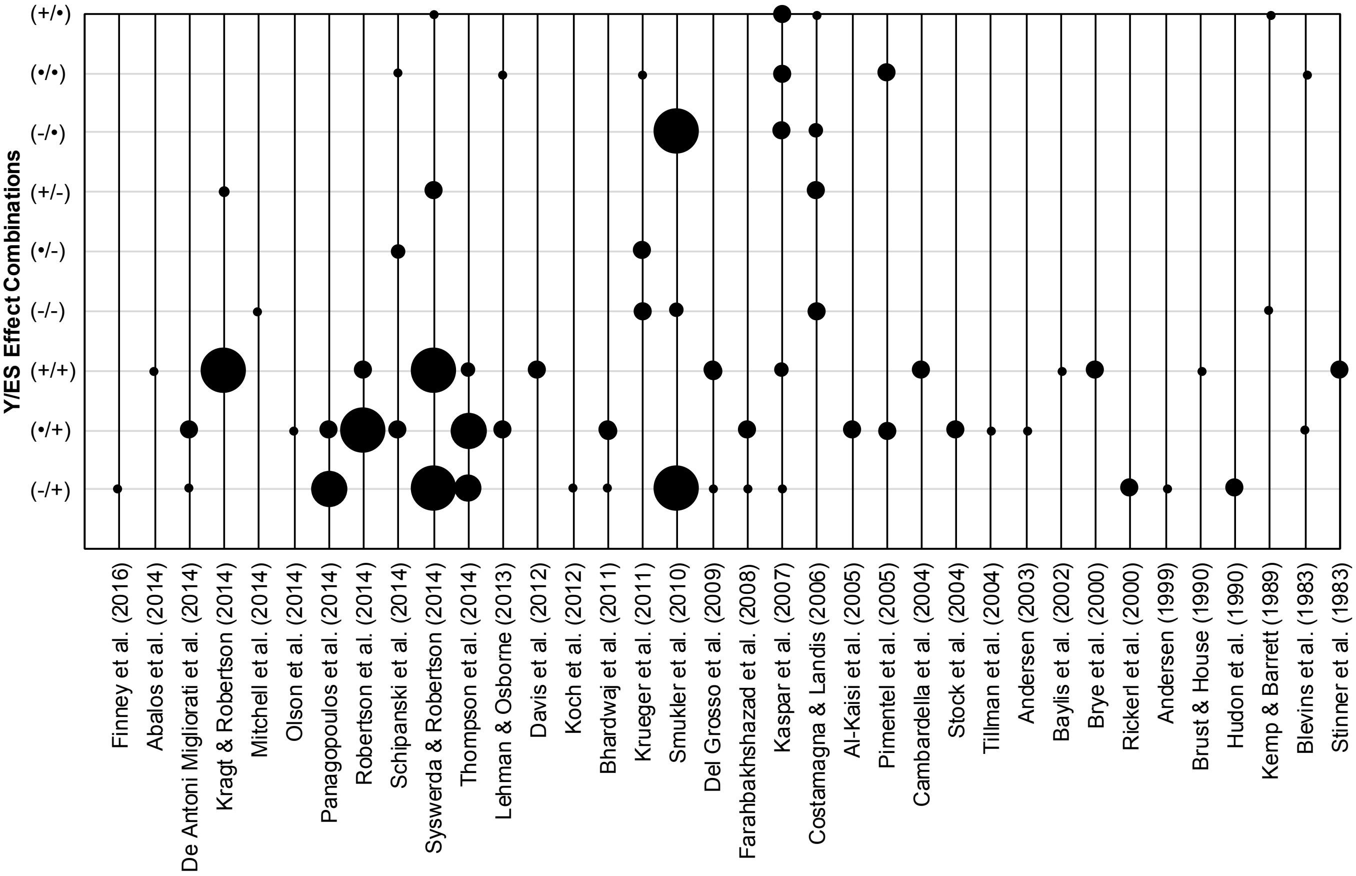

Figure C1. Dot plot of estimated Y/ES effect combinations for (*k* = 36) individual studies. Studies having multiple Y/ES effect combination outcomes (of multiple different BMPs and/or the effect on multiple different crops or ES) show a strong intra-class correlation represented by larger dots.

Appendix D

Review of BMPs and their joint effects on crop yield and ecosystem services – extracted data from included studies.

Temp. Scale = Temporal Scale, Spat. Scale = Spatial Scale, Precip. = Precipitation, Temp. = Temperature, MP = Multiple Practices

Author	*Country (state, province)*	*Temp. Scale*	*Spat. Scale*	*Precip.*	*Temp.*	*Study type*	*Study design*	*Crop*	*BMP Category*	*BMP(s)*	*Ecosystem Service Category*	*Ecosystem Service*	*Metric*	*Summary Ecosystem Service Statement (p. page number)*	**YESs** (the joint effects on crop yield and ecosystem services)
Finney et al. (2016)	Pennsylvania, USA	3	LO	975mm	10.1°C	E	CD	Corn	In-Field	CC (Barley, Canola, Hairy Vetch, Foxtail millet, Italian ryegrass, Oat, Radish, Red Clover, Rye, Soybean, Sorghum, Sun hemp)	Provisioning	FP: -	Yield (kg/ha)	Increasing cover crop biomass... negatively impacted corn yield in the subsequent cropping season (p. 39)	
											Regulating	PR: +	Weed biomass (kg dry matter/ha)	Increasing cover crop biomass was positively correlated with... weed suppression (p. 39)	-/+
Abalos et al. (2014)	International (Canada, Chile, China, Germany, New Zealand, Pakistan, Spain, USA)	4	INT	938mm	13°C	E	CD	Amaranth Barley Capsicum Corn Cotton Rice Radish Rapeseed Wheat	In-Field	NM (Nitrification inhibitors)	Provisioning	FP: +	Crop yield	Our results show that nitrification inhibitors can be recommended in order to increase crop yields (grand mean increase of 7.5%) (p. 136)	
											Regulating	WPWT: +	Crop Nitrogen Use Efficiency (USE)	Our results show that nitrification inhibitors can be recommended in order to increase nutrient use efficiency (grand mean increase of 12.9%) (p. 136)	+/+
De Antoni Migliorati et al. (2014)	Australia	1	LO	776mm	17.6°C	E	CI	Corn	In-Field	NM (Reduction of synthetic N fertilizer applied)	Provisioning	FP: -	Grain yield (t/ha)	Halving the annual conventional N fertiliser rate in the adjusted N treatment extensively penalised maize yield p. 33	
											Regulating	AR: +	N_20 emissions (kg N2O–N ha^{-1}year^{-1})	Halving the annual conventional N fertiliser rate in the adjusted N treatment reduced N_2O emissions by approximately 60% (p. 33)	-/+
								Corn Wheat		NM (Nitrification inhibitors)	Provisioning	FP: •	Grain yield (t/ha)	The use of DMPP with urea at the conventional N rate did not affect crop yields (p. 33)	
											Regulating	AR: +	N_20 emissions (kg N2O–N ha^{-1}year^{-1})	The use of DMPP with urea at the conventional N rate reduced annual N2O emissions by more than 60% (p. 33)	•/+
Kragt and Robertson (2014)	Australia	3	REG	325mm	17°C	EM	CD	Barley Wheat	In-Field	CR (Alfalfa/Lucerne)	Provisioning	FP: +	Yield (kg/ha/year) Sheep grazing (days/year)	There is a positive effect of increasing length of Lucerne phase on grain yields and sheep grazing days (p. 151)	

											Regulating	WRSR: +	Drainage (total mm/year)	The deep-rooted perennial Lucerne pastures in the rotation mix have positive impacts on reducing drainage (p. 152)	+/+
											Regulating	CR: +	Soil organic carbon stock (kg/ha)	Including more pasture in the rotation mix increases soil organic carbon in both regions. In Cunderdin, SOC-stock increases by about 13% when moving from 2 years to 7 years of pasture, while in Kojonup SOC-stocks increase by over 20% (p. 152)	+/+
											Supporting	NC: +	Nitrogen mineralisation (total kg N/ha/year)	...positive relationships between increasing agricultural production (grain and Lucerne yields) and nitrogen mineralisation (p. 152)	+/+
										TI (Stubble retention)	Provisioning	FP: +	Yield (kg/ha/year) Sheep grazing (days/year)	Increasing the proportion of crop residues retained on the soil surface after harvest appears to increase grain yields and sheep grazing days (p. 152)	■
											Regulating	WRSR: -	Drainage (total mm/year)	We find a negative trade-off between production values and drainage with an increase in the proportion of crop stubble retained after harvest (increased production value and increased drainage, which is undesirable in this context) p.153	+/-
											Regulating	CR: +	Soil organic carbon stock (kg/ha)	There were positive effects of stubble retention on SOC-stock (approximately 8–9% increase for every 25% increase in stubble retention rates) (p. 152)	+/+
											Supporting	NC: +	Nitrogen mineralisation (total kg N/ha/year)	There were positive effects of stubble retention on N-mineralisation (approximately 20% increase for every 25% increase in stubble retention rates) (p. 152)	+/+
											Supporting	HA: +	Groundcover	There were positive effects of stubble retention on ground cover (approximately 20% increase for every 25% increase in stubble retention rates) (p. 152)	+/+
Mitchell et al. (2014)	Québec, Canada	3	REG	1000mm	6.3°C	E	CD	Soybean	In-Field	TI (No-till)	Provisioning	FP: -	Yield (kg/ha)	Soybean yield was negatively related with no-till planting (p. 146)	■
											Regulating	PR: -	Aphid numbers and arthropod herbivory (proportion of soybean leaves grazed)	No-till planting methods decreased pest regulation (p. 144)	-/-

Olson et al. (2014)	Illinois, USA	4	LO	1252mm	14.6°C	E	CI	Corn Soybean	In-Field	CC (Hairy Vetch, Rye)	Provisioning	FP: •	Yield (Mg/ha)	The average annual corn and soybean yields were statistically the same for systems with and without cover crops (p. 284)	
											Regulating	CR: +	Soil organic carbon (Mg C/ha)	The cover crop treatments had more SOC stock than that without cover crops for the same soil layer and tillage treatment (p. 284)	•/+
Panagopoulos et al. (2014)	Upper Mississippi River Basin, USA	4	REG	900mm	8.2°C	EM	CI	Corn Soybean	In-Field	TI (No-till)	Provisioning	FP: •	Yield (t/ha)	No-till...did not have any impacts on yield (p. 491)	
											Regulating	WPWT: +	Total phosphorus (TP) losses, average annual nitrate-nitrogen (No3-N) and total nitrogen (TN) losses	No-till resulted in reduced nutrient loadings to surface water bodies compared to the baseline agricultural management (p. 483); could reduce sediment, N, and P exports from UMRB cropland by up to 50% without significantly affecting yields (p. 484)	•/+
											Regulating	ER: +	Average annual sediment (SED)	No-till resulted in reduced erosion compared to the baseline agricultural management (p. 483)	•/+
										CR (Alfalfa)	Provisioning	FP: -	Yield (t/ha)	Reduced crop yields were predicted for the extended rotation; corn-soybean-alfalfa-alfalfa-alfalfa (C-S-A-A-A) cover crop scenario, which were close to 5% for both corn and soybean (p. 491)	
											Regulating	WPWT: +	Total phosphorus (TP) losses, average annual nitrate-nitrogen (No3-N) and total nitrogen (TN) losses	Extended rotation; corn-soybean-alfalfa-alfalfa-alfalfa (C-S-A-A-A) scenario resulted in reduced nutrient loadings to surface water bodies compared to the baseline agricultural management (p. 483); could reduce sediment, N, and P exports from UMRB cropland by up to 50% without significantly affecting yields (p. 484)	-/+
											Regulating	ER: +	Average annual sediment (SED)	Extended rotation; corn-soybean-alfalfa-alfalfa-alfalfa (C-S-A-A-A) scenario resulted in reduced erosion compared to the baseline agricultural management (p. 483)	-/+
										CC (Rye)	Provisioning	FP: -	Yield (t/ha)	Reduced crop yields were predicted for cover crop scenarios, which were close to 5% for both corn and soybean (p. 491); Corn and soybean yields were also reduced when rye was grown as a winter cover crop (p. 491)	

											Regulating	WPWT: +	Total phosphorus (TP) losses, average annual nitrate-nitrogen (N$_\text{O}$3-N) and total nitrogen (TN) losses	The cover crop scenario resulted in reduced nutrient loadings to surface water bodies compared to the baseline agricultural management (p. 483); Rye (*Secale cereale L.*) cover crop within the fallow period was also effective in reducing both sediment-bound and soluble forms of nutrients; could reduce sediment, N, and P exports from UMRB cropland by up to 50% without significantly affecting yields (p. 484)	-/+
											Regulating	ER: +	Average annual sediment (SED)	Rye (*Secale cereale L.*) cover crop within the fallow period was also effective in reducing erosion (p. 483)	-/+
Robertson et al. (2014)	Michigan, USA	4	REG	1027mm	9.9°C	E	CI	Corn Soybean Wheat	In-Field	TI (No-till)	Provisioning	FP: +	Grain yield (Mg/ha)	On average, yields in the no-till system were 9%–21% higher than they were in the conventional system (p. 410)	■
											Regulating	WPWT: +	Nitrogen/ha Nitrate-nitrogen/Mg of yield	Over an 11-year period, beginning 6 years after establishment, the annual row-crop systems showed two- to threefold differences in nitrate losses, ranging from average annual losses of 42 and 62 kg of nitrogen per ha in the no-till and conventionally managed systems, respectively p. 407; Even after accounting for yield differences, leaching differences were substantial: 11.1 kg of nitrate-nitrogen per megagram (Mg) yield in the no-till and 17.9 in the conventional systems.	+/+
											Regulating	CR: +	Global warming impact (carbon dioxide equivalents [C$_\text{O}$2e])	The conventional annual cropping system had a net annual global warming impact (in carbon dioxide equivalents [C$_\text{O}$2e]) of 101 grams (g) of C$_\text{O}$2e per square meter (m^2), whereas the no-till system exhibited net mitigation: –14 g of C$_\text{O}$2e per m^2 (p. 409)	+/+
											Regulating	WRSR: +	Soil moisture (in cm^3 per cm^3)	Enhanced water storage capacity in no-till soils versus conventional (p. 410)	+/+
											Supporting	SF: +	Soil organic matter	Relative to the conventional system, soil organic matter	+/+

														increased in the no-till systems (p. 410)	
										MP: CC (leguminous) & NM (1/3 of conventional systems synthetic fertilizer/chemical inputs)	Provisioning	FP: •	Grain yield (Mg/ha)	In our reduced-input system (with about one-third of the conventional system's chemical inputs; winter cover crops provide additional nitrogen), corn and soybean yields slightly exceed those of our conventionally managed system, and wheat yields lag only slightly (p. 405)	
											Regulating	WPWT: +	Nitrogen/ha Nitrate-nitrogen/Mg of yield	Over an 11-year period, beginning 6 years after establishment, the annual row-crop systems showed two- to threefold differences in nitrate losses, ranging from 24 kg of nitrogen per ha in the reduced-input systems and 62 kg of nitrogen per ha in the conventionally managed systems (p. 407); Even after accounting for yield differences, leaching differences were substantial: 7.3 kg of nitrate-nitrogen per megagram (Mg) yield in the reduced-input system, compared with 17.9 in the conventional systems	•/+
											Regulating	CR: +	Global warming impact (carbon dioxide equivalents [Co2e])	The reduced input and biologically based systems also exhibited net-mitigation (p. 409)	•/+
											Supporting	SF: +	Soil organic matter	Relative to the conventional system, soil organic matter increased in the reduced-input system (p. 410)	•/+
										MP: CC (leguminous) & NM (no synthetic fertilizer/ chemical inputs)	Provisioning	FP: •	Grain yield (Mg/ha)	This nitrogen deficit is especially apparent in the biologically based system, which lacks fertilizer nitrogen inputs: Wheat yields are approximately 60% of the yields under conventional management. This is in contrast to soybean yields, for which the biologically based system is equivalent to the conventional system (p. 406)	
											Regulating	WPWT: +	Nitrogen/ha Nitrate-nitrogen/Mg of yield	Over an 11-year period, beginning 6 years after establishment, the annual row-crop systems showed two- to threefold differences in nitrate losses, ranging from average annual losses of 19 of nitrogen per	•/+

														ha in the biologically based and of 62 kg of nitrogen per ha in conventionally managed systems (p. 407)	
											Regulating	CR: +	Global warming impact (carbon dioxide equivalents [C$_{O}$2e])	The biologically based system also exhibited net-mitigation (p. 409)	•/+
											Supporting	SF: +	Soil organic matter	Relative to the conventional system, soil organic matter increased in the biologically based system (p. 410)	•/+
Schipanski et al. (2014)	Pennsylvania, USA	4	LO	1006mm	10.1°C	EM	CD	Corn Soybean Wheat	In-Field	CC (Red Clover, Rye, Winter Wheat)	Provisioning	FP: •	Grain yield (Mg/ha)	Crop yields for all three cash crops, a key metric of agronomic success, were equivalent between the Cover Crop (CC) and No Cover Crop (NoCC) cropping systems (p. 16)	■
											Regulating	WPWT: +	NO$_3$ leaching	Cover crops increased almost all supporting and regulating services, including N$_{O}$3 retention (p. 16)	•/+
											Regulating	ER: +	Soil loss	Cover crops increased almost all supporting and regulating services, including erosion control (p. 16)	•/+
											Regulating	PR: +	Weed pressure	Cover crops increased almost all supporting and regulating services, including weed suppression (p. 16)	•/+
											Regulating	PR: +	Carabid activity	Cover crops increased almost all supporting and regulating services, including beneficial insect conservation (p. 16)	•/+
											Regulating	CR: +	Soil carbon	Cover crops increased almost all supporting and regulating services, including soil C storage (p. 16)	•/+
											Supporting	BPPP: +	Biomass (Mg/ha)	Cover crops increased almost all supporting and regulating services, including biomass production (p. 16)	•/+
											Supporting	NC: +	Nitrogen mineralisation	Cover crops increased almost all supporting and regulating services, including N supply (p. 16)	•/+
											Supporting	SF: +	Arbuscular mycorrhizal fungi (AMF) colonization	Cover crops increased almost all supporting and regulating services, including AMF colonization (p. 16)	•/+
											Regulating	PR: •	Lepidopteran activity	The exception was insect pest suppression which was not different in the CC system (p. 16)	•/•
											Regulating	AR: -	N$_2$O production	The exceptions was N$_2$O reduction, which decreased in the CC system (p. 16)	•/-
Syswerda and Robertson (2014)	Michigan, USA	4	LO	1027mm	9.9°C	E	CI	Corn Soybean	In-Field	TI (No-till)	Provisioning	FP: +	Grain yield (t/ha/ year)	Grain yield was highest in the no-till system (3.85 ± 0.07 t $ha^{-1}y^{-1}$)	■

								Wheat						(p. 31); Conventional was 3.5 ± 0.2 t $ha_{-1}y^{-1}$ (p. 33)	
											Regulating	WPWT: +	Nitrate leaching (kg NO_3-N/ha/year)	Nitrate leaching levels varied widely across the treatments, with the highest leaching in the conventional system (62.2 ± 9.4 kg NO_3−–N ha^{-1} y^{-1})… No-till was 41.4 ± 3.0 kg NO_3−–N ha^{-1} y^{-1} (p. 33)	+/+
											Regulating	WRSR: -	Drainage (mm/year)	Drainage was highest in the no-till system (412 mm y^{-1}). Intermediate levels of drainage were seen in the conventional system (335 mm y^{-1}) (p. 31)	+/-
											Regulating	CR: +	Global warming impact (g CO^2e/m^2/year)	Negative values indicated net climate change mitigation potential. The conventional systems were the largest net emitters, with 82 g CO_2e m^{-2} y^{-1} (p. 31) No-till was -42 g CO^2e m^{-2} y^{-1} (p. 33)	+/+
											Regulating	WRSR: +	Soil water content (g H_2O/g soil)	Average July soil water content was lowest in the conventional system at 0.11 (± 0.03) g water g^{-1} soil (p. 31) No-till was 0.13 (± 0.02) g water g^{-1} soil (p. 33)	+/+
											Supporting	SF: +	Soil carbon to 1 m (kg C/m^2)	Soil carbon levels to 1 m depth was 6.9 (± 0.6) kg C m^{-2} in the conventional system; No-till was 8.5 (± 0.9) kg C m^{-2} (p. 33)	+/+
											Supporting	BPPP: +	Annual net primary productivity (t/ha/year)	Average annual net primary productivity was 8.2 (± 0.5) in the conventional system; 8.6 (± 0.3) in the no-till system (p. 33)	+/+
											Supporting	BIO: +	Plant diversity (species richness, total number of species)	Plant diversity was lowest in the conventional system (38.8 ± 2.3 species); No-till system had 49.0 ± 2.4 species (p. 33)	+/+
										MP: CC (Alfalfa) & NM (1/3 of conventional systems synthetic fertilizer/chemical inputs)	Provisioning	FP: +	Grain yield (t/ha/ year)	Conventional was 3.5 ± 0.2 t $ha^{-1}y^{-1}$ Reduced input (with reduced chemical inputs and tillage) was 3.6 ± 0.10 t $ha^{-1}y^{-1}$ (p. 33)	
											Regulating	WPWT: +	Nitrate leaching (kg NO_3-N/ha/year)	Nitrate leaching levels varied widely across the treatments, with the highest leaching in the conventional system (62.2 ± 9.4 kg NO_3−–N ha−1 y−1) (p. 31);	+/+

														Reduced input was 24.6 ± 0.7 kg NO_3−–N ha^{-1} y^{-1} (p. 33)	
											Regulating	WRSR: +	Drainage (mm/year)	Intermediate levels of drainage were seen in the conventional system (335 mm y^{-1}). The lowest levels were seen among the reduced input (220 mm y^{-1}) system (p. 31)	+/+
											Regulating	CR: +	Global warming impact (g CO^2e/m^2/year)	Negative values indicated net climate change mitigation potential. The conventional systems were the largest net emitters, with 82 g CO_2e m^{-2} y^{-1} (p. 31) Reduced input was -27 g CO_2e m^{-2} y^{-1} (p. 33)	+/+
											Regulating	WRSR: •	Soil water content (g H_2O/g soil)	Average July soil water content was lowest in the conventional system at 0.11 (± 0.03) g water g^{-1} soil p. 31; Reduced input was 0.11 (± 0.02) g water g^{-1} soil	+/•
											Supporting	SF: -	Soil carbon to 1 m (kg C/m^2)	Soil carbon levels to 1 m depth was 6.5 (± 0.8) kg C m^{-2} in the reduced input (p. 31) Conventional was 6.9 (± 0.6) kg C m^{-2} (p. 33)	+/-
											Supporting	BPPP: +	Annual net primary productivity (t/ha/year)	Average annual net primary productivity was 8.2 (± 0.5) in the conventional system; 8.9 (± 0.3) in the reduced input system (p. 33)	+/+
											Supporting	BIO: +	Plant diversity (species richness, total number of species)	Plant diversity was lowest in the conventional system (38.8 ± 2.3 species) (p. 31) Reduced input system had 77.3 ± 1.7 species (p. 33)	+/+
										MP: CC (Alfalfa) & NM (no synthetic fertilizer/chemical inputs)	Provisioning	FP: -	Grain yield (t/ha/ year)	Grain yield was lowest in the biologically based system (organic) (biologically based (USDA certified organic) with no chemical inputs and tillage) (2.76 ± 0.10 t $ha^{-1}y^{-1}$) (p. 31) Conventional was 3.5 ± 0.2 t $ha^{-1}y^{-1}$ (p. 33)	[redacted]
											Regulating	WPWT: +	Nitrate leaching (kg NO_3-N/ha/year)	Nitrate leaching levels varied widely across the treatments, with the highest leaching in the conventional system (62.2 ± 9.4 kg NO_3−–N ha^{-1} y^{-1})… with the biologically based leaching the least nitrate (19.2 ± 0.8 kg NO_3−–N ha^{-1} y^{-1}) (p. 31)	-/+

											Regulating	WRSR: +	Drainage (mm/year)	Intermediate levels of drainage were seen in the conventional system (335 mm y^{-1}). The lowest levels were seen among the biologically based annual systems (219 mm y^{-1}) (p. 31)	-/+
											Regulating	CR: +	Global warming impact (g CO^2e/m^2/year)	Negative values indicated net climate change mitigation potential. The conventional systems were the largest net emitters, with 82 g CO_2e m^{-2} y^{-1} (p. 31) Biologically based was -134 g CO_2e m^{-2} y^{-1} (p. 33)	-/+
											Regulating	WRSR: +	Soil water content (g H_2O/g soil)	Average July soil water content was lowest in the conventional system at 0.11 (± 0.03) g water g^{-1} soil (p. 31) Biologically based was 0.12 (± 0.01) g water g^{-1} soil (p. 33)	-/+
											Supporting	SF: +	Soil carbon to 1 m (kg C/m^2)	Conventional was 6.9 (± 0.6) kg C m^{-2} Biologically based was 8.3 (± 0.8) kg C m^{-2} (p. 33)	-/+
											Supporting	BPPP: +	Annual net primary productivity (t/ha/year)	Average annual net primary productivity was 8.2 (± 0.5) in the conventional system; 8.4 (± 0.3) in the biologically based system (p. 33)	-/+
											Supporting	BIO: +	Plant diversity (species richness, total number of species)	Plant diversity was lowest in the conventional system (38.8 ± 2.3 species). The biologically based system had the highest plant species richness (83.8 ± 1.7 species) (p. 31)	-/+
Thompson et al. (2014)	Iowa, USA	4	REG	910mm	9.6°C	EM	CD	Corn	In-Field	NM (Nitrification inhibitors)	Provisioning	FP: +	Corn yield	Research shows a corn yield when using a nitrification inhibitor (Nitrapyrin) with fall applied anhydrous ammonia. There is a corn yield increase of approximately 6 percent (p. 1)	[redacted]
											Regulating	WPWT: +	Nitrate-N loss	Research shows a nitrate-N loss decrease of 9 % when using a nitrification inhibitor (Nitrapyrin) with fall applied anhydrous ammonia (p. 1)	+/+
										CC (Rye, Oat)	Provisioning	FP: -	Corn yield	Research shows a corn yield decrease of 6% when using Rye and Oat cover crops (p. 3)	[redacted]
											Regulating	WPWT: +	Nitrate-N loss	Research shows a nitrate-N loss decrease of 30% when using Rye and Oat cover crops (p. 3)	-/+

										CR (Alfalfa)	Provisioning	FP: +	Corn yield	Research shows a corn yield increase of 7% when using at least 2 years of alfalfa in a 4 or 5-year rotation (p. 3)	■
											Regulating	WPWT: +	Nitrate-N loss	Research shows a nitrate-N loss decrease of 42% when using at least 2 years of alfalfa in a 4 or 5-year rotation (p. 3)	+/+
										NM (Organic fertilizers)	Provisioning	FP: •	Corn yield	Research shows a corn yield change of 0% when using liquid swine manure compared to sprung-applied fertilizer (p. 3)	■
											Regulating	WPWT: +	Nitrate-N loss	Research shows a nitrate-N loss decrease of 4% when using liquid swine manure compared to sprung-applied fertilizer (p. 3)	•/+
										NM (Organic fertilizers)	Provisioning	FP: •	Corn yield	Research shows a corn yield decrease of 1% when using liquid swine, dairy, and poultry manure compared to commercial fertilizer (p. 4)	■
											Regulating	WPWT: +	Phosphorus-P Load reduction	Research shows a phosphorus-P load reduction of 46% when using liquid swine, dairy, and poultry manure compared to commercial fertilizer (p. 4)	•/+
										CC (Rye)	Provisioning	FP: -	Corn yield	Research shows a corn yield decrease of 6% when using a winter rye cover crop (p. 4)	■
											Regulating	WPWT: +	Phosphorus-P Load reduction	Research shows a phosphorus-P load reduction of 29% when using a winter rye cover crop (p. 4)	-/+
										TI (Conservation tillage - 30% or more of the soil surface is covered with crop residue after planting)	Provisioning	FP: •	Corn yield	Research shows a corn yield change of 0% when using conservation till – chisel plowing compared to moldboard plowing (p. 4)	■
											Regulating	WPWT: +	Phosphorus-P Load reduction	Research shows a phosphorus-P load reduction of 33% when using conservation till – chisel plowing compared to moldboard plowing (p. 4)	•/+
										TI (No-till)	Provisioning	FP: -	Corn yield	Research shows a corn yield decrease of 6% when using no-till compared to chisel plowing (p. 4)	■
											Regulating	WPWT: +	Phosphorus-P Load reduction	Research shows a phosphorus-P load reduction of 90% when using no till compared to chisel plowing (p. 4)	-/+
Lehman and Osborne (2013)	South Dakota, USA	3	LO	580mm	8°C	E	CI	Corn	In-Field	CR (Peas, Winter Wheat)	Provisioning	FP: •	Yield (kg/ha)	During the four years of GHG measurements there were no	■

														significant difference in grain yield (p. 3)	
											Regulating	AR: •	Mean net annual soil surface gas fluxes (carbon dioxide, nitrous oxide, methane, kg/ha)	No significant differences in gas fluxes from corn due to treatment (2-year vs. 4-year rotation) were observed (p. 1)	•/•
											Regulating	CR: +	Soil carbon (kg/ha)	Measurements of soil carbon showed that the 4-yr rotation accrued 596 kg C ha^{-1} yr^{-1} in the top 30 cm of soil which would be more than sufficient (2.19 Mg CO2 eq ha^{-1} yr^{-1}) to offset the annual global warming potential (GWP) of the nitrous and methane emissions from corn. In contrast, the 2-year rotation lost 120 kg C ha^{-1} yr^{-1} from the top 30 cm of soil resulting in corn being a net producer of greenhouse gases and associated GWP (p. 1)	•/+
Davis et al. (2012)	Iowa, USA	3	LO	974mm	8.7°C	E	CI	Corn Soybean	In-Field	MP: CR (Alfalfa, Red Clover) & NM (reduced synthetic fertilizer/chemical inputs)	Provisioning	FP: +	Grain yield (Mg/ha)	Grain yields were similar to, or greater than those in the conventional system, despite reductions of agrichemical inputs (p. 1) Corn grain yield was on average 4% greater in the 3-yr and 4-yr rotations (reduced input) than in the 2-yr rotation (conventional) (p. 4) Soybean grain yield during the same period was on average 9% greater in the 3-yr and 4-yr rotations than in the 2-yr rotation (p. 4)	
											Regulating	PR: +	Weed seedbank (viable seeds) Weed biomass (Mg/ha)	Weeds were suppressed effectively in all systems, but freshwater toxicity of the more diverse systems was two orders of magnitude lower than in the conventional system (p. 1)	+/+
											Supporting	BPPP: +	Harvested crop mass (Mg/ha)	Mean crop biomass for 2003 to 2011 was 8% greater in the 3-yr and 4-yr rotations than in the 2-yr rotation (p. 4)	+/+
Koch et al. (2012)	Minnesota, USA	2	REG	705mm	6.7°C	E	CI	Soybean	In-Field	CC (Rye)	Provisioning	FP: -	Yield (Mg/ha)	Soybean yields did not differ significantly among treatments at either location although there was a trend for lower yield in two of the rye treatments (p. 750)	

											Regulating	PR: +	Densities of insect infestations	Densities of potato leafhopper, *Empoasca fabae* (Harris), were significantly Densities of soybean aphid, *Aphis glycines Matsumura*, were significantly lower Densities of bean leaf beetle, *Cerotoma trifurcata* (Forster), were significantly lower (p. 750)	-/+
Bhardwaj et al. (2011)	Michigan, USA	4	LO	900mm	9°C	E	CI	Corn Soybean Wheat	In-Field	TI (No-till)	Provisioning	FP: •	Grain yield (Mg/ha)	In general, over the 20-year period, for corn, soybean and wheat crop there was no significant differences in grain yields among the Conventional and No-till* system (p. 426) * no tillage with conventional fertilizer/chemical inputs	■
											Supporting	SF: +	Soil Quality Index (SQI) - 19 soil health indicators	Reduction in tillage (No-till) resulted in increased SQI and improved crop production. The No-till (SQI = 1.02) system outperformed Conventional management (SQI = 0.92) in soil stability and structure improvement (p. 419)	•/+
											Supporting	NC: +	Nitrogen availability	The No-till system outperformed Conventional management in nitrogen availability and use efficiency, and microbial nitrogen processing (p. 419)	•/+
										MP: CC (leguminous) & NM (30% of conventional systems synthetic fertilizer/chemical inputs)	Provisioning	FP: •	Grain yield (Mg/ha)	In general, over the 20-year period, for corn, soybean and wheat crop there was no significant differences in grain yields among the Conventional and Reduced input* system (p. 426) * conventional tillage with ~30% of conventional fertilizer/chemical inputs and a leguminous cover crop	■
											Supporting	SF: +	Soil Quality Index (SQI) - 19 soil health indicators	Reduction in tillage or fertilizer (Reduced Input) resulted in increased SQI and improved crop production. The Reduced Input (SQI = 1.01) system outperformed Conventional management (SQI = 0.92) in soil stability and structure improvement (p. 419)	•/+
											Supporting	NC: +	Nitrogen availability	The Reduced Input system outperformed Conventional management in nitrogen availability	•/+

														and use efficiency, and microbial nitrogen processing (p. 419)	
										MP: CC (leguminous cover crop) & NM (no synthetic fertilizer/chemical inputs)	Provisioning	FP: -	Grain yield (Mg/ha)	The Organic system led to decreased yields in wheat and corn but no significant differences in the soybean grain yields (p. 426)	■
											Supporting	SF: +	Soil Quality Index (SQI) - 19 soil health indicators	Reduction in tillage or fertilizer (Organic) resulted in increased SQI and improved crop production (p. 419)	-/+
Krueger et al. (2011)	Minnesota, USA	3	LO	673mm	4.4°C	E	CI	Corn	In-Field	CC (Rye)	Provisioning	FP: •	Biomass yield (Mg/ha)	Corn biomass yield after killed rye was similar to the control (p. 316)	■
											Regulating	WRSR: •	Soil water (mm)	Soil moisture after killed rye was similar to the control (p. 316)	•/•
											Supporting	NC: -	Soil Nitrate N concentration (g/kg) N content (kg/ha)	Available soil NO_3–N was decreased after both killed rye (35%) compared to the control (p. 316)	•/-
											Provisioning	FP: -	Biomass yield (Mg/ha)	Yield following harvested rye was reduced by 4.5 Mg ha^{-1}. After harvested rye, corn silage yield was reduced by 4.0 Mg ha^{-1} (23%) in 2008 and 5.0 Mg ha^{-1} (22%) in 2009 compared to the control	■
											Regulating	WRSR: -	Soil water (mm)	Soil moisture after harvested rye was 16% lower than the control (p. 316)	-/-
											Supporting	NC: -	Soil Nitrate N concentration (g/kg) N content (kg/ha)	Available soil NO_3–N was decreased after harvested rye (59%) compared to the control (p. 316)	-/-
Smukler et al. (2010)	California, USA	3	LO	508mm	16°C	E	CD	Tomato	Edge of Field	VB (Hedgerows)	Provisioning	FP: -	Yield (Mg/ha/year)	Tomatoes + Max. Hedgerows reduce yield by 8% in reference to Tomatoes only (p. 94)	■
											Regulating	WRSR: +	Infiltration rates (cm/min)	Tomatoes + Max. Hedgerows increase water flow regulation by 1% in reference to Tomatoes only (p. 94)	-/+
											Regulating	CR: •	mean emissions (mgCO_2 equivalents/m^2/h)	Tomatoes + Max. Hedgerows has no effect on climate regulation in reference to Tomatoes only (p. 94)	-/•
											Regulating	CR: +	Carbon storage (Mg C/ha)	Tomatoes + Max. Hedgerows increase carbon storage by 3% in reference to Tomatoes only (p. 94)	-/+
											Regulating	ER: •	Sediment loss (MgTSS/ha/year)	Tomatoes + Max. Hedgerows has no effect on erosion regulation in reference to Tomatoes only (p. 94)	-/•
											Regulating	WPWT: -	Nitrate Leaching (kgNO_3−N/ha/year)	Tomatoes + Max. Hedgerows reduce water quality by 5% in reference to Tomatoes only (p. 94)	-/-

											Supporting	BIO: •	Earthworm diversity (Taxa/farmscape)	Tomatoes + Max. Hedgerows had no effect on earthworm diversity in reference to Tomatoes only (p. 94)	-/•
											Supporting	BIO: +	Plant diversity (Species/farmscape)	Tomatoes + Max. Hedgerows increased plant diversity by 34% in reference to Tomatoes only (p. 94)	-/+
											Supporting	BIO: +	Nematode diversity (Taxa/farmscape)	Tomatoes + Max. Hedgerows increased nematode diversity by 10% in reference to Tomatoes only (p. 94)	-/+
											Supporting	BIO: +	Microbial diversity (PLFA/farmscape)	Tomatoes + Max. Hedgerows increased microbial diversity by 2% in reference to Tomatoes only (p. 94)	-/+
										VB (Hedgerows, Perennial Riparian Corridor)	Provisioning	FP: -	Yield (Mg/ha/year)	Tomatoes + Max. Perennials reduce yield by 13% in reference to Tomatoes only (p. 94)	■
											Regulating	WRSR: +	Infiltration rates (cm/min)	Tomatoes + Max. Perennials increase water flow regulation by 21% in reference to Tomatoes only (p. 94)	-/+
											Regulating	CR: +	mean emissions (mgCO$_2$ equivalents/m^2/h)	Tomatoes + Max. Perennials increased climate regulation by 1% in reference to Tomatoes only (p. 94)	-/+
											Regulating	CR: +	Carbon storage (Mg C/ha)	Tomatoes + Max. Perennials increase carbon storage by 21% in reference to Tomatoes only (p. 94)	-/+
											Regulating	ER: •	Sediment loss (MgTSS/ha/year)	Tomatoes + Max. Perennials has no effect on erosion regulation in reference to Tomatoes only (p. 94)	-/•
											Regulating	WPWT: +	Nitrate Leaching (kgNO$_3$−N/ha/year)	Tomatoes + Max. Perennials increase water quality by 3% in reference to Tomatoes only (p. 94)	-/+
											Supporting	BIO: •	Earthworm diversity (Taxa/farmscape)	Tomatoes + Max. Perennials had no effect on earthworm diversity in reference to Tomatoes only	-/•
											Supporting	BIO: +	Plant diversity (Species/farmscape)	Tomatoes + Max. Perennials increased plant diversity by 50% in reference to Tomatoes only (p. 94)	-/+
											Supporting	BIO: +	Nematode diversity (Taxa/farmscape)	Tomatoes + Max. Perennials increased nematode diversity by 21% in reference to Tomatoes only (p. 94)	-/+
											Supporting	BIO: +	Microbial diversity (PLFA/farmscape)	Tomatoes + Max. Perennials increased microbial diversity by 10% in reference to Tomatoes only (p. 94)	-/+
Del Grosso et al. (2009)	Global	4	INT	−	9.8°C	EM	CI	Corn	In-Field		Provisioning	FP: -	Grain yield	Reduced fertilizer resulted in lower N losses, but crop yields were	■

								Soybean Wheat		NM (Reduction of synthetic N fertilizer applied)				reduced by a similar proportion (p. 44)	
											Regulating	WPWT: +	NO_3 leached	Reduced fertilizer resulted in lower N losses, but crop yields were reduced by a similar proportion (p. 44)	-/+
										NM (Nitrification inhibitors)	Provisioning	FP: +	Grain yield	Use of nitrification inhibitors and split fertilizer applications both led to increased (~6%) crop yields but the inhibitor led to a larger reduction in N losses (~10%) (p. 44)	
											Regulating	WPWT: +	NO_3 leached	Use of nitrification inhibitors and split fertilizer applications both led to increased (~6%) crop yields but the inhibitor led to a larger reduction in N losses (~10%) (p. 44)	+/+
										MP: NM (Nitrification inhibitors) & TI (No-till)	Provisioning	FP: +	Grain yield	No-till cultivation, which led to C storage, combined with nitrification inhibitors, resulted in reduced GHG emissions of ~50% and increased crop yields of ~7% (p. 44)	
											Regulating	CR: +	Soil organic carbon	No-till cultivation, which led to C storage, combined with nitrification inhibitors, resulted in reduced GHG emissions of ~50% and increased crop yields of ~7% (p. 44)	+/+
Farahbakhshazad et al. (2008)	Iowa, USA	4	LO	910mm	9.6°C	EM	CI	Corn	In-Field	TI (No-till)	Provisioning	FP: -	Yield (kg/ha)	Corn yields with no-till (3830 kg C ha^{-1} or 9580 kg dry matter ha^{-1} as a 20-year average) were lower than that with conventional (4190 kg C ha^{-1} or 10500 kg dry matter ha 1 as a 20-year average) (p. 36)	
											Regulating	CR: +	Soil organic carbon [SOC] (kg/ha)	The results indicated that no-till practice significantly increased SOC storage (p .30) The 20-year average annual SOC change rates were 86 and 415 kg C ha^{-1} for conventional and no-till, respectively (p. 35)	-/+
								Soybean			Provisioning	FP: •	Yield (kg/ha)	The conversion of tillage had little effect on the soybean yields (p. 36)	
											Regulating	CR: +	Soil organic carbon [SOC] (kg/ha)	The results indicated that no-till practice significantly increased SOC storage (p .30) The 20-year average annual SOC change rates were 86 and 415 kg C ha^{-1} for conventional and no-till, respectively (p. 35)	•/+

Kaspar et al. (2007)	Iowa, USA	3	LO	837mm	9.2°C	E	CI	Corn	In-Field	CC (Rye)	Provisioning	FP: -	Crop grain yield (Mg/ha)	The corn grain yield of the cover crop treatment was significantly less than that of the control (p. 1507)	■
											Regulating	WPWT: +	Flow-weighted NO_3 concentration, cumulative NO_3 load	Averaged over 4 years, the rye cover crop reduced flow-weighted NO_3 concentrations by 59% and loads by 61% (p. 1503)	-/+
											Regulating	WRSR: •	Drainage (mm)	The rye cover crop treatment did not significantly reduce cumulative annual drainage (p. 1503)	-/•
								Soybean			Provisioning	FP: +	Crop grain yield (Mg/ha)	Soybean yields were not significantly reduced after the rye cover crop (p. 1507)	■
											Regulating	WPWT: +	Flow-weighted NO_3 concentration, cumulative NO_3 load	Averaged over 4 years, the rye cover crop reduced flow-weighted NO_3 concentrations by 59% and loads by 61% (p. 1503)	+/+
											Regulating	WRSR: •	Drainage (mm)	The rye cover crop treatment did not significantly reduce cumulative annual drainage (p. 1503)	+/•
								Corn Soybean	Edge of Field	VB (Gamagrass Buffer and Filter Strips)	Provisioning	FP: •	Crop grain yield (Mg/ha)	The gamagrass treatment did not significantly reduce corn or soybean yields of the harvested area (i.e. not including the gamagrass strip) (p. 1507)	■
											Regulating	WPWT: •	Flow-weighted NO_3 concentration, cumulative NO_3 load	The gamagrass strips did not significantly reduce the average annual flow-weighted NO_3 concentrations, or cumulative NO_3 loads averaged over the 4 years (p. 1504)	•/•
											Regulating	WRSR: •	Drainage (mm)	The gamagrass strips did not significantly reduce cumulative drainage over the 4 years (p. 1503)	•/•
Costamagna and Landis (2006)	Michigan, USA	1	LO	900mm	9°C	E	CI	Soybean	In-Field	TI (No-till)	Provisioning	FP: +	Yield (kg/ha)	Yield differed among treatments, with significantly higher levels in the no-till (1854.7 ± 35.7 kg/ha) than in the conventional treatments (1620.8 ± 78.5 kg/ha) (p. 1622)	■
											Regulating	PR: •	Aphid density (no./plant)	Agricultural treatments did not affect significantly the number of aphids… …we obtained evidence of strong top-down control on A. glycines population growth, but no evidence of bottom-up effects due to differing crop management systems (p. 1623)	+/•

											Supporting	BPPP: -	Aboveground net primary production (g/m^2)	The conventional treatment (515.9 ± 9.5 g/m^2), in the no-till treatment (462.3 ± 14.1 g/m^2) (p. 1622)	+/-
										MP: CC (leguminous) & NM (no synthetic fertilizer/chemical inputs)	Provisioning	FP: -	Yield (kg/ha)	Yield also differed among treatments, with higher levels in the conventional treatments (1620.8 ± 78.5 kg/ha) than in the zero-chemical input treatment (1009.5 ± 78.7 kg/ha) (p. 1622)	■
											Regulating	PR: •	Aphid density (no./plant)	Agricultural treatments did not affect significantly the number of aphids… …we obtained evidence of strong top-down control on A. glycines population growth, but no evidence of bottom-up effects due to differing crop management systems (p. 1623)	-/•
											Supporting	BPPP: -	Aboveground net primary production (g/m^2)	Aboveground net primary production was significantly lower in the zero-chemical input treatment (322.2 ± 22.3 g/m^2) than in the conventional treatment (515.9 ± 9.5 g/m^2) (p. 1622)	-/-
Al-Kaisi et al. (2005)	Iowa, USA	3	REG	910mm	9.7°C	E	CI	Corn Soybean	In-Field	TI (No-till)	Provisioning	FP: •	Yield (Mg/ha/yr)	Corn or soybean yields of no-tillage and chisel plowing systems were not statistically different averaged over seven yr of tillage practices in a corn–soybean rotation in any of the five soil associations (p. 643)	■
											Regulating	CR: +	Soil organic carbon (Mg/ha)	No-tillage resulted in greater SOC contents than chisel plowing at the end of 7 years of tillage practices averaged over the CNW, GPS, KFC, M, and OMT soil associations (p. 635)	•/+
											Supporting	NC: +	Total Nitrogen (Mg/ha)	No-tillage resulted in greater TN contents than chisel plowing at the end of 7 years of tillage practices averaged over the CNW, GPS, KFC, M, and OMT soil associations (p. 635)	•/+
Pimentel et al. (2005)	Pennsylvania, USA	4	LO	1104mm	12.4°C	E	CI	Corn Soybean Wheat	In-Field	MP: CC (Hairy Vetch, Rye), CR (Alfalfa, Red Clover) & NM (no synthetic fertilizer/chemical inputs)	Provisioning	FP: •	Yield (kg/ha)	Depending on the crop, soil, and weather conditions, organically managed crop yields on a per-ha basis can equal those from conventional agriculture (p. 580)	■
											Regulating	CR: +	Percentage Soil Carbon	Soil organic matter (soil carbon) was higher in the organic farming systems (p. 580)	•/+

											Regulating	WPWT: •	Nitrate Leaching (parts per million (ppm))	Similar rates of nitrate leaching were found to those in conventional corn and soybean production (p. 580)	•/•
											Supporting	NC: +	Percentage Soil Nitrogen	Nitrogen was higher in the organic farming systems (p. 580)	•/+
Cambardella et al. (2004)	Iowa, USA	4	LO	773mm	10.2 °C	E	CI	Corn	In-Field	TI (Ridge-till)	Provisioning	FP: +	Yield (Mg/ha)	Long-term average corn yields were greater under ridge-tillage at the watershed scale compared with conventional tillage (p. 264)	
											Regulating	ER: +	Sediment loss	Sediment loss was lower under ridge-tillage at the watershed scale compared with conventional tillage (p. 264)	+/+
											Supporting	SF: +	Soil Quality Index	Amounts of total and biologically active soil organic matter, infiltration, and soil quality index values were greater under ridge-tillage at the watershed scale compared with conventional tillage (p. 264)	+/+
Strock et al. (2004)	Minnesota, USA	3	LO	670mm	6.9°C	E	CI	Corn Soybean	In-Field	CC (Rye)	Provisioning	FP: •	Yield (Mg/ha)	Corn and soybean yield varied from year to year, but within each year, there was no statistically significant differences among cropping systems (p. 1012)	
											Regulating	WPWT: +	Nitrate Nitrogen Concentration and Loss (NO_3-N mg/L, kg/ha)	Over three years…NO_3-N was reduced 13% for a corn-soybean cropping system with a rye cover crop following corn than with no rye cover crop (p. 1010)	•/+
											Regulating	WRSR: +	Drainage discharge (mm)	Over three years, subsurface tile-drainage discharge was reduced by 11%...for a corn-soybean cropping system with a rye cover crop following corn than win no rye cover crop (p. 1010)	•/+
Tillman et al. (2004)	Georgia, USA	3	LO	1201mm	18.6°C	E	CI	Cotton	In-Field	CC (Balansa Clover, Crimson Clover, Hairy Vetch, Rye)	Provisioning	FP: •	Seed cotton yield (kg/ha)	Because yields for cover crop treatments were never lower than those for control cotton, we concluded that planting cotton in strip-killed and strip-tilled cover crops did not adversely affect cotton production (p. 1229)	
											Regulating	PR: +	Pest and predator insects	Reduction in the number of times in which economic thresholds for *heliothines* (pests) were exceeded in crimson clover and rye compared with control fields indicated that the buildup of predaceous fire ants and	•/+

														G. punctipes (predators) in these cover crops subsequently resulted in reduction in the level of *heliothines* in these cover crops compared with conventional tillage cotton without cover crops (p. 1217)	
Andersen (2003)	Norway	3	REG	760mm	6.8°C	E	CI	Barley Oats Wheat	In-Field	TI (Reduced-till: no-till or spring harrowing)	Provisioning	FP: •	Mean grain yield (1000 kg/ha) Grain weight per hectolitre (kg/hl)	Yield and GWHL were generally as high in plots with reduced tillage as in autumn ploughed plots (p. 148)	■
											Regulating	PR: +	Individuals per main shoot	The agromyzid Chromatomyia fuscula and the bird-cherry oat aphid, Rhopalosiphum padi were more numerous in autumn ploughed plots (p. 147) Generally, more carabids were captured in reduced tillage (p. 146)	•/+
Baylis et al. (2002)	USA (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, Pennsylvania, South Dakota, Texas, Wisconsin)	3	NAT	934mm	11.2°C	EM	CI	Corn	In-Field	TI (Conservation tillage: primarily no-till and mulch till, leaving at least 30% of the ground covered with crop residue)	Provisioning	FP: +	Bushel per acre yield	...the impact of conservation tillage on corn production costs and yields across the United States and found the practice to be generally beneficial (p. 386)	■
											Cultural	CS: +	Water-based recreation benefits: fishing, boating/floating, and swimming ($million/year)	The moderate conservation tillage adoption scenario results in an approximately $175 million increase in U.S. water-based recreational benefits Water-based recreational benefits would increase $67 million to $243 million (p. 390)	+/+
Brye et al. (2000)	Wisconsin, USA	3	LO	870mm	6.9°C	E	CI	Corn	In-Field	TI (No-till)	Provisioning	FP: +	Corn yield (Mg/ha/yr)	Similar productivity than the chisel-plow ecosystem suggests that a no-tillage ecosystem is more sustainable than the chisel-plow agroecosystem in terms of reducing potential adverse environmental impacts associated with soil water movement (p. 715) Average corn yields (± standard error [SE]) for the agroecosystems were 9.2 (0.7) and 9.0 (0.6) Mg ha^{-1} yr^{-1} for the chisel plow and no-tillage treatments (p. 716)	■
											Regulating	WRSR: +	Soil water storage (mm)	Higher soil water contents than the chisel-plow ecosystem suggests that a no-tillage ecosystem is more sustainable than the chisel-plow agroecosystem in terms of reducing	+/+

														potential adverse environmental impacts associated with soil water movement (p. 715)	
											Regulating	WRSR: +	Drainage (mm)	Total drainage was 563mm of water for the no-tillage maize ecosystem and 793 mm of water for the chisel plow maize ecosystem (p. 715)	+/+
Rickerl et al. (2000)	South Dakota, USA	3	LO	654mm	6.9°C	E	CI	Corn Oats Soybean	Edge of Field	VB (Wetland Buffer and Filter Strips - Alfalfa)	Provisioning	FP: -	Crop production/field (Mg), total dollars (annual average/field)	Buffering wetlands reduced crop hectares and production levels, but slightly increased average yields hectares (p. 223) Net returns from buffered wetland fields were relatively close to, but slightly lower than, net returns from maximum acres of crop production (p. 224)	
											Regulating	WPWT: +	Nutrient (ppm) Nitrate-N, Ortho-phosphate, Kjeldahl-N, Bray P, Nitrogen, Phosphorus	Results showed that the wetland buffer vegetation effectively removed nutrients, thus reducing nutrient content in wetland soils and vegetation (p. 220)	-/+
											Supporting	NC: +		Results showed that the wetland buffer vegetation effectively cycled captured nutrients through hay and forage crops (p. 220)	-/+
Andersen (1999)	Norway	3	REG	760mm	6.8°C	E	CI	Barley Oats Wheat	In-Field	TI (Reduced-till: no-till or spring harrowing)	Provisioning	FP: -	Mean grain yield (1000 kg/ha) Grain weight per hectolitre (kg/hl)	Yield was higher in autumn ploughed plots than in plots with reduced tillage (no-tillage or spring harrowing) (p. 652) There was a tendency for GWHL to be higher in autumn ploughed plots (p. 652)	
											Regulating	PR: +	Individuals per main shoot	Generally, more carabids and staphylinids (predators,) were caught in reduced tillage (p. 651) The agromyzid Chromatomyia fuscula (pest) was most common in autumn ploughed plants p. 651	-/+
Brust and House (1990)	North Carolina, USA	3	LO	1187mm	15.5°C	E	CI	Corn	In-Field	TI (No-till)	Provisioning	FP: +	Yield (kg/ha)	No-tillage systems had greater grain yields compared with conventional tillage systems (p. 199)	
											Regulating	PR: +	Number of Southern Corn Rootworm eggs, and soil predators	Predator activity was greatest in no-till systems, while in conventional systems (including irrigated) predator activity was much lower (p. 199)	+/+

														Root ratings and percent stand loss showed that southern corn rootworm feeding was greatest in conventional systems and least in no-tillage systems, regardless of irrigation (p. 199)	
Hudon et al. (1990)	Québec, Canada	3	LO	949mm	8°C	E	CI	Corn	In-Field	TI (No-till)	Provisioning	FP: -	Yield (g/plant)	Both conventional and plowing-disking in spring gave significantly higher yield over 5 years compared to no-tillage treatments (p. 27) However, it should be noted that although a small decrease in yield was apparent, the conservation tillage may still be preferred when erosion is a problem (p. 34)	■
											Regulating	PR: +	European Corn Borer Plant Damage	No-till reduced significantly ECB damage to plants (p. 27)	-/+
										TI (Ridge-till/Strip-till)	Provisioning	FP: -	Yield (g/plant)	Both conventional and plowing-disking in spring gave significantly higher yield over 5 years compared to no-tillage treatments (p. 27) However, it should be noted that although a small decrease in yield was apparent, the conservation tillage may still be preferred when erosion is a problem (p. 34)	■
											Regulating	PR: +	European Corn Borer Plant Damage	No-till with strip ridges reduced significantly ECB damage to plants (p. 27)	-/+
Kemp and Barrett (1989)	Ohio, USA	2	LO	889mm	13°C	E	CI	Soybean	Edge of Field	VB (Buffer and Filter Strips – Grassy Corridors)	Provisioning	FP: +	Yield (soybeans per metre of soybean row)	Yield differed significantly among all treatments, with treatments divided by grassy corridors > undivided controls (p. 114) Yield per row^{-m} in plots divided by grassy corridors was 8.5% higher than in control plots (p. 120)	■
											Regulating	PR: •	Leaf damage (%) Densities of defoliators Arthropod abundance	Levels of leaf damage and arthropod abundances generally were similar between control plots and plots divided by grassy corridors	+/•
											Provisioning	FP: -	Yield (soybeans per metre of soybean row)	Plots divided by successional corridors produced the lowest yield, with values 10% lower than in control plots (p. 120)	■
											Regulating	PR: -	Leaf damage (%) Densities of defoliators Arthropod abundance	Plots divided by successional corridors, which had the lowest yields and the highest levels of defoliation, also had significantly	-/-

														higher abundances of *Epilachna varivestis*, lepidopteran larvae, leafhoppers, and murids than controls during at least one sampling period (p. 114)	
Blevins et al. (1983)	Kentucky, USA	3	LO	1148mm	13.1°C	E	CI	Corn	In-Field	TI (No-till)	Provisioning	FP: •	Corn grain yield (t/ha)	At low rates of N fertilization the 10-year average corn yield was higher for conventional tillage than for no-tillage, but at high rates of N fertilization it was equal or higher for no-tillage treatments receiving lime (p. 135)	■
											Regulating	ER: •	Soil bulk density	Tillage treatments had no effect on soil bulk density in the 0-15 cm layer (p. 135)	•/•
											Supporting	NC: +	Organic C and N (%)	In the 0-5 cm surface layer, organic C and N were approximately twice as high with no-tillage as with conventional tillage (p. 135)	•/+
Stinner et al. (1983)	Georgia, USA	3	LO	1178mm	16.9°C	E	CI	Sorghum	In-Field	TI (No-till)	Provisioning	FP: +	Grain yield (kg/ha)	Grain yields in 1979 were significantly greater (P <0.01) in no-tillage (5546 kg/ha) than in conventional systems (4562 kg/ha) (p. 4) Yields in no-tillage systems were equal to or higher than those in conventional tillage (p. 11)	■
											Regulating	WPWT: +	Soil nutrient leaching	No-tillage soils leached less N and Ca than did conventional tillage soils (p. 11)	+/+
											Supporting	NC: +	Mean nutrient concentrations	Nutrient cycling processes in no-tillage systems resembled those in the old field, suggesting that no-tillage systems retained or mimicked nutrient conservation mechanisms thought to exist in natural or less disturbed ecosystems (p. 11-12)	+/+

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Appendix E

Additional descriptive results.

Overview

The mean number of **YESs** over studies was four per study; with the largest amount of studies falling under the category which investigated two **YESs** (Fig E.1).

Soil classifications

Of the 24 studies that included information on soil type/classifications: 41% of studies classified soil as Silt Loam, 25% Loam, 17% Clay Loam, 8% Loamy Sand and 8% Sandy Clay Loam. For some other variables (i.e. candidate moderating factors) of interest – soil type, elevation, topography – data were not consistently reported and available across studies.

BMPs

The most frequent individually applied BMP category were *reduced tillage* (25%) which most often took the form of comparing a no-till treatment to a conventional mechanical-tillage control (Fig. E.2A). Thirty-one **YESs** (22%) combined multiple practices, most often, a combination which included *cover crops* and *nutrient management* (Fig. E.2B, Table E.1).

BMP Category

Of the BMPs investigated, 117 (83%) were categorized as In-Field (*on-farm*) practices, and 24 (17%) as Edge of Field (*off-farm*) practices.

Study Type and Study Design

Of the extracted **YESs**, 74% were categorized as *empirical* studies while 26% were categorized as *empirical-modelled* studies; that is, studies where a model was built that used modelled parameters estimated from empirical data (Fig. E.3A). While 67% were from studies that employed a *control-impact* design and 33% from a *correlative design* (Fig. E.3B).

Spatial Scale and Temporal Scale

The majority of **YESs** were scored at the *local* spatial scale (70%), followed by *regional* (26%), *international* (3%) and *national* spatial scales (1%) (Fig. E.3C). Meanwhile most **YESs** were scored within the *very long* temporal scale (i.e. decades) (51%), followed closely by *long* (i.e. several years to <10 years) (43%) and then less at *short* (i.e. weeks) (4%) and *medium* temporal scales (i.e. months to a year) (2%) (Fig. E.3D).

At the individual-study level (*k* = 36) multiple **YESs** come disproportionately from *regional* spatial scales and *very long* temporal scales. At the individual-study level the majority of studies occur at the *local* spatial scale (67%), followed by *international* (25%), *regional* (6%) and *national* spatial scales (3%). While individual studies most often took place at *long* temporal scales (56%), followed by *very long* (33%), and then *short* (6%) and *medium* (6%).

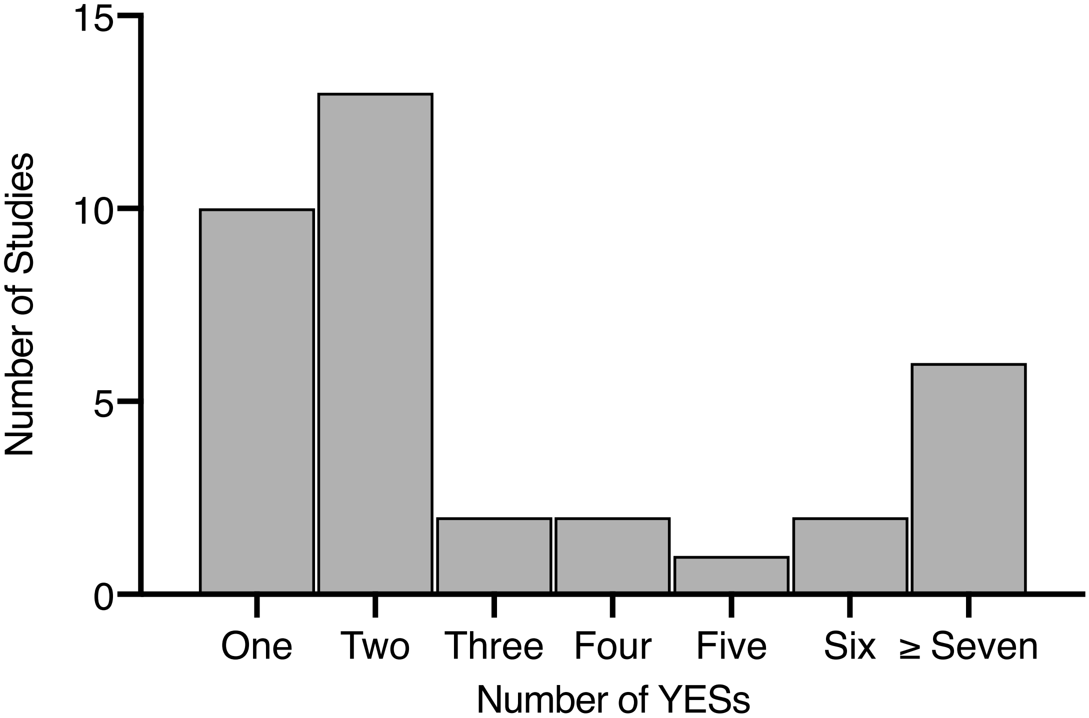

Figure E.1. The number of **YESs** (*n* = 141) distributed over (*k* = 36) studies.

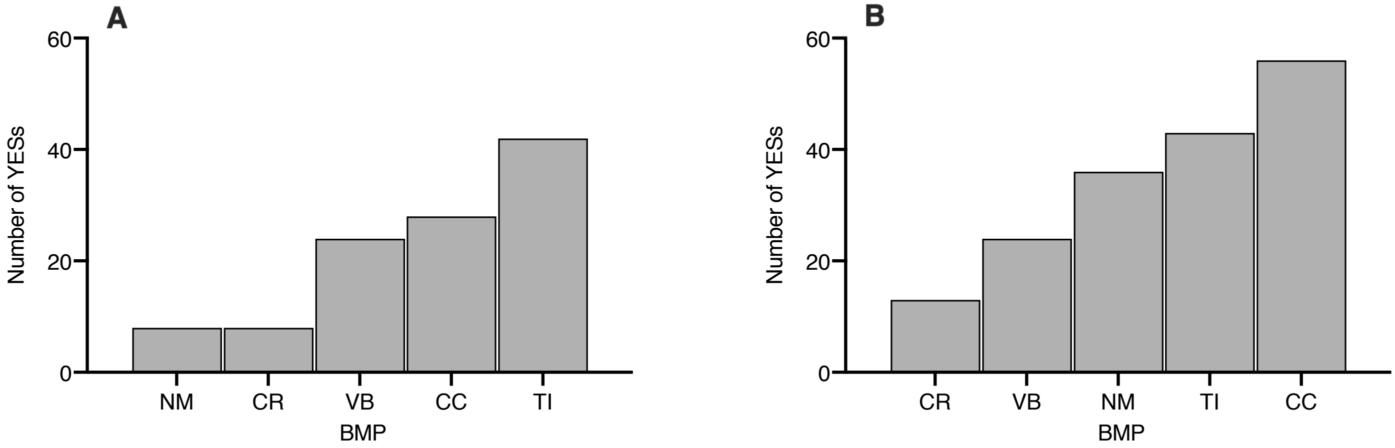

Figure E.2. The number of **YESs** distributed over (A) individually-applied BMPs (cover crops, crop rotations, nutrient management, reduced tillage, perennial vegetative buffers) (*n* = 110) and (B) individually-applied BMPS *and* practices applied in combination (*n* = 172).

Table E.1. The frequency counts of BMP combinations distributed over **YESs** and individual studies. Several studies (*n* = 12) investigated multiple different BMPs for **YES** outcomes.

BMPs	Number of YESs	Number of Individual Studies
VB	24	4
CC	28	10
CR	8	4
NM	8	4
TI	42	19
CC + NM	25	4
CR + NM	2	1
NM + TI	1	1
CC + CR + NM	3	1
TOTAL	**141**	**48**

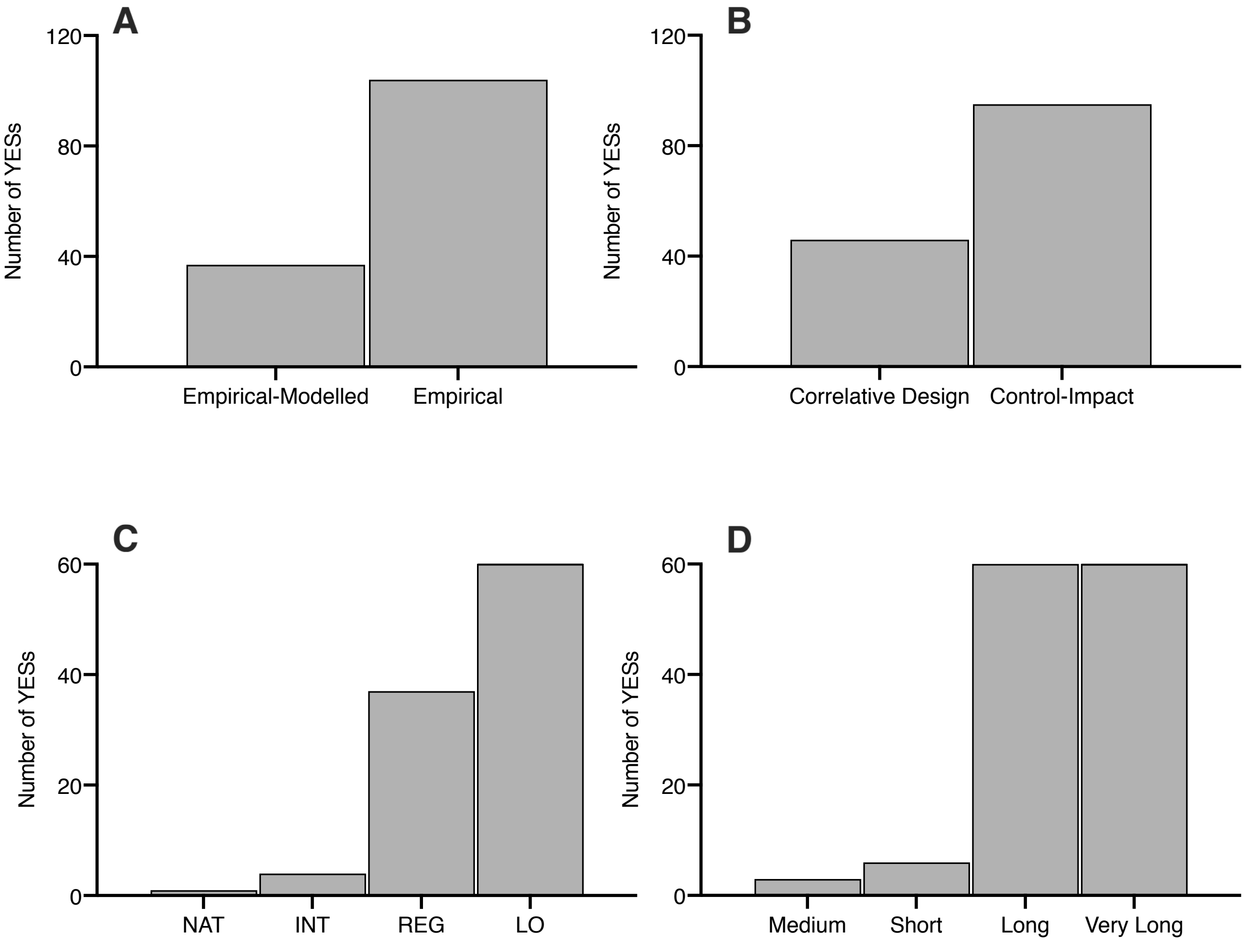

Figure E.3. The number of **YESs** distributed over (A) study type, (B) study design, (C) spatial scale (local, regional, international, national), and (D) temporal scale (each panel *n* = 141).