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Abstract

In the Mediterranean region, the long-term provision of agro-ecosystem services is threatened by accelerating climate change, unsustainable farming practices and other pressures. Alternative management practices such as conservation agriculture could be expected to ensure sustainability of ecosystem services from Mediterranean agro-ecosystems. Conservation agriculture is characterized by minimal soil disturbance, permanent soil cover, and diversification of crop species. We analyzed the impacts of several forms of alternative agricultural management practices (conservation tillage, cover cropping, mulching, manual weed management, organic fertilizer use, no-irrigation system) on multiple ecosystem services based on 155 published case studies (1994-2015). The effect size of various management options on four provisioning and four regulating ecosystem services were quantified. Impacts of conservation management options are not uniform. All regulating services were positively affected by the conservation management options except for the system without irrigation. In contrast, the provisioning services were inconsistently influenced by the conservation management options. For crop yield, environmentally sustainable soil management was beneficial, but organic fertilization (effect size = -0.17), manual weed management (effect size = -0.35) and no-irrigation system (effect size = -0.5) led to lower crop yields. The impact on crop biomass was mainly negative but not significant. Water availability was especially important to enhance both provisioning and regulating services. Overall, alternative agriculture management practices led to more positive than negative effects on ecosystem services in the study region. Stimulating the application of conservation management practices is therefore an important policy option for decision makers given the vulnerability of ecosystem services in the Mediterranean basin.

Keywords: Farming practices, Farming system, Literature review, Trade-offs, Mediterranean region, Conservation agriculture

doi:10.1007/s10113-018-1447-y

1. Introduction

Ecosystems in the Mediterranean basin provide numerous ecosystem services to society and host high levels of biodiversity (Pretty, 2008; Martín-López et al., 2016; Malek and Verburg, 2017). Yet, they are threatened by both climate change and socio-economic factors (Giorgi, 2006; Hill et al., 2008; Bajocco et al., 2012). The Mediterranean climate is characterized by wet and mild winters and hot and dry summers (Perez, 1990; Sanz-Cobena et al., 2017), generating strong seasonal dryness with increased water stress. Due to climate change, many Mediterranean ecosystems are threatened by potentially severe water shortages (Wimmer et al., 2015; Holman et al., 2017) and drought-related loss of ecosystems in the future (Guiot and Cramer, 2016). At the same time, unsustainable rural land management accelerates land degradation in the Mediterranean basin (Geist and Lambin, 2004; Hill et al., 2008; Bajocco et al., 2012; van Vliet et al., 2015). For example, intensified agriculture with a high application of fertilizers and pesticides, along with machinery, has degraded the quality of soil and water (Zalidis et al., 2002; Debolini et al., 2018). The combination of climate change and land degradation increases the vulnerability of agro-ecosystems and the economy depending on them (Berry et al., 2006; Thomas, 2008). It is likely that demand for agricultural production in the Mediterranean basin increases in the future (Iglesias et al., 2011), which requires necessary mitigation and adaptation actions (Foley et al., 2011; Smith et al., 2013).

Agricultural management affects ecosystem services in different ways (Andersen et al., 2013; Palm et al., 2014). Although yields may increase in the short term with intensive management, qualitative relationships between ecosystem services may often indicate negative effects of intensive farming on regulating services, such as air and water quality regulating services (Pilgrim et al., 2010). To meet food security as well as environmental objectives in agro-ecosystem management, sustainable solutions will need to enhance multiple ecosystem services and minimize trade-offs effects (Kroeger and Casey, 2007; Pretty, 2008; Foley et al., 2011; Smith et al., 2013).

Conservation agriculture is now increasingly recognized for its capacity to minimize trade-offs between ecosystem services and maximize synergies between them (Hobbs et al., 2008; Pretty, 2008; Palm et al., 2014). Conservation agriculture is characterized mainly by minimal soil disturbance, permanent soil cover, and diversification of crop species (FAO, 2008). It aims to improve biodiversity and biological processes in soils, and encourages applications of organic fertilizers to limit interference with soil biological processes (FAO, 2015b). Conservation agricultural practices therefore provide an alternative for preserving multiple ecosystem services provided in agricultural land (Poisot et al., 2004; Howden et al., 2007). Several conservative practices were reviewed for the Mediterranean Basin (e.g., Kassam et al., 2012; Aguilera et al., 2013a,b). However, these review studies focused either on a single ecosystem service (e.g., carbon sequestration, Aguilera et al. (2013a)) or a limited number of management options (e.g., fertilization and irrigation, Aguilera et al. (2013b)) – this limits their use for a comprehensive overview of relationships between multiple services affected by farming practices.

The objective of this study is to fill this knowledge gap by conducting a meta-analysis on the impact of conservative management practices on ecosystem services in the Mediterranean basin based on published literature. Our goal is to identify the positive and negative impacts of conservation farming practices on ecosystem services in the Mediterranean basin, providing evidence-based recommendations for sustainable land management in the Mediterranean basin in the future.

2. Material and methods

2.1. Literature selection

For a systematic and reproducible literature review, we followed a four-step procedure (Collaboration for Environmental Evidence, 2013). Target literature was selected following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) framework: *Identification, Screening, Eligibility, Inclusion* (Moher et al., 2009) (Supplementary Fig. SF1). Literature searches were conducted in the ISI Web of Knowledge core database targeting peer-reviewed articles published online until April 30th, 2015 in two steps. In a first query, we tested it by including a specific management option such as 'irrigation' because water shortage is conceived as a potential threat to the Mediterranean agricultural system (Fader et al., 2016; Malek and Verburg, 2017). The search terms for the first query was thus *("agro*" OR "agri*" Or "farm*") AND (mediterranean*) AND (ecosystem*) AND (management*) AND (irrigat*)* in the topic field. This query yielded 45 papers. Then, we strove to capture the diversity of farming practices studied in case studies by not including any à priori restrictive search terms. This additional query was made with combinations of keywords including *("agro*" OR "agri*" Or "farm*") AND (mediterranean*) AND (management*)* in the topic field. Similarly, we strove to include all papers that contained relevant information on ecosystem services, and a large number of indicators that were used in the literature to quantify the supply of those services. We therefore refrained from using 'ecosystem services' as a search term. Doing so helped to include relevant papers such as traditional agronomy research out of the domain of ecosystem services. The additional query returned data records for 1,881 peer-reviewed articles.

The first (n = 45) and the second query (n = 1,881) resulted in total 1,926 papers (*Identification*). After removing duplicate articles (n = 17) and adding one relevant article manually as suggested by a contacted author (Roper et al., 2013), a total of 1,910 articles was used as the initial data base. From this initial database, we screened articles using title, abstract and full text (Supplementary Fig. SF1, (*Screening, Eligibility*). We selected empirical case studies which measured ecosystem services-related properties both for conservation (treatment) and conventional (control) management options. This step excluded pure simulation modeling studies and reviews. We focused on papers reporting results from the Mediterranean Basin but included six well-designed papers (see the caption of Supplementary Fig. SF1) reporting from Mediterranean climate regions outside the basin (i.e., South and South West Australia, the Cape of South Africa, Central Chile, and California (di Castri and Mooney, 1973; Perez, 1990)). Finally, a total of 155 publications were included in the main analysis (The geolocations of studied management practices are provided in Supplementary Fig. SF2). For the full list of the included papers, the reader is referred to the Supplementary materials.).

2.2. Identification of management and ecosystem services

2.2.1. Management types and options

We considered six major management types (i) tillage, (ii) mulching, (iii) use of cover crops, (iv) fertilization, (v) weed management, and (vi) water management (Table 1), all of which had more than 10 case studies in our literature database. In the following, we describe shortly each management type and the corresponding pairwise conventional (control) and conservation (treatment) management options.

Tillage. Conservative tillage aims to minimize soil disturbance. Tillage physically disturbs upper soil layers, thereby facilitating soil aeration, water infiltration as well as inhibiting weeds growth (Phillips et al., 1980). However, it is also known that tilling damages soil structure and harms soil organisms, which can lead to soil quality degradation (Six et al., 2000; Montgomery, 2007a). The effect of tillage in yield and biomass production has also been questioned (Alvarez and Steinbach, 2009). In the Mediterranean region, heavy tillage using machinery is prevailing as it is in many other agricultural regions. However, conservation tilling (i.e., reduced tillage frequencies or tillage depths) or no-tilling has also been applied in the region (Sartori and Peruzzi, 1994; Vita et al., 2007). For our analysis, we considered conservation tillage including no-tillage and reduced-tillage as treatment and the conventional tillage as control.

Mulch. Mulching is another alternative soil management practice. It helps to maintain more vegetation cover on the topsoil, thereby protecting the soil surface. This practice is known to help maintain the soil structure, benefiting many soil organisms (FAO, 2015a). It also protects the soil from erosion and keeps soil moisture (García-Orenes et al., 2009). Generally, organic materials such as plant residues, straw, and leaves are used for mulching, but non-organic materials such as a plastic cover are also applied as well (Kasirajan and Ngouajio, 2012). In our study, mulch was regarded as a conservation practice, thus considered as a treatment. No-mulch was used as the control in the meta-analysis.

Use of cover crops. Cover crops are planted after harvesting and before planting of cash crops to cover the ground, to prevent the soil loss and to maintain soil quality, water retention, and soil nutrients (Reeves, 1994). Cover crops may positively affect soil water relationships depending on climate and management (Unger and Vigil, 1998). To meet those objectives, cover crops should have rapid growth rates and good disease tolerance (Reeves, 1994, p. 137-138). They also contribute to weed suppression (Amossé et al., 2013). Legumes, herbal crops, and grain crops are often cultivated as cover crops (e.g., Ruiz-Colmenero et al., 2013; Campigli et al., 2014; Njeru et al., 2014), legumes being particularly interesting in organic farming for their improvement of N nutrition (Amossé et al., 2014). In our analysis, use of cover crops was considered as treatment and no use of cover crops as control.

Fertilization. Use of organic fertilizer has been reported to have less impact on environmental conditions, which potentially secures more ecosystem services (Sandhu et al., 2010). Several reviews of the effect of organic practices on environmental impacts revealed that organic fertilizer use improves soil quality, typically by leading to higher soil organic matter content (Mondelaers et al., 2009; Tuomisto et al., 2012). For the effect of fertilizer management, we compared organic fertilizer or non-fertilizer with inorganic fertilizer as control. We did not distinguish between different types of input organic materials in our analysis because of insufficient data.

Weed management. Weeds are plants competing with crops for water and nutrient during the growing season (Hager, 2015). A significant yield loss can occur due to the light and nutrient competition between crops and weeds (Slaughter et al., 2008) - therefore weed control is critically important in agriculture. In conventional agriculture, farmers often control weeds using agro-chemicals. Since negative effects of chemical weed management methods on ecosystems, biodiversity and human health have been reported (Cox and Surgan, 2006; Buchanan et al., 2011; Blair et al., 2015; Holt et al., 2016), there have been many efforts to reduce their usage. In our analysis, we compared the impact of conservative weed management practices which do not require chemicals such as mow, manual controlling (treatment) against practices involving chemical applications (control).

Water management. Irrigation provides a controlled amount of water to the crop to reduce water stress (Walker, 1989). In semi-arid regions such as the Mediterranean basin, irrigation increases productivity compared to rain-fed agriculture (Iglesias et al., 2011). Yet, irrigation can have negative side effects. For example, poor management can lead to salinization by overusing groundwater (Baldock et al., 2000; Bouarfa et al., 2009). In our analysis, we contrasted rain-fed systems as treatment with irrigated systems as the control group. Various irrigation systems including surface, drip, and sprinkler methods were all regrouped as 'irrigation', for simplicity.

Table 1: Six major management types and corresponding conventional (control) and conservative (treatment) management options evaluated in the meta-analysis.

Management type	Conventional option (control)		Conservative option (treatment)	
	Name	Issues	Name	Desired effect
Tillage	Conventional tillage	Severe soil disturbance and increased greenhouse gas emissions	Reduced tillage; No tillage	Minimal soil disturbance, greenhouse gas emissions, improved soil cover and erosion control
Mulch	No mulch	Soil erosion, soil degradation, soil moisture loss	Mulch (residue, straw, grain, plastic)	
Cover cropping	No cover cropping		Cover cropping	
Fertilization	Chemical fertilizer application	Soil and water quality degradation	Organic fertilization; No fertilization	Soil and water quality improvement
Weed management	Chemical application	Biodiversity loss and food safety	Manual control; No weed control	Nurturing biodiversity and food safety
Water management	Irrigation	Avoiding water stress but increasing salinization and water pollution	Rain-fed (no irrigation)	Reducing soil and water pollution

2.2.2. *Ecosystem services indicators*

The linkage between indicators and ecosystem services was done based on several established frameworks (Dale and Polasky, 2007; Stott et al., 2009; Dominati et al., 2010; de Groot et al., 2010; Verhulst et al., 2010; Palm et al., 2014) (Supplementary Table ST1). Ecosystem service categories were defined using the Common International Classification of Ecosystem Services (CICES) classification V4.3 (Haines-Young and Potschin, 2013). The CICES follows a nested hierarchical structure of ecosystem services, which includes the levels of 'section', 'division', 'group', and 'class' (Haines-Young and Potschin, 2013). For our analysis we chose the CICES 'group' level to aggregate indicators (Supplementary Table ST2). We made short names for the ecosystem services categories based on the CICES description for readability (Supplementary Table ST1). From now on, the short names refer to the CICES 'group' level unless mentioned otherwise. For the detailed CICES classification, we refer readers to the Supplementary table ST3.

The mean, standard deviation, and sample size for indicators studied in each case study were extracted from texts, figures, and tables of the original literature. If a study presented the data only on the figures, we used WebPlotDigitizer (Rohatgi, 2017) to extract the data.

2.3. *A meta-analysis: impacts of management options on ecosystem services*

We analyzed the impact of different management options on ecosystem services from publications through a meta-analysis. A meta-analysis is a statistical method to summarize the results from findings across multiple case studies by calculating effect sizes (Higgins et al., 2002; Vetter et al., 2013). The effect size is a measure of the magnitude of effects of a treatment group (Lipsey and Wilson, 1993). We calculated the response ratio as an effect size unit for each indicator (Hedges et al., 1999; Borenstein et al., 2009) (Eq. 1). This metric has been widely used for meta-analyses in ecology and agricultural studies (e.g., Aguilera et al., 2013a; Curran et al., 2014; Torralba et al., 2016). The response ratio was calculated as a proportionate change in the indicator value of the treatment group ($\overline{X_{CS}}$) compared to the pairwise control group ($\overline{X_C}$). We used the natural logarithm of the response ratio (log(RR); lRR) for the analysis:

$$log\ (Response\ Ratio) = ln(\overline{X_{CS}}/\overline{X_C}) = ln(\overline{X_{CS}}) - ln(\overline{X_C}). \quad (1)$$

Positive values indicate a higher value in the treatment group (conservation practices), whereas negative values indicate a lower in the treatment group (conservation practices).

To account for differences in measures reported in different studies, we calculated the weighted mean of lRR from individual studies for deriving representative response ratio per indicator. In the meta-analysis, numbers from the studies are weighted by the inverse of the reported standard deviation/standard error of the indicators, thereby, a case study which is more certain about the estimated effect is weighed higher during aggregation (Borenstein et al., 2009). Weighting by the standard deviation is the standard approach in the meta-analysis as it explicitly accounts for the variance, however the standard deviation was not reported in all case studies. We contacted the corresponding authors of the studies which did not provide uncertainty information (n = 33) but obtained answers only from five authors. Moreover, the uncertainty information actually provided was often incompatible among the studies due to heterogeneous criteria (e.g., the standard deviation of the sampled raw data or the standard error of the aggregated mean). To secure statistical significance by keeping a sufficient sample size, we decided to weight observations using the sample sizes: studies with larger sample sizes were weighted higher during aggregation (Adams et al., 1997). With this simpler approach, the weighted log response ratio (WlRR) of management option i is calculated as

$$WlRR_i = \frac{1}{N_i} \sum lRR_{ij} \times W_{ij}, \tag{2}$$

where N_i is the number of the studies for the management i, lRR_{ij} is the log response ratio of the management i in study j, and W_{ij} is the weight, which is defined as

$$W_{ij} = \frac{N_{ij}^{CS} N_{ij}^{C}}{N_{ij}^{CS} + N_{ij}^{C}}, \tag{3}$$

where N_{ij}^{CS} and N_{ij}^{C} are the sample size of the conservation option and the conventional option of the management i in study j, respectively (Hedges and Olkin, 1985; Adams et al., 1997). Note that if a study had not provided the sample size, we excluded the study from the analysis (n=1).

For the uncertainty analysis, we report the means and 95% confidence intervals (CIs) of the WlRR. The CIs were constructed by non-parametric bootstrapping ($n_{boot} = 10,000$) (Adams et al., 1997) using the percentile method (Davison and Hinkley, 1997). The bootstrapping was only conducted for management options with more than seven case studies (n ≥ 8) as the bootstrap is unreliable when the sample size is too small (Efron and Tibshirani, 1994). For those with the sample size less than 8 (n < 8), we reported the mean weighted response ratio (WlRR) without estimated CIs. We considered the effect of treatment as significant if the 95% bootstrap CI did not overlap with zero. To aid interpretation, mean response ratios and lower and upper limits of CIs were graphically examined using violin plots (n ≥ 8) (Adler, 2005). When the sample size was less than 8 (n < 8), the strip chart was constructed to visualize data points. All calculations were done in `R` version 3.3.1 (R Core Team, 2016) using the packages `boot` (Canty and Ripley, 2017) and `vioplot` (Adler, 2005).

3. Results

3.1. Management types

The final selection of publications included 155 articles covering 189 observed locations (Supplementary Fig. SF2): most of the case studies were located in the Mediterranean basin (96.2%); there were four study sites in the Mediterranean climate located in North America, two in South America, and one in Australia. In the Mediterranean basin, case studies were concentrated in European Mediterranean countries. The majority of the studies (92.9%) were implemented on agricultural land, 59.6% among which analyzed cereal crops, 22.6% orchard, and 12.3% horticulture. A small portion (4.5%) of the studies analyzed silvopastoral and *dehesa* systems, which is a typical extensive multifunctional agro-silvopastoral system in the Mediterranean region especially in Spain and Portugal (Joffre et al., 1988; Fra-Paleo, 2010).

Ten different management options were found. The most frequently studied management was 'Tillage' (n = 87) followed by 'Fertilization' (n = 47), 'Mulch' (n = 23), 'Water management' (n = 22), 'Cover Crop' (n = 21), and 'Weed management' (n=14). We took these six major management types ($n > 10$) in the following analysis. Less frequently encountered management options included ‘Crop rotation’ (n = 10), ‘Grazing’ (n=5), ‘Planting density’ (n = 1), and ‘Intercropping’ (n=1).

As it is shown by the main diagonal of the matrix, the majority of case studies focused on a single management type (n = 95; 60.9%, Supplementary Fig. SF4). In some studies multiple management options were jointly investigated in combinations. Some pairs were distinctive: tillage and mulch (n = 15) and tillage and cover crop (n = 10). Several soil management practices were often studied together. Tillage was most frequently studied with other management practices (n = 19). At most four management practices were analyzed in a same study (n = 1).

3.2. Indicators used in the literature

In the selected case studies, 167 indicators were used. The most frequently measured indicator was ‘yield’ (n = 70) followed by ‘soil organic carbon (SOC)’ (n = 40), ‘biomass’ (n = 28), and ‘total nitrogen (TN)’ (n = 24). Among all the studied indicators only 7.8% indicators (n = 13) appeared in more than 10 case studies. About 60% of the indicators appeared only in a single case study (n = 100). The use of the indicators was related to management types (Fig. 1). For example, ‘bulk density’ was frequently measured in studies dealing with the cover crop management, whereas studies about weed or water management hardly considered bulk density simultaneously (Fig. 1). Likewise, for water management, ‘pH’ and ‘harvest index (HI)’ were frequently measured, and ‘soil loss’ and ‘runoff’ were often used in the studies that investigated the use of cover crops.

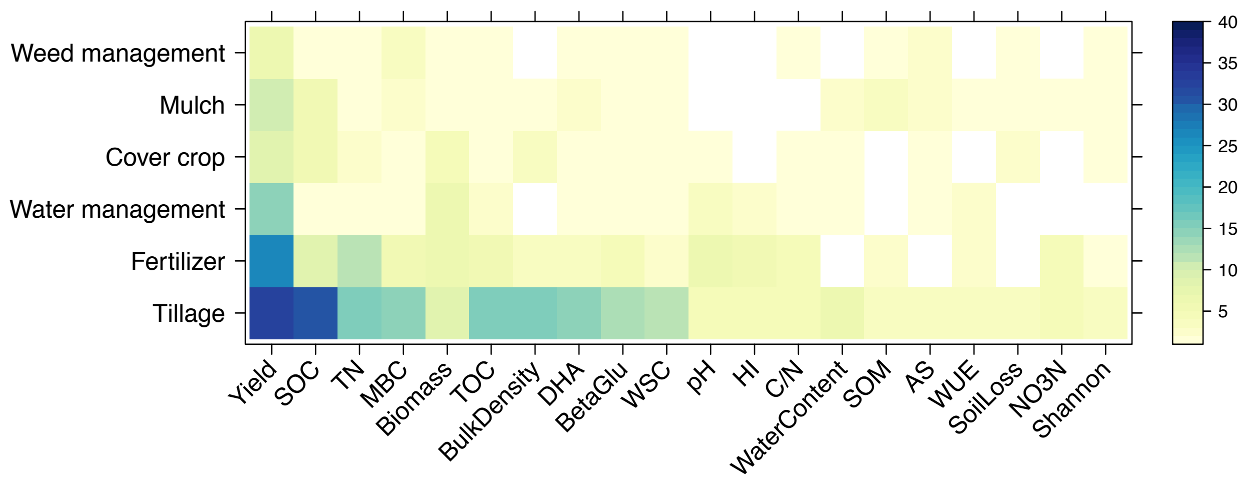

Figure 1: Top 20 indicators addressed across the case studies for each management practices. The colors represent the number of case studies; Y-axis refers to management types; x-axis refers to indicators: SOC: Soil Organic Carbon, TN: Total Nitrogen, MBC: Microbial Biomass Carbon, TOC:Total Organic Carbon, BulkDensity: Bulk density, DHA: Dehydrogenase Activity, BetaGlu: beta-Glucosidase, WSC: water soluble carbon, HI: Harvest Index, SOM: Soil Organic Matter, AS: Aggregate stability, WUE: Water Use Efficiency, Shannon: Shannon Index. The explanation of indicators is given in Supplementary Table ST2.

The indicators were assigned to nine different ecosystem services described in Supplementary Table ST1: four types of provisioning and five types of regulating services (Fig 2). Cultural services were not analyzed in the selected case studies. The ‘Pest control’ regulating service was only observed in studies that were excluded from further analysis due to seldom encountered management options. The majority of studies analyzed one type of ecosystem service (66.4%, n = 103), whereas 33.5% of studies analyzed multiple ecosystem services in a study (48 studies analyzed two services, 4 studies analyzed three services). The most frequently studied ecosystem service was 'Soil formation' regulating services (n = 76) followed by 'Food' provisioning service (n = 68) (Fig 2).

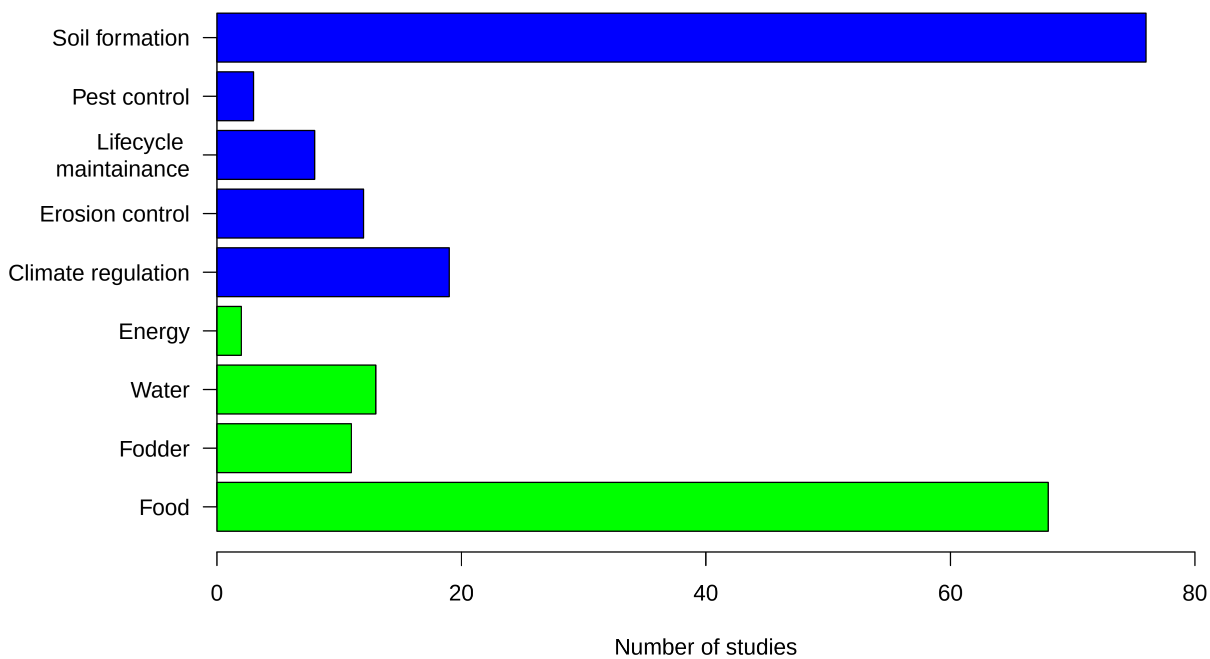

Figure 2: The frequency with which ecosystem services were included across the case studies. The color indicates the different ecosystem services groups: Provisioning ecosystem services are depicted green and regulating ecosystem services blue.

3.3. Impacts of conservative management practices on ecosystem services

Overall, conservation management increased yield and biomass. The yield was even slightly higher in reduced soil disturbance systems as a result of conservation tillage, mulch, and cover crops. However, the effect of tillage itself was not significant (Fig. 3, (a)).

For mulching, water content was higher than in conventional farming systems (Fig. 3, (b)), which might explain the increased yield when mulching is applied. Exceptions of the positive effect on yield were the use of organic fertilizer and organic weed management (mow, manual controlling), as well as rain-fed. WlRR was -0.14 and -0.24 for the organic fertilizer and the manual weed management, respectively. Under the rain-fed system, yield was most negatively affected (WlRR = -0.501, significant). Indicators related to 'Soil formation' regulating service showed an overall positive effect size by the conservative practices (Fig. 3, (a)-(d)). 'Soil organic carbon' as an indicator for 'Climate regulation' or 'Soil formation ' services was affected positively by reduced tillage (WlRR = 0.088, significant), use of organic fertilizers (WlRR = 0.15, significant) and cover crop (WlRR = 0.213) and mulch (WlRR = 0.403). 'Species richness' was only

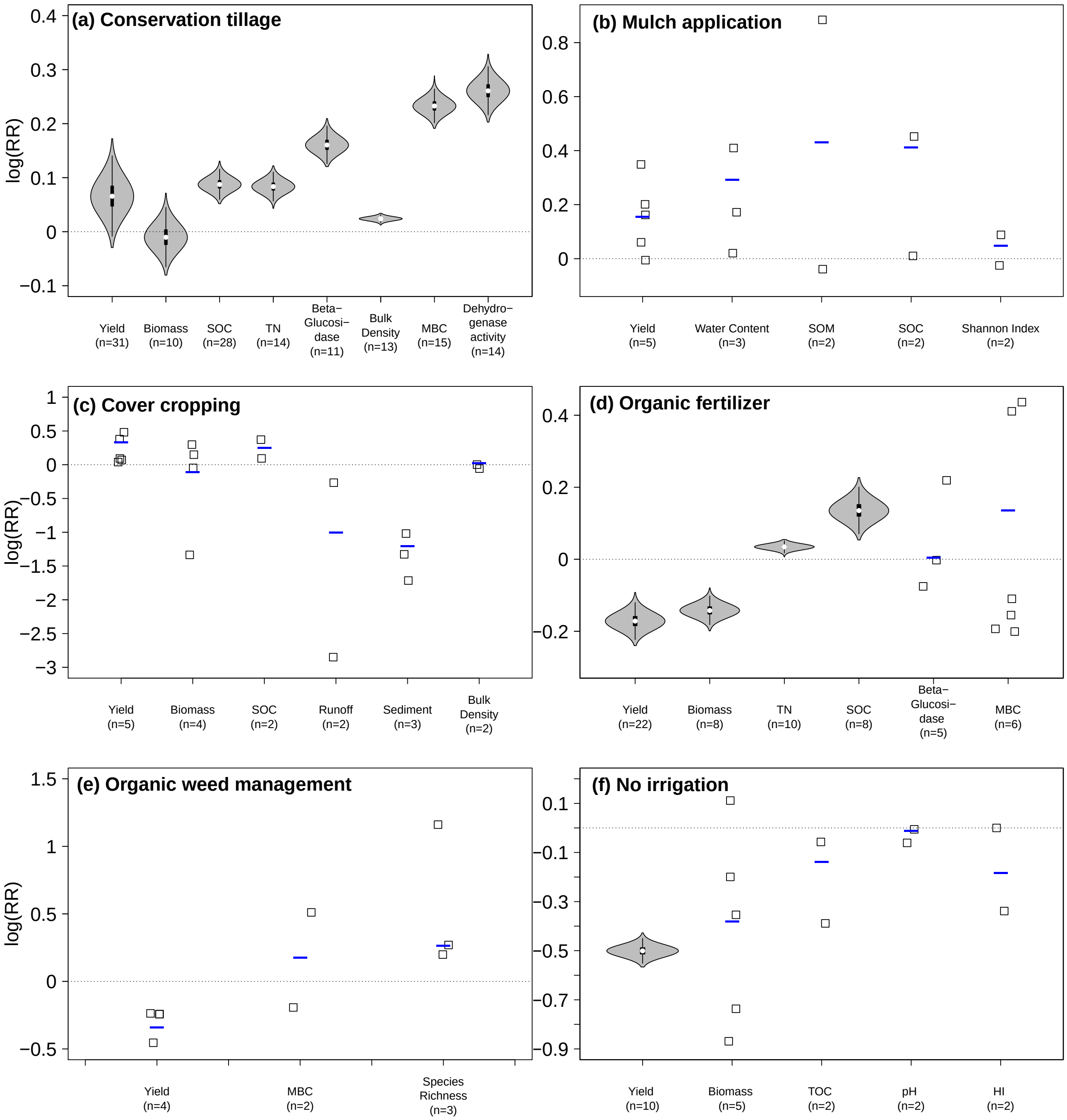

Figure 3: Violin plot (a, d, f) with overlaid boxplot of the mean effect size (log response ratio; log(RR)) of the conservation management options on different indicators for ecosystem services from Table ST2. The variance was constructed by non-parametric bootstrapping (n_{boot} = 10000) when the sample size was lager than seven (n ≥ 8). When the sample size is less than eight (n < 8), strip chart (b, c, e) of the effect size was plotted (jittered for clarity). Blue hyphens indicate the mean weighted response ratio for those with the sample size less than eight. A dashed line at zero distinguishes between situations where conservation management options are better than conventional management options (log(RR) > 0) and situations where conventional management options are better than conservation management options (log(RR) < 0). We considered the effect of treatment as significant if the violin plot did not overlap with zero. SOC: Soil organic carbon, SOM: Soil organic matter, TOC: Total organic carbon, TN: Total nitrogen, MBC: Microbial biomass carbon, HI: Harvest Index.

found in case studies that considered the weed management, and the WlRR positive, 0.246. It should be noted that the sample size for mulching, cover cropping, organic weed management was less than eight ((Fig. 3, (b), (c), (e)).

The aggregated results showed a positive effect on regulating services by all types of conservation practices (Table 3). The provisioning services showed mixed results and the relationships between provisioning and regulating services were mixed thereby. For example, the results showed positive changes in both 'Food' and 'Water' provisioning services. Note that this result does not necessarily include a causal relationship between them. The use of organic fertilizer or non use of fertilizer had a positive impact on regulating services, whereas it had a negative impact on provisioning services. Non-irrigated system had a negative impact on all types of services. Among other regulating services, 'Erosion control' was affected by cover crops. Cover crop application reduced the sediment loss as well as run off (Fig. 3).

Table 2: Summary results of the weighted response ratio (WlRR) and the bootstrap confidential intervals

Variables	Weighted response ratio (WlRR)	Standard Error	5 % CI	95 % CI	Sample size
A. Conservation tillage					
Yield	0.066	0.0281	0.011	0.122	32
Biomass	-0.01	0.021	-0.0498	0.0328	10
Total nitrogen (TN)	0.084	0.01	0.065	0.1038	14
Soil organic carbon (SOC)	0.088	0.013	0.0751	0.1262	28
Beta - Glucosidase	0.161	0.0126	0.1374	0.187	11
Bulk Density	0.024	0.003	0.0181	0.0296	13
Microbial biomass carbon (MBC)	0.233	0.0117	0.2102	0.2555	15
Dehydrogenase activity	0.261	0.0164	0.229	0.294	14
B. Mulch					
Yield	0.1462				5
Water Content	0.284				3
Soil organic matter (SOM)	0.423	-	-	-	2
Soil organic carbon (SOC)	0.4034	-	-	-	2
Shannon Index	0.0398	-	-	-	2
Beta-Glucosidase	0.212	-	-	-	1
Microbial biomass carbon (MBC)	0.101	-	-	-	1
C. Cover cropping					
Yield	0.299	-	-	-	5
Biomass	-0.141	-	-	-	4
Soil organic carbon (SOC)	0.213	-	-	-	2
Runoff	-1.041	-	-	-	2
Sediment	-1.239	-	-	-	3
Bulk Density	-0.0076	-	-	-	2
Shannon Index	0.021	-	-	-	1
Soil Loss	-1.068	-	-	-	1
D. Organic fertilization					
Yield	-0.1724	0.019	-0.208	-0.135	22
Biomass	-0.1421	0.0147	-0.1565	-0.0941	8
Total nitrogen (TN)	0.0437	0.0053	0.033	0.0539	10
Soil organic carbon (SOC)	0.15	0.024	0.105	0.1976	8
Beta-Glucosidase	-0.0012	-	-	-	5
Microbial biomass carbon (MBC)	0.129	-	-	-	6

Table 2: Summary results of the weighted response ratio (WlRR) and the bootstrap confidential intervals (cont.)

Variables	Weighted response ratio (WlRR)	Standard error	5 % CI	95 % CI	Sample size
E. Weed management					
Yield	-0.3571	-	-	-	4
Microbial biomass carbon (MBC)	0.159	-	-	-	2
Species Richness	0.246	-	-	-	3
Shannon Index	0.529	-	-	-	1
Total organic carbon (TOC)	0.09	-	-	-	1
Total nitrogen (TN)	0.0883	-	-	-	1
F. Rain-fed (no irrigation)					
Yield	-0.501	0.019	-0.539	-0.463	10
Biomass	-0.391	-	-	-	5
Total organic carbon (TOC)	-0.1475	-	-	-	2
pH	-0.021	-	-	-	2
Harvest Index	-0.193	-	-	-	2

4. Discussions

Benefits from the application of multifunctional agriculture have been studied earlier (e.g., Labarthe, 2009; Renting et al., 2009; Andersen et al., 2013; Balbi et al., 2015). Yet, impacts of various management practices have not been analyzed quantitatively so far. Here, we synthesize agricultural indicators to test the impacts of different farming practices on multiple ecosystem services. The goal was to focus not only on a specific indicator (Supplementary Table ST2), but particularly on an aggregated level of ecosystem services. The results therefore provide a synthesis of the combined impacts of conservation farming practices (Table 3).

4.1. The impacts of management options on ecosystem services

4.1.1. Provisioning services

Food production is the primary function of agricultural land (Palm et al., 2014; Balbi et al., 2015). Changing climate as well as unsustainable farming practices threaten food supply in the Mediterranean basin (Iglesias et al., 2011). Our results show a potential for alternative management options to increase crop yield. The conservation management options that have been applied to reduce soil disturbance such as tillage, mulch and cover crop increased yield (Table 3) to some degree (Fig. 3). This positive effect on yield corroborates earlier studies made under the Mediterranean climate (see a review study from Kassam et al. (2012)). For example, Crabtree (2010) showed 30-50 percent of crop productivity increases due to the no-till management over 10 years in south western Australia under the Mediterranean climate. However, previous studies outside Mediterranean climate regions have shown that in cooler and wetter places the impact could be the opposite (Ogle et al., 2012): a positive impact was found in Sub-Sahara Africa (Giller et al., 2009), yet negative or negligible results were reported from Argentina (Alvarez and Steinbach, 2009), Scandinavia (Rasmussen, 1999) and North America (DeFelice et al., 2006). Management options were found to both directly and indirectly affect soil and water conditions in agricultural areas (Zalidis et al., 2002).

Table 3: The conservation managements were compared to the paired conventional managements. For a detailed description, see Table 1: up arrow: positive effect, down arrow: negative effect, -: not significant, * indicates a sample size larger than eight for which an uncertainty analysis could be performed.

	Provisioning services				Regulating services			
	Food	Fodder	Water	Energy	Climate regulation	Erosion control	Lifecycle maintenance	Soil formation
Conservation tillage	-*	-*			↑*			↑*
Mulch	↑		↑			↑		↑
Cover crop	↑	↓			↑	↑		↑
Use of organic fertilizer	↓*	↓*		↓*	↑*			↑*
Organic weed management	↓				↑			↑
Rain-fed (no irrigation)	↓*	↓	↓					↓

Conservation farming practices affect water and soil nutrient status positively, and this in turn increases yield (Giller et al., 2009; Gordon et al., 2010; Palm et al., 2014). We found similar effects on improved soil quality and water storage (Fig. 3), and this could explain the slightly increased yield in mulching systems. Furthermore, the positive effect of conservation farming on yield was particularly observed during the dry season as it led to relative yield stabilization (López-Bellido et al., 1996). However, it should be also noted that rain-fed management in some Mediterranean regions is not sufficient to supply enough water to maintain both provisioning (i.e., food) and regulating services.

Organic weed management and the use of either organic or no fertilizer improved 'Soil formation' regulating services but showed a negative effect on 'Food' provisioning service such as food crop yield. This trade-off relationship caused by organic managements among other conservation agricultural managements has been widely recognized globally (de Ponti et al., 2012; Seufert and Ramankutty, 2017), indicating that the yield difference between organic and conventional farming is about 20%. A possible reason for this trade-off is the difficulty of managing phosphorus in organic systems (Oehl et al., 2002).

4.1.2. Regulating services

Most of the regulating services analyzed in our study were positively affected by conservation management, highlighting its role for the improvement of soil conditions. The 'Soil formation' regulating service was the most studied ecosystem service – it was positively affected by most of the considered conservation options (Table. 3).

A list of indicators for the 'Soil formation' service was found in the case studies with respect to physical, chemical and biological conditions. Although it is often not clear which soil properties are most appropriate to reflect the impact of conservative management on ecosystem service provision (Palm et al., 2014), our review showed positive effects of conservation management across all indicators in physical, chemical and biological soil conditions. Some soil indicators related with soil carbon could be further linked to the 'Climate regulation' service.

The 'Climate regulation' service was positively affected by conservation management. This result is in line with previous review studies. The review by Aguilera et al. (2013a) shows that conservation tillage has a positive effect on carbon sequestration, especially when combined with organic fertilizer application and mulching. Also, N_2O emissions were reduced by 23% by applying organic fertilizers compared to conventional fertilizers (Aguilera et al., 2013b). Among conservative management options, mulching was the most effective method with the largest effect size to increase 'soil organic carbon (SOC)' in our results. This is in line with the results from Blanco-Canqui and Lal (2007) and Palm et al. (2014) showing the importance of organic residue for carbon sequestration.

Improvement of soil cover had a positive effect on the 'Lifecycle maintenance' in our data set. Conventional practices in agricultural land systems are generally recognized as leading to a loss of biodiversity by disturbing soil (McLaughlin and Mineau, 1995) and habitats. Soil disturbance destroys not only the soil structure but also associated soil biodiversity (Montgomery, 2007a; Kassam et al., 2012). Alternative management options can provide an opportunity to improve biodiversity related indicators. Furthermore, the enhanced soil biodiversity can have a synergistic relationship with other ecosystem services. Bender et al. (2016) highlight the importance of soil biota for the ecosystem service provision through their essential role in important ecosystem functions.

The largest effect size across all regulating services was found for the 'Sediment retention' (WlRR = -1.239) and 'Runoff reduction' (WlRR = -1.041) for cover crop management. The conservative soil cover management decreased runoff and soil loss, thereby contributing to an improved 'Erosion control' (Table 3). Cover crops are primarily applied to prevent top soil from the wind and water erosion (Langdale et al., 1991; Fageria et al., 2005). As soil erosion removes fertile top soils and therefore impacts productivity (Pimentel et al., 1995), the reduced soil erosion provides an important opportunity. This pronounced benefit of the conservation farming practice on erosion control is also applicable globally (Montgomery, 2007b; Borrelli et al., 2017).

We were unable to draw conclusions about rain-fed water management for some indicators, as the sample size was too small. Nevertheless, those indicators we could study were all negatively affected by rain-fed water management. This result partially supports the importance of water stress in this region. Water shortage is one of the biggest challenges in the Mediterranean basin (Iglesias et al., 2007). Improving water availability can be a key issue to secure multiple ecosystem services. Irrigation requirements are likely to increase by between 4 and 18 % by 2°C global warming in the Mediterranean basin (Fader et al., 2016). However, it should also be noted that poor management of irrigated agriculture can potentially cause other impacts on water availability and the environment in the Mediterranean region (Pereira, 2004). In addition, depending on where the irrigation system has been installed, it can increase soil erosion in cultivated soils on slopes, often found in the Mediterranean Basin such as Greece (Baldock et al., 2000). An improved efficient irrigation system would be beneficial for water resource management in the future (Pereira, 2004; Fader et al., 2016).

4.1.3. Cultural services

In our case studies, cultural services were not assessed, and we therefore excluded them from the analysis. Given the touristic attraction of the highly valued Mediterranean landscape, cultural services might be a potential asset for farmers to diversify their income (Nickerson et al., 2001; Sharpley and Vass, 2006; Brandth and Haugen, 2011). With some effort, this could be done without much harm to the environment as the relationships between cultural services and other ecosystem services were found out to be 'no-effect' or 'synergistic' in a recent review study (Lee and Lautenbach, 2016). An example of cultural ecosystem services from agricultural areas is 'agritourism' by allowing people to watch or to physically experience farming activities (Bennett et al., 2009). In addition, 'traditional ecological knowledge' is a representative example of cultural ecosystem services in the region, which is related to the management practices of farmers and the transmission of their experience and knowledge (Iniesta-Arandia et al., 2015).

4.2. Possible applications of the results

Our results should have the potential to be used in several different applications including the parameterization of integrated earth system models. First, the results can be used as observations against which one can test the capacity of simulation models to represent reality. For further development of such models that incorporate processes of conservation agriculture, our results can be used as a reference. Second, the results can be used as additional information to the model outputs concerning processes that are not modelled explicitly. Third, the results can be used in multi-objective assessments or trade-off analyses.

4.3. *Limitations of the meta-analysis*

Although we followed a standardized process to systematically collect publications and data points, some considerations should be taken account. We only considered peer-reviewed published literature and thus excluded 'grey literature' that could contain relevant information on management options and ecosystem services in the Mediterranean basin, e.g., in the Maghreb countries. We only included case studies based on in-situ experimental results, implying that off-site effects of the farming practices are not accounted for. Off-site effects such as maintenance of drinking water quality, reduction of pollution from agriculture, reduction of salinization, and eutrophication in soils and water are crucial for many surrounding areas (Pascual et al., 2017). These topics could be addressed in the future research.

There was some bias observed between the studied management options. The largest number of studies concerned tillage, whereas weed management had the fewest data points. To develop more general and comprehensive recommendations, more studies dealing with rarely studied management options would be needed. In addition, it would be helpful if each case study would provide relevant uncertainty information to weight case studies properly.

For the preliminary analysis, we selected indicators based on their frequency in order to permit comparison, also their relevance was assessed based on suggestions from previous studies (Supplementary Table ST1). Yet, the uncertainties of selecting indicators could not be measured. Developing more suitable indicators is ongoing work in the ecosystem service community (e.g., Maes et al., 2016; Diaz-Balteiro et al., 2017; Grunewald et al., 2017; Lavorel et al., 2017), one might therefore expect a potentially clearer connection between tested indicators and the quantification of ecosystem services.

5. Conclusions

Our analysis of the scientific literature demonstrates that conservation agricultural management when compared with conventional agriculture, can have both positive and negative impacts on ecosystem services supply: most techniques improved soil quality, but some could potentially decrease the crop yields. Overall, sustainable agricultural management options were beneficial for ecosystem service supply in the Mediterranean basin. As could be expected, water availability plays a key role in agricultural management in the Mediterranean basin for the enhancement of both provisioning and regulating services. In particular, conservation management tended to alleviate trade-offs and fostered synergies in ecosystem service supply. The incorporation of such management practices in policy conventions and measures could provide a meaningful contribution to secure multiple ecosystem services. This incorporation should take into account that farmers may experience a yield reduction from organic fertilizer use or organic weed management, which can be expected to affect their income immediately. For the further research, longer-term studies will be required to test the conservative management practices.

Acknowledgements

This project was funded by the EU FP-7 project OPERAs (grant number 308393). APGN, AB, WC and IRG contribute to the Labex OT-Med (no. ANR-11-LABEX-0061) funded by the French government through the A*MIDEX project (no. ANR-11-IDEX-0001-02). We would like to thank

Bumsuk Seo for his help with the analysis. We acknowledge the support of the German Academic Exchange Service (DAAD) in the form of an International Travel Grant which enabled H.L. to attend the Ecosystem Services Partnership 2018.

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