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Ecosystem service delivery of agri-environment measures: A synthesis for hedgerows and grass strips on arable land

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ABSTRACT

In north western Europe, agricultural systems are generally managed to maximize the potential delivery of provisioning ecosystem services. This has often been at the expense of other ecosystem services. Because the current supply of most ecosystem services is insufficient to meet the increasing demand, particular attention to ecosystem service delivery and hence multifunctionality in agriculture is vital. In this paper, we quantitatively assessed the impact of hedgerows and grass strips bordering parcels with annual arable crops on the simultaneous delivery of a set of ecosystem services and from there we identified synergies and trade-offs on virtual parcels. After a systematic literature search, mixed models were applied on observations from 60 studies and quantitative effect relationships between ecosystem service delivery and hedgerow and grass strip characteristics were developed. Next to the hedgerow, until a distance of twice the hedgerow height, arable crop yield was reduced by 29%. Beyond this distance, until 20 times the hedgerow height, crop yield was increased by 6%. Compared to a similar arable parcel without hedgerow or grass strip, soil carbon stock was 22% higher in the hedgerow, on average 6% higher in the adjacent parcel next to the hedgerow and 37% higher in the upper 30 cm soil layer in the grass strip. Both hedgerows and grass strips intercepted nitrogen from the surface (69% and 67%, respectively) and subsurface (34% and 32%, respectively) flow and phosphorus (67% and 73%, respectively) and soil sediment (91% and 90%, respectively) from the surface flow. More natural predator species were found on parcels with hedgerows, but the number of predators was unaffected. On parcels with grass strips, both predator density and diversity was higher and aphid density was reduced. Our calculations on parcel level indicate that the trade-off between arable crop yield and regulating ecosystem services depends on hedgerow width and height and parcel dimensions. A similar trade-off is found on parcels with grass strips, but increasing grass strip width results in a proportionally higher delivery of regulating ecosystem services.

1. Introduction

Agricultural systems are generally managed to maximize the delivery of provisioning ecosystem services, such as food, forage, fibres, bioenergy and pharmaceuticals (Power, 2010). The pursuit of these services by agricultural intensification and expansion across the globe has resulted in high biodiversity loss (Tsiafouli et al., 2015) and ecosystem degradation (Foley et al., 2005; Ogle et al., 2005; Pimentel and Kounang, 1998). Like other ecosystems, agroecosystems have the potential to deliver multiple ecosystem services (Bennett et al., 2009) and to sustain a certain level of biodiversity (Rey Benayas and Bullock, 2012), but the focus on provisioning services has in many cases been at the expense of other services. Because the demand for most ecosystem services is increasing (Millennium Ecosystem Assessment, 2005) and in order to address the adverse side effects of intensive agriculture, a multifunctional land use and land management has been called for (Bennett et al., 2009; Gordon et al., 2010). Measures have been proposed to combine agricultural production with the delivery of other ecosystem services and the conservation and restoration of biodiversity. Examples can be found in the agri-environment schemes in the context of the EU Common Agricultural Policy (Kleijn et al., 2011). Some of these measures imply the introduction of non-crop habitats in the agricultural landscape (Rey Benayas and Bullock, 2012). Extensive research on the effects of non-crop habitats on the delivery of individual

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ecosystem services and on biodiversity has been performed. For instance, Falloon et al. (2004) calculated that conversion of arable land to grass strips or hedgerows increases soil organic carbon (SOC) by 1.30% $year^{-1}$ and 1.23% $year^{-1}$, respectively. In the review of Dorioz et al. (2006), high trapping efficiencies for nitrogen, phosphorus and sediment were reported for grass strips. Marshall et al. (2006) found that grassy field margins have a positive effect on abundance and diversity of plants, bees and grasshoppers. Holland and Fahrig (2000) concluded that landscape-level carabid diversity increases with the amount of woody field borders.

Despite the existing knowledge on the delivery of individual ecosystem services, there is an urgent need for an integrated evaluation of the simultaneous changes in multiple ecosystem services. This will allow us to identify synergies and trade-offs between services (Bennett et al., 2009) and is key for the optimization of the potential benefits of non-crop habitats on agricultural land (Power, 2010). Additionally, we need to examine the extent of the effect on ecosystem service delivery into the adjacent parcel and the role of vegetation and parcel characteristics such as hedgerow width or parcel slope. To address these research gaps, quantitative, spatial relationships that describe the effects of non-crop habitats on ecosystem service delivery need to be derived. In this study, we present an integrated overview of the effects of two types of non-crop habitats, i.e. hedgerows (HR) and grass strips (GS) bordering parcels with annual arable crops, on a selected set of ecosystem services. These measures were selected because they entail parcel level interventions that can easily be adopted by individual land users, such as farmers, and because they are abundant and popular in numerous European and other temperate areas (Baudry et al., 2000; Marshall and Moonen, 2002). Ecosystem services considered here were crop yield, and the regulating services global climate regulation, water purification from nitrogen and phosphorus, erosion reduction and pest regulation. We performed a systematic literature review and quantified the size of the effect of HR and GS on the delivery of these ecosystem services using quantitative meta-analysis techniques. Next, we investigated the role of HR and GS characteristics on ecosystem service delivery. Finally, we integrated the delivery of multiple individual ecosystem services into an overall assessment in order to identify trade-offs and describe the multifunctional role of HR and GS on agricultural parcels.

2. Material and methods

2.1. Definitions and scope of literature search

Hedgerows are defined here as unfertilized, perennial, linear, woody structures, established on agricultural field borders and consisting of shrubs and/or trees. Both hedges and tree rows are considered and we will investigate whether both HR types affect the result differently. The distinction between hedges and tree rows is based on management; if the stems are pruned and thus branchless and if no shrubs are present under the trees, the row is considered as a tree row. Otherwise, the row is considered a hedge. Grass strips are defined here as linear areas that are never intentionally fertilized, sprayed, or tilled and consisting of perennial structures, established on agricultural field borders and consisting of graminoids, often in combination with other herbaceous species (but no woody species). Flower strips only consisting of annual species are not included given the focus on perennial elements.

The systematic literature search is performed conform the PRISMA guidelines (Moher et al., 2009) and the process is described in Appendix A. Candidate papers were selected for further reading based on their title and abstract, when they met the following criteria: (i) the study region is situated within the temperate regions of the globe (as defined by Olson et al. (2001)), (ii) empirical data of the indicator of interest are available (modelling studies are thus excluded), (iii) true controls are present allowing indicator comparison with and without HR or GS and (iv) interaction of HR and GS with arable crops. We expect that the effect of HR and GS on grasslands, vineyards or orchards will be different and this is beyond the scope of this paper. Additionally, the reference lists of the retained studies were searched. If the experimental setup or data were unclear, additional information was searched for in other papers of the authors. When results were only given in figures, the data were extracted using WebPlotDigitizer v3.10 (Rohatgi, 2014).

2.2. Ecosystem service indicators

Hedgerow impact on **crop yield** is expressed as relative crop yield ($R_{HR\text{-}yield}$), which is the ratio of the crop yield influenced by the HR to the crop yield without HR influence. We only withheld yield data specifically linked to the distance from the HR. If the distance was not specifically mentioned, we did not retain the observation. To allow comparison between different experiments, the distance is expressed in relative terms of the height of the HR. For this, we use D/H, which is the ratio of the distance from the HR (D) to the height of the HR (H) (Van Vooren et al., 2016). This means e.g. that for a HR height of 20 m and a plot on a distance of 10 m from the HR, D/H is 0.5. Hedgerow height was given in all studies. Own empirical measurements (Van Vooren et al., 2016, unpublished results) from 2014 and 2015 on crop yield, the set-up of which is described in Appendix B, were included in this dataset. Because we assumed no effect of GS on crop yield, apart from the arable area loss, we did not further investigate this.

The indicator for global climate regulation is relative **soil carbon stock**. On HR parcels, an effect extending into the cropped area is expected and relative soil carbon stock is the ratio ($R_{HR\text{-}C}$) of the carbon stored within the HR-influenced parcel zone to carbon stored in the unaffected zone. Similar to crop yield, soil carbon data were related to D/H. If not given, HR height was estimated based on HR species and age. Carbon stock in the GS was compared to carbon stock in the adjacent parcel ($R_{GS\text{-}C}$). Again, own measurements from 2014 and 2015 (unpublished results) were added to the HR dataset. The set-up of our own experiments is described in Appendix B. Preferably, carbon stock data were extracted from the retained papers. When only carbon concentration was given, data on bulk density and sampling depth were needed to calculate the stock. When bulk density was not given, this was estimated based on organic matter and mineral bulk density (see equation 1, Adams (1973)). This was done for 4 out of 20 retained studies.

$$BD = \frac{100}{(\%OM/0.244) + (100 - \%OM)/MBD} \quad (1)$$

BD stands for bulk density ($g\ cm^{-3}$), OM for organic matter and MBD for mineral bulk density. MBD typically has a value of 1.64 $g\ cm^{-3}$ (Post and Kwon, 2000).

Water purification was quantified as the amount of nitrogen and phosphorus that was intercepted from the water flow. **Nitrogen interception** was calculated based on the ratio of nitrogen inflow into the HR or GS to the nitrogen outflow out of the HR or GS ($R_{HR\text{-}N}$ and $R_{GS\text{-}N}$). Surface and subsurface flow data were analyzed separately. We used the same approach as Mayer et al. (2007) and thus did not distinguish among different N forms (e.g. ammonium, nitrate, etc.). **Phosphorus interception** was calculated based on the ratio of P inflow into the HR or GS to the P outflow out of the HR or GS ($R_{HR\text{-}P}$ and $R_{GS\text{-}P}$). Because we found only one study reporting data from subsurface flow and most P is transported in the surface flow (Vought et al., 1995), we limited ourselves to surface flow data. We did not distinguish among different P forms. Appendix C shows N and P interception for all N and P forms. The indicator for erosion reduction, **soil sediment interception**, was calculated as the ratio of total suspended solids (TSS) inflow into the HR or GS to the TSS outflow out of the HR or GS ($R_{HR\text{-}E}$ and $R_{GS\text{-}E}$).

Preferably, N, P and TSS mass was extracted from the papers. When flow volume and concentration were given, mass was calculated. If no