# Expert views about farming practices delivering carbon sequestration in Mediterranean agro-ecosystems

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**Abstract.** Changing the farm management towards the delivery of ecosystem services (ES) can be promoted by the establishment of Payments for Ecosystem Services (PES). Designing a PES system requires measuring the biophysical effects of farming practices on the ES at farm scale. However, standardized methodologies that allow comparing results across spatial and temporal scales do not exist. The objective of this study was to estimate the contribution of several farming practices to ES delivery, specifically carbon sequestration, according to expert knowledge. We used a survey-based Delphi method to analyze the opinions of researchers, technicians/managers and Non-Governmental Organizations representatives, about the farming practices observed in representative sheep and mixed sheep-crops farms in Aragón, Spain. We asked experts to rate, along a six-point Likert scale, the positive contribution of these practices to carbon sequestration. The results showed that the farming practices with the highest potential to deliver carbon sequestration according to the experts were: maintaining semi-natural vegetation; utilizing manure correctly; maintaining grasslands; preserving hedges, shrubs and trees among arable fields; reducing ploughing/tilling; and active management of forest (forestry/silviculture). These results together with the consideration of other important ES will allow designing a generic PES system based on objective indicators that can be applied in the field.

**Keywords.** Farm management – Mixed farming – Sheep – Environment – Delphi method.

***Opinion d'experts sur la contribution des pratiques agricoles à la séquestration du carbone dans les agro-écosystèmes méditerranéens***

***Résumé.*** *Un changement de la gestion des systèmes d'exploitation vers l'approvisionnement de services écosystémiques (SE) peut être favorisé par la mise en place de paiements pour services écosystémiques (PSE). Concevoir un système PSE nécessite de mesurer les effets biophysiques des pratiques agricoles sur les SE à l'échelle de l'exploitation. Cependant, des méthodes standarisées qui permettent de comparer les résultats à diverses échelles spatiales et temporelles n'existent pas. L'objectif de l'étude était d'estimer la contribution de plusieurs pratiques agricoles á l'approvisionnement des SE, la séquestration du carbone précisément, selon les connaissances d'experts. Nous avons utilisé une méthode Delphi basée sur une enquête pour analyser les opinions des chercheurs, des techniciens / gestionnaires et des représentants des Organisations Non Gouvernementales avec de larges connaissances et expériences, sur les pratiques agricoles observées dans les systèmes mixtes ovins-cultures caractéristiques en Aragon, Espagne. Nous avons demandé à des experts d'évaluer, sur une échelle de type Likert à six points, la contribution positive de ces pratiques à la séquestration du carbone. Les résultats ont montré que les pratiques des exploitations permettant le plus grand potentiel de séquestration du carbone sont, selon les experts: le maintien de la végétation semi-naturelle; l'utilisation correcte du fumier; le maintien des prairies; la préservation des haies, des arbres et des arbustes au milieu des champs cultivables; la réduction du labour; et la gestion active de la forêt (foresterie / sylviculture). Ces résultats, conjointement avec d'autres SE importants, permettent la conception d'un système de PSE générique basé sur des indicateurs objectifs qui peuvent être appliqués sur le terrain.*

***Mots-clés.*** *Gestion exploitation – Systèmes mixtes – Ovin – Environnement – Méthode Delphi.*

## I – Introduction

The future of animal farming is controversial due to its contribution to climate change through the greenhouse gas emissions from livestock (Steinfeld *et al.*, 2006). Many studies report that emissions per kg of product (milk or meat) decrease with the intensification of production. However, pasture based livestock systems perform other nonmarket functions (positive externalities), such as rural development and important ecosystem services (ES) such as the maintenance of agricultural landscapes or the conservation of biodiversity (Rodríguez-Ortega *et al.*, 2014). When we consider these other functions, emissions per kg increase with intensification (Ripoll-Bosch *et al.*, 2013).

In this context, apart from mitigation strategies, we need to design sustainable alternatives promoting the sequestration and storage of carbon in agro-ecosystems in the long term. Soil carbon sequestration has the highest mitigation potential in the agricultural sector (Soussana *et al.*, 2010). Promoting farm management towards higher carbon sequestration and delivery of other ES can be achieved with a Payment for Ecosystem Services (PES) system. Designing an effective PES system at farm scale requires rewarding the positive effect of farming practices on the targeted ES. Carbon sequestration is usually analyzed at the field/patch scale and direct relationships with livestock practices are difficult to establish (see Rodríguez-Ortega *et al.* (2014) for a review). Similarly, standardized methodologies that allow comparing results across spatial and temporal scales do not exist.

The objective of this study was to evaluate, according to expert knowledge, the contribution of farming practices to carbon sequestration in Mediterranean agro-ecosystems.

## II – Material and methods

We carried out an expert consultation with an on-line Delphi panel, valuing the contribution of several farming practices on carbon sequestration for climate change regulation (the contribution was also analyzed for other important ES not presented here). The Delphi method allows many 'informed' individuals in different disciplines or specialties to contribute, with information or judgements, to understand a problem area that is much broader in scope than the knowledge that any one of the individuals possesses (Curtis, 2004).

The experts were chosen covering different types of knowledge and backgrounds: (1) researchers on agriculture-environment relationships (n = 28) and (2) technicians/managers from the government and Non-Governmental Organizations related to agriculture and environmental conservation, as well as professionals/practitioners of agricultural associations, local agribusiness and cooperatives in the area of study (n = 28). The minimum number of experts by category was fulfilled (Okoli and Pawlowski, 2004). From the 66 farming practices with potential to deliver public goods in Europe (Cooper *et al.*, 2009), we selected 26 that can influence carbon sequestration. These practices were adapted to 10 monitored sheep and mixed sheep-crops farms in Mediterranean mountains and semiarid lowlands in Aragón. The Delphi questionnaire had three parts. First, we included a brief illustrated description of the Mediterranean agro-ecosystems under study. Second, we collected some personal data and asked all experts to make a self-appraisal on their knowledge about each ES (carbon sequestration and others). In the third part, respondents had to rate the (positive) contribution of each farming practice to carbon sequestration (and other ES) according to a six-point Likert type scale (0: none, 1: very low, 2: low, 3: intermediate, 4: high, 5: very high contribution). We also included the "don't know" option. The contribution of each farming practice on carbon sequestration was represented as a percentage of the total contribution of all farming practices to this ES. We plotted results with and without correcting for self-appraisal (0.2: very low, 0.4: low, 0.6: intermediate, 0.8: high and 1: very high knowledge). Differences between the two categories of experts (researchers *vs*. technician/managers) were analyzed with a Kruskal-Wallis test. Only the first round of the Delphi method is analyzed here.

# III – Results and discussion

## 1. Contribution of farming practices to carbon sequestration

According to the assessment of the respondents on their own knowledge, the ES carbon sequestration was the least well known among those included in the study. Figure 1 shows the preliminary results (first round) of the Delphi questionnaire ranking the farming practices that contribute to carbon sequestration, with and without self-appraisal.

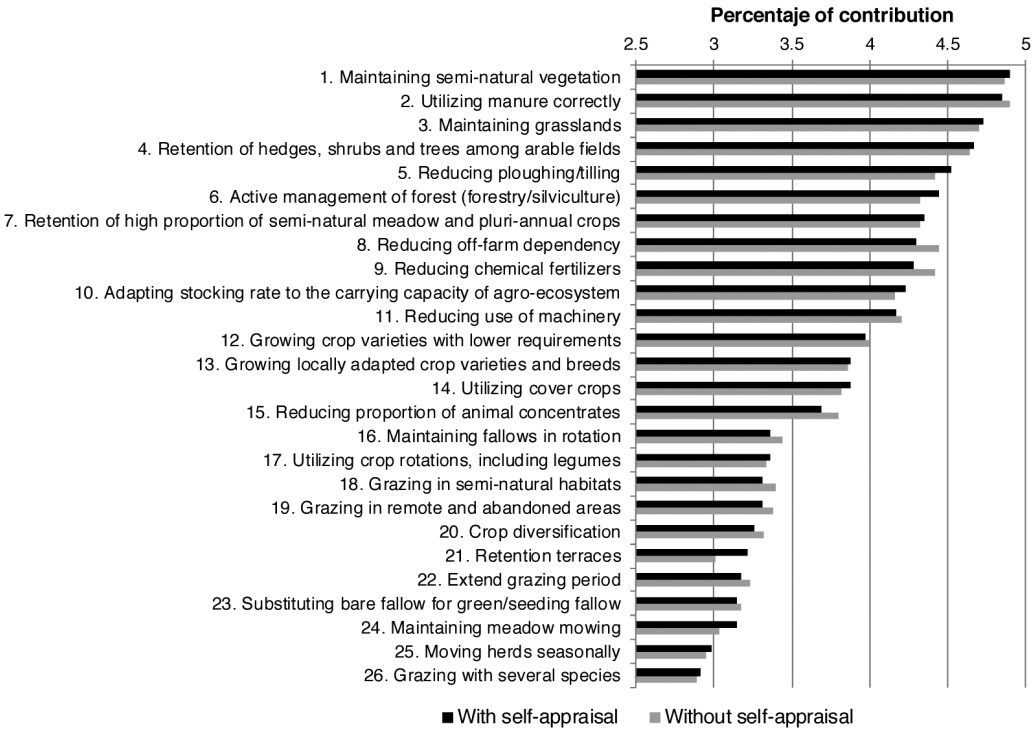


**Fig. 1. Contribution of agricultural practices on carbon sequestration.**

According to the experts, the farming practices related to management of vegetation and soils were the most important in carbon sequestration. In terms of vegetation, the maintenance of the *semi-natural vegetation* (shrubs and trees) and the *grasslands* had the highest potential of carbon sequestration. According to the bibliography, converting grasslands to forest can lead to an accumulation or to a release of soil carbon depending on the environmental conditions; however, both forest and grasslands accumulate more carbon in soils than arable lands (Soussana *et al.*, 2004). Experts also scored as high contribution the *retention of hedges, shrubs and trees among arable fields*. In terms of soils, the *correct use of manure* was the second practice in importance. Farm manure constitutes a large source of organic carbon. Spreading manure, especially when it is composted, contributes to maintain or increase the soil carbon stock, to a greater extent in grasslands than in arable lands (Soussana *et al.*, 2004). *Reducing ploughing/tilling* was also an important management practice to reduce carbon losses and increase sequestration (Aguilera *et al.*, 2013). Tillage

reduces the physical protection of the organic matter, reducing the humified soil organic matter fraction (Post and Kwon, 2000) and increasing the turnover of aggregates that accelerates the decomposition of soil organic matter within aggregates (Paustian *et al.*, 2000).

## 2. Differences between expert categories

Both expert categories (researchers and technician/managers) valued equally the contribution of the farming practices to carbon sequestration, except for two of them (Fig. 2): *growing crop varieties with lower requirements* (p = 0.0182) and *growing locally adapted crop varieties and breeds* (p = 0.0280); for which technician/managers estimated a higher contribution. This difference may disappear in the second round in which valuations are expected to converge.

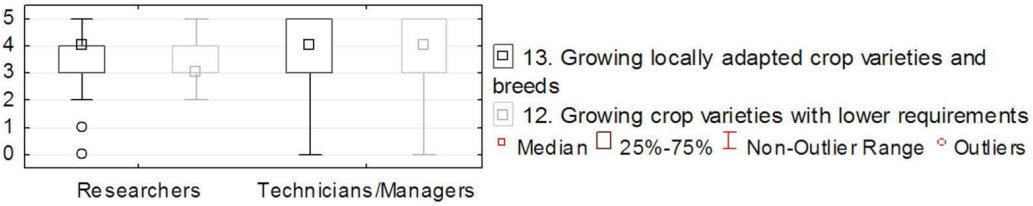


**Fig. 2. Box-plot of the contribution of two agricultural practices to carbon sequestration according to the opinions of researchers and technicians/managers.**

# IV – Conclusions

The carbon sequestration service was less known than other ES provided by Mediterranean agroecosystems. Experts rated the highest those farming practices related to management of vegetation (semi-natural vegetation; grasslands; hedges, shrubs and trees among arable fields) and soils (manuring; ploughing/tilling). The assessment of farming practices and carbon sequestration, integrated with other important ES, allows comparing their relative contribution, so we could reward different farming practices according to policy priorities.

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