Sustainability through use of cover crops in Mediterranean tree crops such as olives and vines: current knowledge and challenges.

Gómez, José A.

Institute for Sustainable Agriculture (IAS) CSIC. Avenida Menéndez Pidal S/N 14004. Cordoba Spain. Email: joseagomez@ias.csic.es

Acknowledgements

The contents of this communication have been possible thanks to the contribution of different research projects. I would highlight specially the contribution of projects AGL2015-65036-C3-1 and Vinedivers (Spanish Ministry of Economy and Competitiveness), P12-AGR-931 (Andalusian Government) and FEDER funds which are currently funding research on this subject in the laboratory of Soil Erosion at IAS-CSIC.

Keywords: olive, vines, sustainability, water balance, erosion, Mediterranean.

Abstract

Tree crops cover a large area of European landscape, 13.3 Mha, with olive, grapes, nuts and almonds been the most extended and mostly concentrated in Mediterranean areas. The cultivation of tree crops in rain limited Mediterranean areas depend on an adequate management of water balance that, been historically mostly based on bare soil, has create severe erosion and offsite contamination problems in sloping areas. The use of temporary cover crops can be an alternative to control these problems with a larger effect on erosion control than on reducing runoff, and a moderate impact on soil properties. This impact depend strongly on the ability to implement in commercial farms temporary cover crops that achieve a significant development during the rainy season while simultaneously minimizing the competition for soil water with the major crop. This has balance between soil protection and yield has been achieved in some conditions but not in others, and a significant reduction in yield has been reported for the some situations. This potential risk of yield decrease, combine with the difficulty to see a collapse in yield due to soil degradation by water erosion in the short/medium term can explain, partially, the reluctance of farmers for an extensive use of temporary cover crops. The development of improved strategies for using temporary cover crops which could include the use of water balance models, new varieties better adapted to the region, and strategies for restoring ground cover in severely degraded orchards seems to be necessary, coupled with regulations and incentive to their use by farmers. Future research should focus in the less understood elements of this system, among them root development, biomass production, phenology under different microclimate of the cover crops and the main tree crops, use of cover crops mixes, which are hampering the fine tuning of the system for specific conditions. It is also necessary a better definition and measurement of the impacts of cover crops on biodiversity that should be related to the landscape conditions.

1. Tree crops in Mediterranean conditions.

Tree crops are an important part of the European agricultural landscape with more than 13 Mha of permanent tree crops in the EU-28. The majority of these tree crops, approximate 80% of the surface, are concentrated in areas with Mediterranean type of climate, Table 1. This is not surprising since the majority of these crops in the EU (such as olives, citrus or almonds) are best grown under a Mediterranean type of climate. The only exception among the dominant tree crops to this trend are vines. The 3.2 Mha of vines in the EU-28 are distributed across the continent among 21 countries, from Sweden to Malta, albeit the majority of its growing areas are also concentrated in Mediterranean areas.

A major reason for that distribution is the good conditions in terms of temperature and radiation. Other reasons are the rusticity of some of these tree crops, particularly olives and almonds, which allows cultivation in areas not suitable for other crops or grazing and their double role as a food and cash crop. However, the Mediterranean type of climate is characterized by a limited, and highly variable, precipitation in relation to the potential evapotranspiration (ETo) and by a dry season during the period of maximum temperature and ETo, see Figure 1. As a result of the need to insure productivity and survival of trees and crops under limiting water conditions, agronomical practices in orchards in Mediterranean areas evolved in the direction of prioritizing the improvement of soil water balance for the tree. Historically this has been achieved using three major elements. One is a low tree plant density, which allows a large soil volume for the roots to explore for soil water, with the other two been a limitation of the canopy size by pruning and elimination of weeds to prevent competition for soil water with the tree. This, agronomically sounded, strategy has been successful for allowing tree cultivation over centuries in Mediterranean areas, but it has also created landscapes, like the one shown in Figure 2, characterized by cultivation in a simplified landscape on sloping areas with limited ground cover. This has resulted in some environmental problems, particularly severe in some areas of the Mediterranean. Several studies have noted these problems, particularly in olives growing areas (e.g Beauffoy, 2001; Scheidel and Krausmann, 2011). They can be summarized in: soil degradation by accelerated water erosion, decrease of water quality by offsite contamination, decrease of biodiversity and an increasing pressure on water resources in areas where irrigation, which is almost exclusively deficit irrigation, has expanded in recent decades.

In an effort to mitigate some of these problems it has been an continuous attempt for in introducing the use of cover crops in tree crops on Mediterranean areas, at least since 1969 (Ruíz de Castroviejo, 1969). It is worth clarifying that when talking about cover crops in the context of rainfed (or deficit irrigation) tree crops in Mediterranean conditions we always refer to temporary cover crops. Figure 3 summarized the concept of temporary cover crops which is based on seeding, or allowing growing, of herbaceous vegetation in the lanes during the rainfall season (fall and winter) controlling chemically or mechanically the cover crop in early spring to prevent losses of soil water by transpiration, and maintaining its residues over the surface until next fall when, ideally, it will regrow from seeds produced during the previous year. This communication revises some of the issues regarding sustainable cultivation of tree crops in Mediterranean conditions with the use of cover crops, focusing particularly in olives and vines.

2. Change of erosion and runoff losses and soil properties in experiments at plot scale.

Most of the available information on the impact of the use of temporary cover crop as an alternative to bare soil comes from experiments at plot scale. Figure 4 summarizes results from experiments carried out under natural rainfall conditions in experiments lasting 2 or more years in plots at least 12 m long, in order to limit the bias induced by short term experiments or those performed at very small scale not including relevant processes. It is apparent in Figure 4-A that the use of cover crops has a clear and significant effect on reducing soil losses in olive orchards and vineyards at plot scale. In all the experiment this reduction was found, with an average reduction close to 60% and a clear correlation. The effect on average annual runoff is depicted in Figure 4-B. In this case the effect of the use of cover crops is not as clear and although there is an overall reduction in average annual runoff of approximately 25%, this reduction is site specific with some orchards and vineyard presenting very small reductions in cover crops (CC) compared to conventional tillage (CT) or no tillage with bare soil with herbicide (NT) or even slight increase in runoff, with others showing a large reductions. The reasons for that different answer in runoff and soil losses have been discussed in detail elsewhere (e.g. Gómez et al., 2011). They can be summarized in that while the reduction in soil losses is primarily the result of physical protection by the cover crop and its residues the mechanism controlling infiltration is more complex. In situations where infiltration is limited by surface sealing or reduced porosity of the top soil the over crop has a clear effect, however in situations while the infiltration rate is controlled by saturation of the soil profile or by subsurface layers the effect of the cover crops is very small or negligible. In Mediterranean areas it is frequent to have orchards and vineyards on shallow soils and also periods of high precipitation in which the soil profile is close to saturation. It reasonable to expect that this different answer in runoff and soil losses when using cover crops can be a widespread phenomenon in Mediterranean tree crops. Maetens et al. (2012) in a metanalysis of plot experiments in Europe also noted a higher effect of conservation tillage in reducing soil losses compared runoff losses when compared to conventional systems. Figure 5 shows for two long term experiments in vineyards and olives the annual variability of the reduction in runoff and soil losses. It is apparent the same trend commented before and also that this variability must be related to the interaction between rainfall, soil conditions and soil management within each year, since the overall correlation with annual rainfall is weak.

The spatial distribution of soil properties within an orchards or vineyard is different to those in a field crop, tending to a mosaic pattern in which the influence of the tree and the cover crop induces differences in some of them, like infiltration rate or bulk density. When interpreting and modelling hydrological processes, such as runoff generation, water balance or water erosion, this heterogeneity, depicted in Figure 6, needs to be considered. For instance Castro et al. (2006) showed the relevance of run-on in the under canopy and cover crop area with some of the runoff generated in the area of the lane with bare soil These effects have been incorporated into the efforts for modelling runoff and water erosion in olives and vineyards at hillslope scale. For instance, Romero et al. (2007) developed and validated values for the CN method for different soil management in olive orchards which have been used successfully in water balance models in olives (Abazi et al, 2012). The CN method has also been used for determining runoff losses in water balance modes in vines in Mediterranean conditions (e.g. Celette et al., 2010) although in these case the CN values were apparently taken from the values developed for orchards in USA by the USDA. The effect of soil management in water erosion in olives and vines has been incorporated in RUSLE through calibration of C values for specific conditions. Gómez et al. (2003) proposed several C values for different olive plant density and soil management in orchards. These C values seem to provide reliable predictions of soil losses when compared to long-term erosion rates estimations (Vanwallegem et al. 2011) or plot data (Marin, 2013). Auerswald and Schwab (1999) proposed C values for USLE for different soil management and vine plant density in Germany, although to our knowledge, these values have not been validated. When comparing C values for vines proposed by different authors in Europe (Gómez et al. 2016) it is noticeable that they show significant differences, probably for a combination of differences in the conditions for which they have been determined and the lack of a standard approach for its calibration and validation. Overall, all the C values proposed for olives and vines capture the trend towards reduced erosion with the use of cover crops, albeit there is the need for extensive validation regarding the predicted values of soil loss.

The modification of soil properties induced by the cover crop in an orchard and vine tend to be limited to the area where the cover crop is implanted, usually only a fraction of the orchard see Figure 6, and tend to be concentrated in the top 0-20 cm of the soil (see for instance Gómez et al., 2009). For this reason their overall impact on nutrient and carbon content in the orchards and vines, albeit significant, tend to be limited. An element of major concern when extrapolating the benefits of the cover crops, in term of runoff and soil loss reduction, from experimental areas to commercial farms in the large variability in the “quality” (understood as the ability to provide enough ground cover and biomass during the rainy season in a significant area of the orchard) found at the field, see Figure 7.

In transects within a relatively small areas Gómez et al. (unpublished data) measured in spring (before killing the cover crop) values of aboveground biomass for the cover crop area from 0.1 t ha^{-1} (almost bare soil) to 1.8 t ha^{-1} (which provided a good ground cover). There are several reasons for this large disparity in cover crops development, among them differences in soil quality, seed bank and soil management among different orchards, These results point to the need of more focused efforts in developing innovative strategies for achieving successful implementation of temporary cover crops in these situations which in many cases are associated to severely degraded soils. Gómez et al. (2014a) discussed the implications of these large differences between experimental results and field situations when trying to estimate regional erosion rates for olive growing areas in Andalusia. He noted a variation of approximately 30% in the predicted average erosion rate and severely degraded area estimation under current common agricultural policy (CAP) regulations regarding the compulsory use of cover crops when introducing a decrease in the efficiency of these cover crops based on calibrating the C factor of RUSLE based on observations of cover crops status from field visits to several orchard in the region.

3. Water balance

Water is the major limiting factor for agricultural production in semiarid environment with soil management playing a major role in controlling that water balance (Henderson, 1979). A modification of soil management such as the use of temporary cover crops in Mediterranean tree crop con not be successful without understand the implications for yield due to the modification of the water actually available to the crop. Figure 8 depicts the results of some experiments comparing the impact on yield of temporary cover crops in olive and wine yield. It is apparent that in some situations the system of temporary cover crops has been adjusted to provide soil protection while achieving yields that are similar to those under bare soil management (e.g. CC controlled in early spring in Figure 8), although in other situations, (e.g. those controlled in mid-late spring in Figure 8) there is a significant decrease in yield. This decrease when comparing those approaches (CC vs. CT) has been noted by other researchers in long-term experiments (e.g. Ferreira et al. 2013) and it remains a major obstacle for expanding the use of temporary cover crops in Mediterranean tree crops particularly under rainfed conditions. An alternative to fine tune the management of cover crops under a broad range of conditions is the use of simulation models to study its impact on water balance. The literature describes several models developed for vines or olives. For instance, Celette et al. (2011) presented Wallis as a simple model to simulate water partitioning in a crop association and use it to study the case of an intercropped vineyard, while Abazi et al. (2013) presented WABOL, other conceptual model for the case of intercropped olives. These studies concluded that the models provided realistic simulations, and they could be useful tools in providing a better understanding of cover crops in olives and vines, although in both studies the authors mentioned the need for an extensive validation of the model results. Parameterization of these models is of paramount importance and some of their key parameters still remain relatively poorly understood. A better understanding of the phenology and root development of the tree crops and cover crops species under different conditions, the effect capillary rise of subsurface layers during the dry season, and improved determination of the transpiration of the tree and cover crops in complex situation such as only partial ground cover or vertic soils are among the processes on which future research could be focused.

Even with the caveats mentioned by the authors, these conceptual models have provided insight into the feasibility of cover crop use under different conditions. Figure 9 summarizes the results of a study made by Abazi et al. (2012) in which the variations in olive transpiration under different conditions in cover crop and conventional tillage conditions were evaluated for Andalusia. The model results predicted for some situations no significant differences in olive transpiration while it also predicted in other locations that CT seems to have slightly higher transpiration compared to CC, which agree with the agronomical experiments depicted previously commented. These conceptual models incorporate the effect of soil depth into soil water storage capacity, and so they have the potential to be used in the evaluation on the decrease of vine or olives potential productivity due to the reduction of soil water availability accompanying the decrease of available soil depth by accelerated erosion. Gómez et al. (2014a) evaluate the effect of decreasing soil depth on olive potential productivity under two contrasting situations: soils with relatively good water holding capacity and stony soils with worse water holding capacity. Figure 10 summarizes some of the major results of of this study. One is that for soils with relatively deep rooting zones and good soil water holding capacity the decrease in potential yield appears clearly only at very shallow soil depths (see lines for Cordoba situation in Figure 10). The other is that the slope of the decrease in potential yield with decreasing soil depth is not very steep, so the year to year decrease in potential year can be masked by other factors such as climate variability, pest and effect of agronomical practices. Both facts combined can help to understand, at least partially, the low priority given by farmers to the implementation of soil erosion control practices in olives. Basically because the effects of soil degradation in the reduction of potential yield are difficult to be observed in the short or medium term, and its worst effects will be suffered in the future. Vanwalleghem et al. (2011) noted this situation in an mountainous olive growing area in Southern Spain in which the loss of approximately 40 cm of rooting depth (from 120 to 80 cm approximately) in olive orchards in the area in the time span of two centuries was accompanied by an increase in yield, attributed to improved agronomical practices. This situation, soil degradation due to soil erosion which is not currently decreasing yields dramatically and it will not do it in the medium term, can be a recurrent pattern in some of the tree crops growing areas in Mediterranean regions. All these facts considered suggest the need for regulations and incentives for erosion control on tree crops growing areas in the Mediterranean regions, particularly when most of the cost of erosion from these areas is been payed downstream. Costs of soil erosion from agricultural areas in Europe has been estimated by Montanarella (2007) as an average of 48 € ha^{-1} $year^{-1}$

(within the range from 4.8 to 93 € ha^{-1} $year^{-1}$) with off-site damages representing more than 90% of this costs.

4. Possible strategies for implementation cover crops.

Table 2 summarizes the major kind of cover crops alternatives and some of the main issues regarding the choice of the most adequate option for a given objective, as well as some of the major features and decisions to be considered regarding their implantation and management. In the context of limited water availability the decision for temporary cover crops aimed mostly to soil management has oriented many of the experiences in olives and wined towards the use of grasses. Several research projects has pursued the selection of grasses from local species which present a shorter growing cycle and could emerge with the first rains in fall and complete the seed development by late winter or early spring. This is the situation depicted in Figure 11 in which a difference in phenology of several weeks can be appreciated among several grasses. A shorter, best adapted, cycle will results in a lower risk for water competition but also in a better persistence of the introduced cover crop in the plot, since it will have greater chances of producing seed before been controlled. In the search of better adapter species of grasses, precocity in emergence and a shorter size (an eventually lower biomass production) are also characters favored. In vineyards, and lately although sporadically in olives, it is relatively frequent the use of mixes combining many species designed to increase biodiversity providing a large period with flowers in the orchard (e.g. Sweet et al., 2010, Gómez et al., 2014b). There is a limited understanding of the dynamic of these mixes composed by a large number of different species. Gómez et al. (2014b) noted how a large number of them were not found in surveys in the seeded plots one and two years after their seeding, indicating how a lower number of species composed the majority of the flora in the plots. A better understanding the dynamic of mixes, in terms not only of composition and long term evolution but also in terms or air and root biomass production of the different components are necessary if we want to evaluate these promising new alternatives using water balance models. The use of less diverse mixes can provide useful in this objectives, as well as in optimizing expenditure in seed of species that could actually been viable in a mix for a given condition. Figure 12 shows preliminary results of a study comparing the evaluation of a simple mix with three species chosen from local flora for their potential.

Despite all these efforts, statistics indicates that in many situations farmers still choose not to seed but to develop a cover crop from the flora naturally present in the orchard or vineyard. In Spain, for instance of the 30% of the olive orchards using some kind of cover crops, 97% of this was from natural weeds and only 3% were seeded (MAGRAMA, 2013). Cost is probably the major reason for this situation, although other reasons, such as the loose coupling between severe erosion and yield losses discussed above can also play a role. Within this context might be appropriate to consider strategies for introducing cover crops that will require a very limited cost for farmers, for instance species that could be easily propagated by them. Also concentrating more studies in situations where the naturally present weeds cannot be an alternative, such as in extremely degraded soils with poor fertility and exhausted seed bank.

5- Biodiversity

An improvement in biodiversity is one of the benefits frequently mentioned when recommending the use of cover crops in tree crops under Mediterranean conditions. However, for an issue which is extremely complex involving different orders of plants and animals and different scales the experimental data are relative limited and indicate less conclusive results than when compared to other of the questions commented in this article. For instance, Beaufoy (2008) evaluating the results of a project evaluating the future of olive production in sloping land in several EU countries noted how the evaluation of the impact on biodiversity was extremely superficial, indicating the need for a more focused research. In the last years more publications have been published on the subject indicating the need for stablishing a clear link between the biodiversity indicator measured and the landscape conditions where the study was performed. Paredes et al. (2016) presented the results of a metanalysis evaluating the effect of cover crops in olive orchards in reducing the effect of several pests in Andalusia (Southern Spain), expected due to the increase of natural predators for these pests when using cover crops. Their results show that the presence or not of cover crops explained a very small part of the pest response, with local, landscape and regional variability explaining a large proportion of the variability in pest response variables. This study points to perennial vegetation close to the focal crop as a promising alternative strategy for conservation biological control that should receive more attention. Focusing in a different indicator of biodiversity, songbirds, Castro-Caro et al. (2015) predicted that the presence of ground cover and landscape heterogeneity would have a positive effect on songbird communities, although the effect would be greatest in homogeneous environments. The same team however in another study (Castro-Caro et al., 2014) measured a different response in the abundance and richness of omnivorous vs insectivorous birds to the use of cover crops depending on the presence or not of hedgerows. In their study, they indicated how the richness of insectivorous birds increased with the presence of cover crops, or hedgerow, in the olive orchards, with a maximum increase in richness when both elements (cover crops and hedgerows were present simultaneously). However, in the case of omnivorous birds they did not found a significant increase with any the presence of a cover crop, hedgerows, or both elements in the olive orchards compared to an orchard managed with a bare soil and not hedgerows. These examples illustrate the complexity of the relationship between use of cover crops and biodiversity. In this context it is not surprising that metanalysis evaluating the impact of cover crops on biodiversity in vineyards have found a moderate impact (Winter et al., 2016). However, despite this complexity many of the studies on biodiversity indicate that for a proper understanding of the effect of cover crops in Mediterranean tree crops they need to be linked to the landscape structure and, particularly, to the role of other vegetation in that landscape. The need for this link has been noted also in erosion studies. For instance, Gómez et al. (2014c) in study in a small catchment on a vertic soil note the relevance of gully erosion which could explain the high erosion rates in very rainy years which had high runoff coefficients. It is clear that much benefit could be achieved if some of the future studies evaluating the impact of cover crops could incorporate this across scale effects and interaction with other vegetation for hydrological and biodiversity studies. Also for innovative approaches in the design of environmental regulations that link the benefits of the use of vegetation on landscape, biodiversity and erosion control on solid technical knowledge.

6. Summary

Tree crops cover a large area of European landscape, 13.3 Mha, with olive, grapes, nuts and almonds been the most extended and mostly concentrated in Mediterranean areas. The cultivation of tree crops in rain limited Mediterranean areas depend on an adequate management of water balance that, been historically mostly based on bare soil, has create severe erosion and offsite contamination problems in sloping areas. The use of temporary cover crops can be an alternative to control these problems with a larger effect on erosion control than on reducing runoff, and a moderate impact on soil properties. This impact depend strongly on the ability to implement in commercial farms temporary cover crops that achieve a significant development during the rainy season while simultaneously minimizing the competition for soil water with the major crop. This has balance between soil protection and yield has been achieved in some conditions but not in others, and a significant reduction in yield has been reported for the some situations. This potential risk of yield decrease, combine with the difficulty to see a collapse in yield due to soil degradation by water erosion in the short/medium term can explain, partially, the reluctance of farmers for an extensive use of temporary cover crops. The development of improved strategies for using temporary cover crops which could include the use of water balance models, new varieties better adapted to the region, and strategies for restoring ground cover in severely degraded orchards seems to be necessary, coupled with regulations and incentive to their use by farmers. Future research should focus in the less understood elements of this system, among them root development, biomass production, phenology under different microclimate of the cover crops and the main tree crops, use of cover crops mixes, which are hampering the fine tuning of the system for specific conditions. It is also necessary a better definition and measurement of the impacts of cover crops on biodiversity that should be related to the landscape conditions.

References

Abazi, U., Lorite, I., Gómez, J.A. 2012. Impact of cover crops on soil conservation in olive orchards under different agroecological conditions combing a conceptual soil water balance model (WABOL) and RUSLE. Geophysical Research Abstracts Vol. 14, EGU2012-4174.

Abazi, U., Lorite, I.J., Cárceles, B., Martínez Raya, A., Durán, V.H., Francia, J.R., Gómez, J.A. 2013. WABOL: A conceptual water balance model for analyzing rainfall water use in olive orchards under different soil and cover crop management strategies. Computers and Electronics in Agriculture, 91: 35-48.

Auerswald, K. Schwad, A. 1999. Erosion risk (C factor) of different viticultural practices. Vitic. Enol. Sci. 54: 54-60.

Beaufoy, G. EU Policies for Olive Farming. Unsustainable on all Counts; BirdLife International-WWF: Brussels, Belgium, 2001.

Beaufoy, G. 2008. Reflections from an external evaluator on the future of olive production systems on sloping land. Journal of Environmental Management 89:140–142

Biddoccu, M., Ferraris, S., Opsi, F., Cavallo, E. 2016. Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North–West Italy). Soil & Tillage Research 155: 176–189

Castro, G., Romero, P., Gómez, J.A., Fereres, E. 2006. Rainfall redistribution beneath an olive orchard. Agricultural Water Management 86 : 249 – 258.

Castro-Caro, J., Gómez, J.A., Sánchez, F.S. 2014. The role of cover crop and hedges in intensive olive orchards: Preventing soil erosion and promoting biodiversity. The Earth Living Skin: Soil, Life and Climate Changes EGU – SSS Conference. Bari, Italy.

Castro-Caro, J.C., Barrio, I.C., Tortosa, F.S. 2015. Is the effect of farming practices on songbird communities landscape dependent? A case study of olive groves in southern Spain. J Ornithol 155:357–365

Celette, F., Ripoche, A, Gary, C. 2010. WaLIS—A simple model to simulate water partitioning in a crop association: The example of an intercropped vineyard. Agricultural Water Management 97: 1749–1759

EUROSTAT, 2016. European Comission. http://ec.europa.eu/eurostat/web/agriculture/statistics-illustrated Last accessed: July 1st 2016.

Ferreira, I.Q.; Arrobas, M.; Claro, A. M.; Rodrigues, M.A. (2013). Soil management in rainfed olive orchards may result in conflicting effects on olive production and soil fertility. Spanish Journal of Agricultural Research, 11: 472-480.

Gómez, J.A.; Battany, M.; Renschler, C.S.; Fereres, E. Evaluating the impact of soil management on soil loss in olive orchards. Soil Use Manag. 2003, 19, 127–134.

Gómez, J.A. 2005. Effects of soil management on soil physical properties and infiltration in olive orchards – implications for yield. In Integrated soil and water management for orchard development. Role and importance. FAO Land and Water, Bulletin 10, Roma.

Gómez, J.A., Sobrinho, T.A., Giráldez, J.V., Fereres, E. 2009. Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain. Soil & Tillage Research 102: 5–13.

Gómez, J.A., Llewellyn, C., Basch, G, Sutton, P.B., Dyson, J.S., Jones, C.A. 2011. The effects of cover crops and conventional tillage on soil and runoff loss in vineyards and olive groves in several Mediterranean countries. Soil Use and Management 27: 502 – 514.

Gómez, J.A., Infante-Amate, J., González de Molina, M., Vanwalleghem, T., Taguas, E.V., Lorite, I. 2014a. Review: Olive Cultivation, its Impact on Soil Erosion and its Progression into Yield Impacts in Southern Spain in the Past as a Key to a Future of Increasing Climate Uncertainty. Agriculture 4: 170 - 200.

Gómez, J.A., Campos, M., Guzmán, G., Castillo-Llanque, F., Giráldez, J.V. 2014b. Use of heterogeneous cover crops in olive orchards to soil erosion control and enhancement of biodiversity. The Earth Living Skin: Soil, Life and Climate Changes EGU – SSS Conference. Bari, Italy.

Gómez, J.A.; Vanwalleghem, T.; De Hoces, A.; Taguas, E.V. 2014c. Hydrological and erosive response of a small catchment under olive cultivation in a vertic soil during a five year period: Implications for sustainability. Agric. Ecosyst. Environ. 2014: 229–244.

Gómez, J.A, Biddoccu, M., Guzmán, G., Cavallo, E. 2016. A simplified Excel tool for implementation of RUSLE2 in vineyards for stakeholders with limited dataset. Geophysical Research Abstracts Vol. 18, EGU2016-5142.

Henderson, D.W. 1979. Soil Management in Semi-Arid Environments. In: Ecological Studies Volume 34 "Agriculture in Semi-Arid Environments", 224-237

Maetens, W., Poesen, J., Vanmaercke, M., 2012. How effective are soil conservation techniques in reducing plot runoff and soil loss in Europe and the Mediterranean?. Earth-Science Reviews 115:21–36.

MAGRAMA, 2013. Encuesta sobre superficie y redimiento de los cultivos. Análisis de las técnicas de mantenimiento de los suelos y de los métodos de siembra en España. Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA). Madrid.

Marín, V.J. 2013. Interfaz gráfica para la valoración de las pérdida de suelo en parcelas de olivar. Universidad de Cordoba: Cordoba, Spain.

Montanarella, L., (2007). Trends in Land Degradation in Europe. In: M.V.K. Sivakumar and N. Ndiang'ui (Editors), Climate and Land Degradation. Environmental Science and Engineering Springer Berlin Heidelberg, pp. 583-104

Paredes ,D., Cayuela, L., Gurr, G.M., Campos, M. 2015. Is Ground Cover Vegetation an Effective Biological Control Enhancement Strategy against Olive Pests? PLOS One http://dx.doi.org/10.1371/journal.pone.0117265

Romero, P., Castro, G., Gómez, J.A., Fereres, E., 2007. Curve number values for olive orchards under different soil management. Soil Science Society of America Journal 71, 1758–1769.

Ruiz-Colmenero, M., Bienes, R., Marqués, M.J. 2011. Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. Soil & Tillage Research 117: 211–223

Ruíz de Castroviejo, J. 1969. Explotación de olivares en asociación con trébol subterráneo. Agricultura 443-Marzo: 135-139.

Scheidel, A., Krausmann, F. 2011. Diet, trade and land use: a socio-ecological analysis of the transformation of the olive oil system. Land Use Policy 28: 47-56.

Soriano, M.A., Cabezas, J.M. Ramos, A., Lora, A., Gómez, J.A. 2016. Characterization of cover crops for use in olive groves and vineyards in certified systems under Mediterranean conditions. AgroEnviron 2016 West Lafayette, IN. USA.

Sweet, R.M., Schreiner, R.P. 2010. Alleyway Cover Crops Have Little Influence on Pinot noir Grapevines (Vitis vinifera L.) in Two Western Oregon Vineyards. Am. J. Enol. Vitic. 61: 240 – 252.

Vanwalleghem, T.; Amate, J.I.; de Molina, M.G.; Fernández, D.S.; Gómez, J.A. 2011. Quantifying the effect of historical soil management on soil erosion rates in Mediterranean olive orchards. Agric. Ecosyst. Environ. 2011, 142, 341–351.

Winter, S, Zaller, J.G., Kratschmer, S., Pachinger, B., Strauss, P., Bauer, T., Paredes, D., Gómez, J.A., Guzmán, G., Landa, B., Nicolai, A., Burel, F., Cluzeau, D., Popescu, D., Bunea, C., Potthoff, M., Guernion, M., Batáry, P., 2016. How does vineyard management intensity affect ecosystem services and disservices – insights from a meta-analysis. Geophysical Research Abstracts Vol. 18, EGU2016-1769, 2

Table List

Table 1: Summary of tree crops extension in the European Union (in 1000 ha). NA indicates non available. Countries with predominant Mediterranean climate have figures in red, in green figures is France that presents some area with Mediterranean climate. Own elaboration from Eurostat (2016) available data.

Table 2: Summary of alternatives of cover crops based on objectives and major questions regarding management practices.

	Total	Olives	Grapes	Citrus	Almonds	Nuts	Apples	Pearls	Peaches and nectarines	Cherries
European Union (28 countries)	13333	4 992	3178	521	654	1 240	539	117	226	173
Belgium	41	0	0	0	0	5	7.06	9.08	0	1.31
Bulgaria	96	0	38.71	0	0.57	6.76	4.81	0.34	3.71	9.3
Czech Republic	46	0	15.81	0	0	0	8.98	0.88	0.48	2.3
Denmark	7	0	0	0	0	0	1.38	0.36	0	1.1
Germany	195	0	100.1	0	0	1	31.65	1.92	0	7.2
Estonia	3	0	0	0	0	0	0.9	0	0	0
Ireland	13	0	0	0	0	12	0.62	0	0	0
Greece	1357	938.3	109.8	49.1	12.57	54.95	12.93	4.97	48.1	13.8
Spain	5491	2526.5	941.1	302.46	548.6	697.9	30.79	23.64	86.51	26.5
France	1038	17.1	753.9	4.16	1.12	52.41	52.5	5.36	9.89	8.1
Croatia	84	17.5	25.6	2.17	0.31	10.52	5.8	1.04	1.06	3.1
Italy	2775	1130.4	683.8	140.16	57.43	198.39	53.01	30.15	67.51	29.4
Cyprus	30	11.0	5.8	2.69	2.76	3.08	0.63	0.08	0.45	0.2
Latvia	7	0	0	0	0	0	2.8	0.2	0	0.1
Lithuania	34	0	0	0	0	0	11.7	0.9	0	0.8
Luxembourg	7	0	1.3	0	0	5	0.24	0.02	0	0
Hungary	131	NA	73.1	0	0.2	0.6	33.36	2.89	NA	16.1
Malta	1	0	0.7	0	0	0	0	0	0	0
Netherlands	37	0	0.2	0	0	0	7.91	8.6	0	0.8
Austria	65	0	44.8	0	0	3	6.97	0.44	0.17	0.2
Poland	559	0	0.6	0	0	13	162.4	9.2	2.4	39.1
Portugal	844	351.3	178.9	19.8	30.15	173.08	13.66	12.01	3.75	6.4
Romania	388	0	177.7	0	0	3	60.28	3.46	1.65	5.7
Slovenia	19	NA	15.7	0	0	0	2.64	0.21	NA	0.2
Slovakia	14	0	8.8	0	0	0	3.65	0.13	0.4	0.2
Finland	3	0	0	0	0	0	0.6	0	0	0

Sweden	3	0	0.1	0	0	0	1.3	0.1	0	0.1
United Kingdom	46	0	1.8	0	0	0	20	1	0	0.7

Table 1: Summary of tree crops extension in the European Union (in 1000 ha). NA indicates non available. Countries with predominant Mediterranean climate have figures in red, in green figures is France that presents some area with Mediterranean climate. Own elaboration from Eurostat (2016) available data.

Purpose	Kind of cover crops	Main features	Management	
			Alternatives	Decisions
Biodiversity	Mixes, including several species with flowers	Composition, persistence of the differences species, phenology	Composition of mix Control methods: herbicide, mowing, grazing, tillage? Extension of cover crop	Which us? Cost Control method: When? Frequency? Layout in the slope, width of cover crop?
Fertility	Legumes/Legumes and grasses	¿Annuals or perennials? ¿Phenology? ¿Resilience? ¿Size? ¿Precocity? ¿Biomass production and ground cover?		
Erosion	Grasses			
Grazing	Legumes/Legumes and grasses			
Trafficcability	Grasses			

Table 2: Summary of alternatives of cover crops based on objectives and major questions regarding management practices.

Figure list

Figure 1: Average monthly precipitation and potential evapotranspiration (ETo) for Cordoba, Southern Spain. Average from 2001 to 2015. Error bars indicates standard deviation.

Figure 2: View of olive cultivation in a mountainous area in Southern Spain (Montefrío).

Figure 3: Evolution of a temporary cover crop in an olive orchard during the year.

Figure 4: Comparison of average annual runoff losses (A) and soil losses (B) between cover crops (CC) and bare soil management by tillage (CT) or herbicide (NT) in olives and vineyards. Own elaboration from data in Biddoccu et al. (2016) and Gómez et al. (2009, 2011).

Figure 5: Annual ratio of soil (A) and runoff losses (B) between cover crops (CC) and bare soil management by tillage (CT) or herbicide (NT) in olives and vineyards. Own elaboration from data in Biddoccu et al. (2016) and Gómez et al. (2011 and unpublished data).

Figure 6: View of orchards showing the area of influence of the olive canopy and the cover crop.

Figure 7: Comparison of two olive orchards declaring use of cover crops, Note narrow over crop strips in the upper picture compared to the one below.

Figure 8: Comparison of wine and olive yield in conventional tillage (CT) and temporary cover crop (CC). Own elaboration from data in Gómez (2005) and Ruíz-Colmenero et al. (2011).

Figure 9: Predicted olive transpiration for the average conditions rainfed olives in eight locations in Andalusia under conventional tillage (CT) and temporary cover crop (CC) for period 2006-2010. Error bars are standard deviation. Adapted from Abazi et al. (2012).

Figure 10: Potential olive tree yield for different average annual rainfall and rooting depth for two contrasting situations: Obejo, sandy soils with coarse material and moderate water holding capacity; Cordoba, fine textured soils with high water holding capacity. Adapted from data in Gómez et al. (2014a).

Figure 11: View of a cover crops experiment in Cordoba (Southern Spain) in early May. It is apparent the different in phenology between raygrass (front of picture still green) with Bromus (mid position in the picture, already eared and dried).

Figure 12: Distribution of root biomass with depth for different cover crops alternatives. Adapted from Soriano et al. (2016).

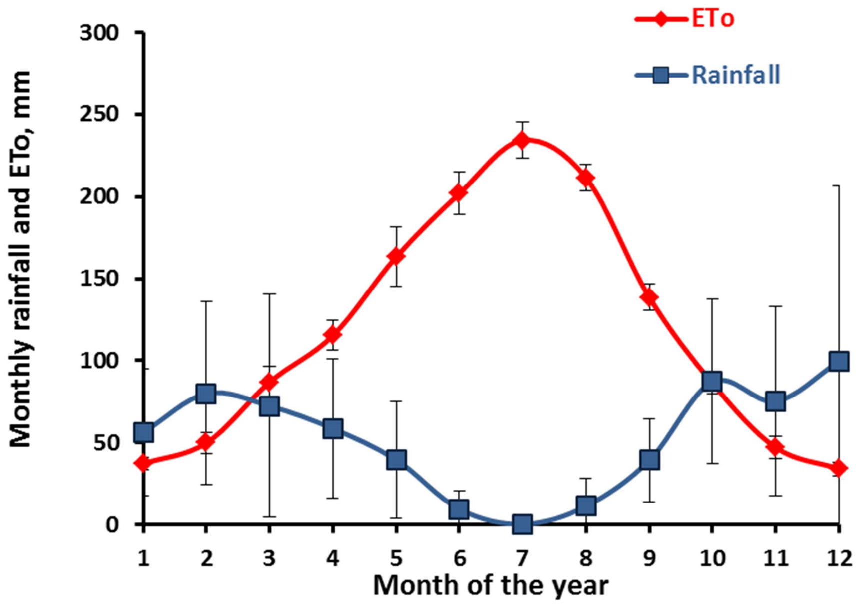


Figure 1: Average monthly precipitation and potential evapotranspiration (ETo) for Cordoba, Southern Spain. Average from 2001 to 2015. Error bars indicates standard deviation.

Figure 2: View of olive cultivation in a mountainous area in Southern Spain (Montefrío).

Late summer

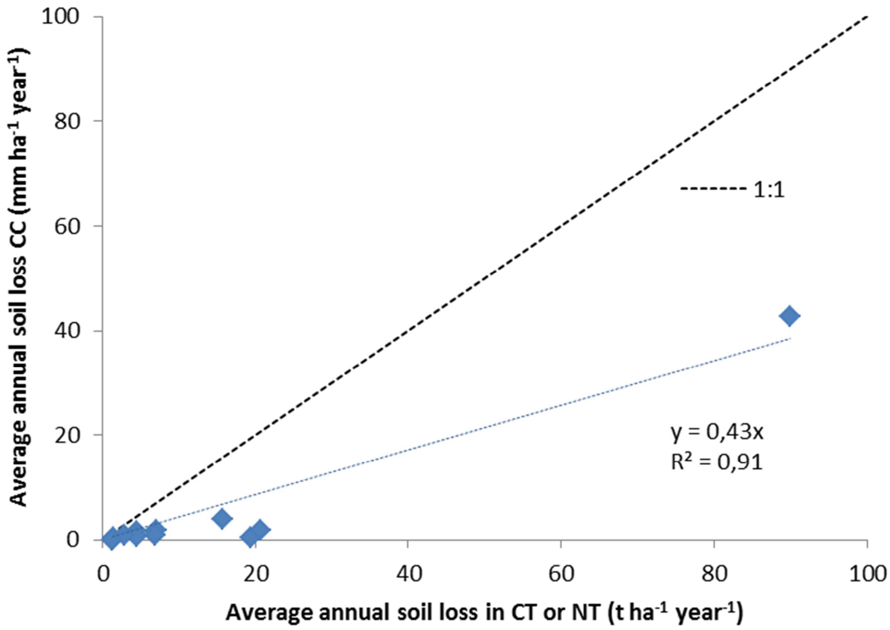
Fall

Spring

Winter

Figure 3: Evolution of a temporary cover crop in an olive orchard during the year.

A)



B)

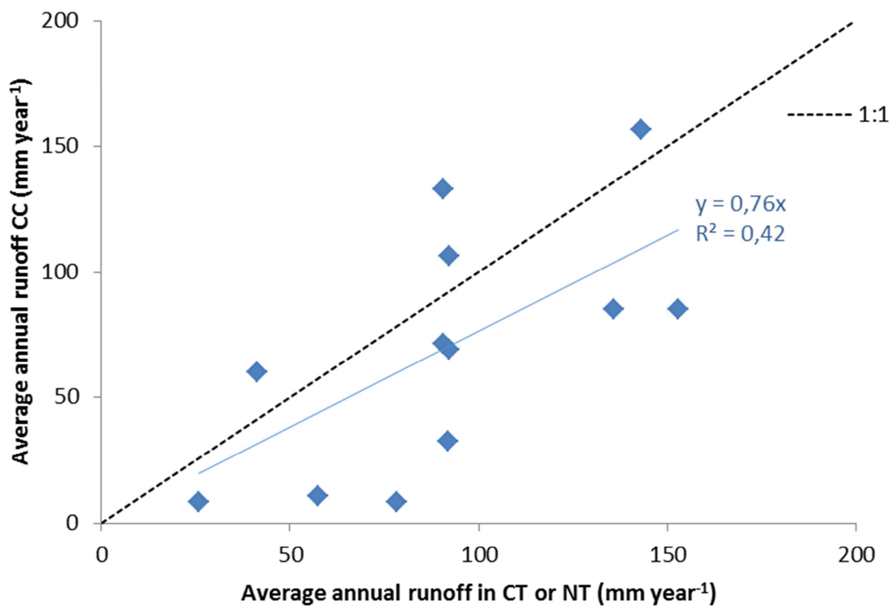
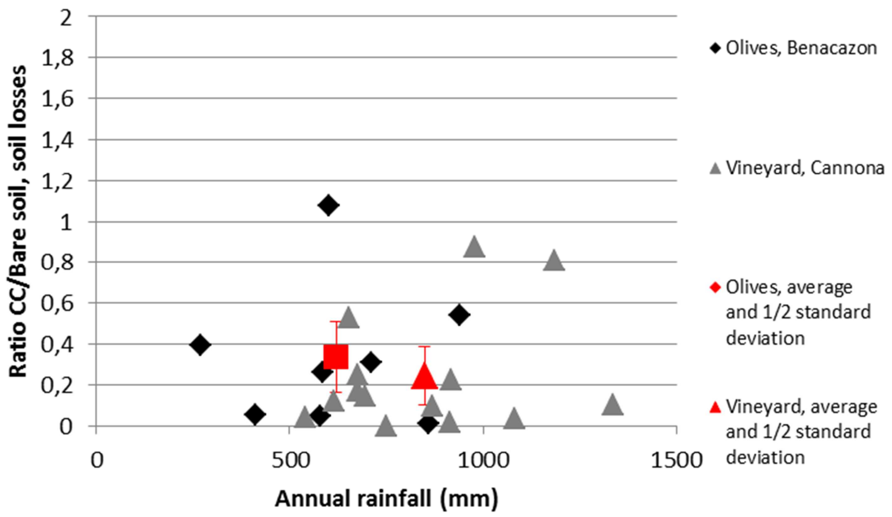


Figure 4: Comparison of average annual soil losses (A) and runoff losses (B) between cover crops (CC) and bare soil management by tillage (CT) or herbicide (NT) in olives and vineyards. Own elaboration from data in Biddoccu et al. (2016) and Gómez et al. (2009, 2011).

A)



B)

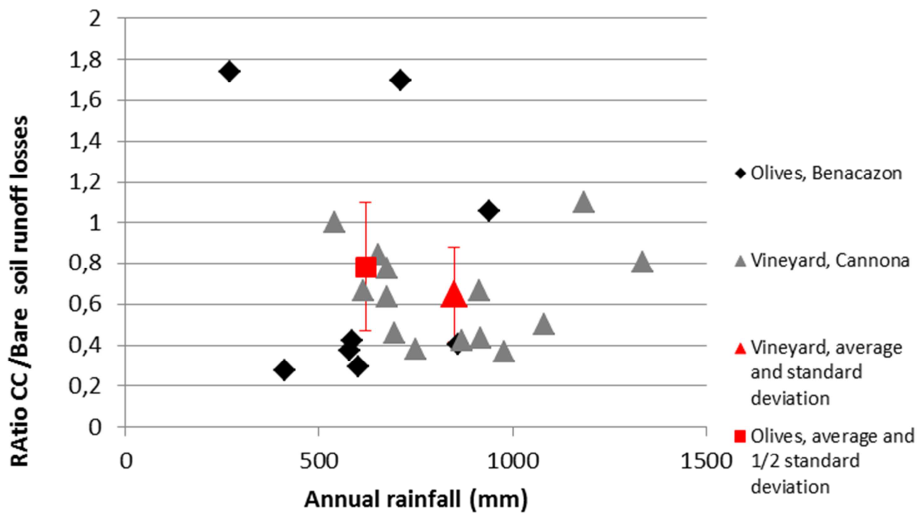


Figure 5: Annual ratio of soil (A) and runoff losses (B) between cover crops (CC) and bare soil management by tillage (CT) or herbicide (NT) in olives and vineyards. Own elaboration from data in Biddoccu et al. (2016) and Gómez et al. (2011 and unpublished data).

Figure 6: View of orchards showing the area of influence of the olive canopy and the cover crop.

Figure 7: Comparison of two olive orchards declaring use of cover crops, Note narrow over crop strips in the upper picture compared to the one below.

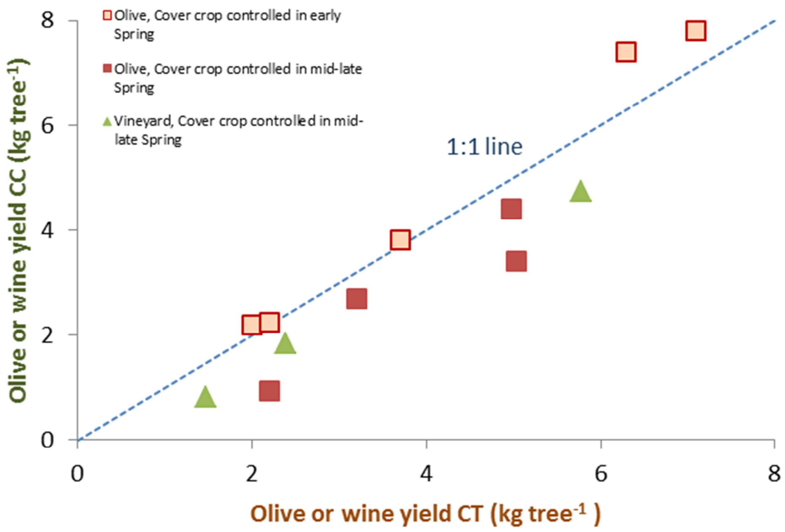


Figure 8: Comparison of wine and olive yield in conventional tillage (CT) and temporary cover crop (CC). Own elaboration from data in Gómez (2005) and Ruíz-Colmenero et al. (2011).

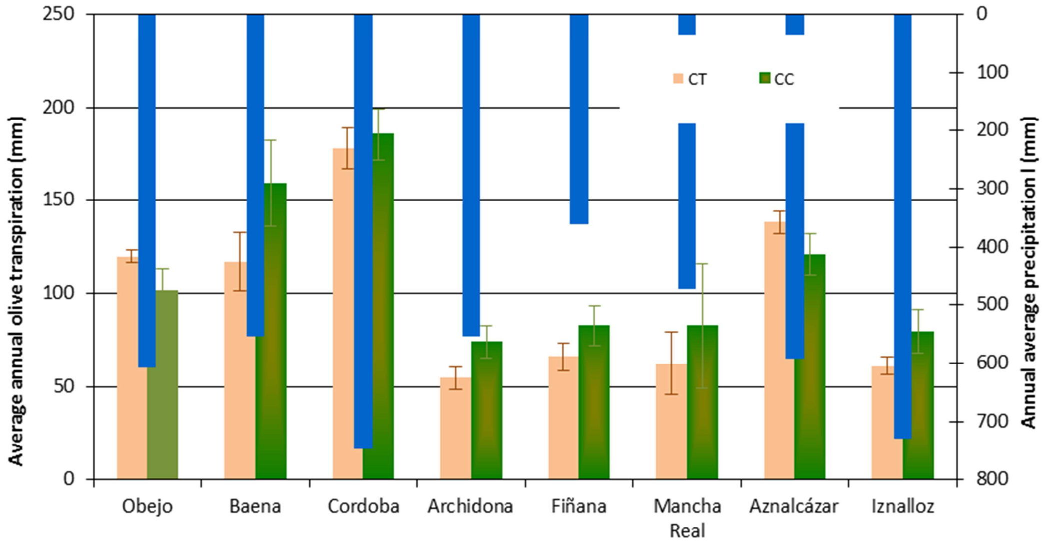


Figure 9: Predicted olive transpiration for the average conditions rainfed olives in eight locations in Andalusia under conventional tillage (CT) and temporary cover crop (CC) for period 2006-2010. Error bars are standard deviation. Adapted from Abazi et al. (2012).

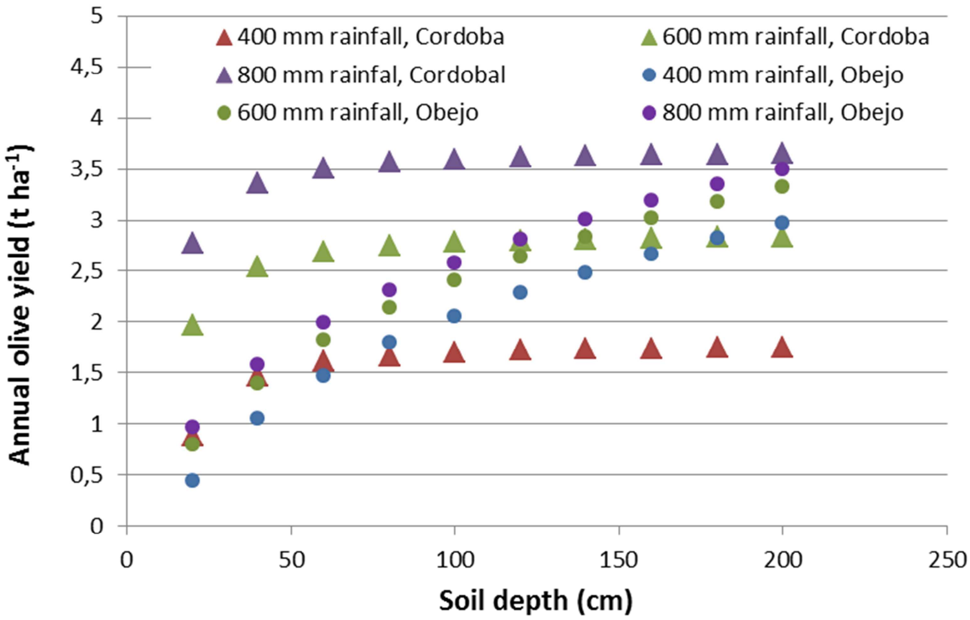


Figure 10: Potential olive tree yield for different average annual rainfall and rooting depth for two contrasting situations: Obejo, sandy soils with coarse material and moderate water holding capacity; Cordoba, fine textured soils with high water holding capacity. Adapted from data in Gómez et al. (2014a).

Figure 11: View of a cover crops experiment in Cordoba (Southern Spain) in early May. It is apparent the different in phenology between raygrass (front of picture still green) with Bromus (mid position in the picture, already eared and dried).

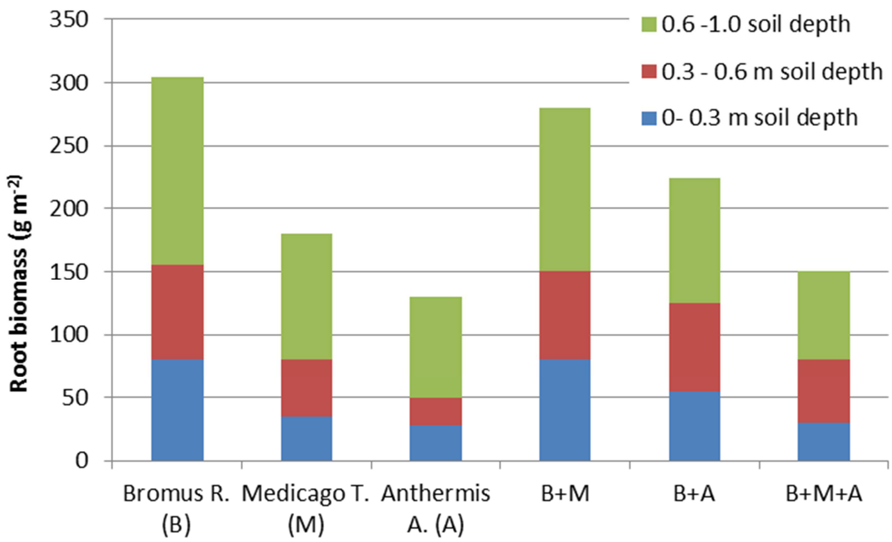


Figure 12: Distribution of root biomass with depth for different cover crops alternatives. Adapted from Soriano et al. (2016).