LIFE

Climate Change Mitigation

Deliverable C.5: Report on policy suggestions for climate change mitigation policies

February 2020

LIFE CLIMATREE (LIFE14 CCM/GR/ 000635)

A novel approach for accounting and monitoring carbon sequestration of tree crops and their potential as carbon sink areas

The **LIFE CLIMATREE** project “A novel approach for accounting and monitoring carbon sequestration of tree crops and their potential as carbon sink areas” (LIFE14 CCM/GR/000635) is co-funded by the EU Environmental Funding Programme **LIFE Climate Change Mitigation**.

Implementation period: 16.7.2015 until 28.6.2020

Participating Beneficiaries:

University Research Institute urban environment human resources Panteion Universtity, Athens

---

ΓΕΩΠΟΝΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ
AGRICULTURAL UNIVERSITY OF ATHENS

UNIVERSITY OF WESTERN MACEDONIA

---

terra nova

UNIVERSITÀ DEGLI STUDI DELLA BASILICATA

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Cultural management techniques of fruit trees for mitigating CO_2 emissions

During the last decades intense public and political concern has arisen on the impact of human activity on climate change. The increase of greenhouse gases (GHGs) in the atmosphere due to different anthropogenic activities is the cause for the adverse environmental effects experienced, such as global warming. The global carbon (C) balance has been disturbed since the Industrial Revolution, which has caused a rise in C emissions and an increase in the levels of atmospheric carbon dioxide (CO_2) and other GHGs, such as methane (CH_4) and nitrous oxide (N_2O). Among all GHGs, CO_2 is the most important one, as it occurs in the greatest concentration and has the strongest radiative forcing among all.

The CO_2 emissions can be managed by increasing the efficiency of energy conversion and by the use of energy sources, which have either a low carbon content or zero carbon at all, such as wind, solar and hydraulic energies. On the other hand, the existing high atmospheric CO_2 levels must be manipulated by adopting or even developing sustainable and effective technologies of CO_2 capture, storage and sequestration. One of such sustainable and quite cost effective approach to manage the levels of CO_2 is carbon sequestration. The term "carbon sequestration" describes natural or even deliberate actions and processes through which CO_2 is captured and removed from the atmosphere. The natural processes involve the removal and storage of CO_2 in terrestrial environments, oceans, and geologic formations. Different terrestrial ecosystems like, orchards, forest and agricultural land, play an important role in CO_2 sequestration. The natural sequestration of CO_2 takes place mainly by photosynthetic organisms present in the terrestrial as well as aquatic environments, which absorb CO_2 from the atmosphere and together with water and solar irradiation convert it into glucose and at final stages it is stored as organic carbon in biomass such as tree trunks, branches, foliage, fruits, roots and soils. These carbon pools are composed of live and dead above and below ground biomass and wood products with long and short life. Above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter are the major carbon pools in any ecosystem. Prolific flowering and fruiting of trees increase carbon removal from the atmosphere and store substantial amount of carbon as cellulose. In this regard, orchards are perceived as powerful sinks of atmospheric CO_2 that could contribute to climate change mitigation due to their capacity to retain carbon in the permanent woody structures (i.e. branches, trunk and coarse roots) as well as in the soil.

As the agricultural sector is responsible for approximately 10% of the GHGs emissions, there is undeniably important relationship between agriculture and climate change, while at the same time the agricultural sector is particularly vulnerable to the climate change effects.

CLIMATREE focuses on the efficiency of perennial fruit tree species as CO_2 sequestration tools and on proposing viable cultivation management techniques, which will increase carbon sequestration in orchards and simultaneously decrease its emission. The attention was focused on five main fruit tree species, with great impact and importance on the Mediterranean region, i.e. olive, orange, apple, peach and almond. These trees were selected, besides their importance, due to the fact that both evergreen (olive and orange tree) and deciduous (peach, apple and almond) trees should be included in the project. Carbon sequestration through growing fruit trees is known to be a cost-effective option for mitigation of global warming, global climatic change and is expected to provide additional income for the formers.

On this context, the present project wishes to highlight the strong connection between adoption of sustainable agricultural practices and CO_2 sequestration.

For all the above reasons sustainable management practices have been proposed and listed below, in order to increase tree productivity per cultivated area, reduce CO_2 emissions from cultural management and increase CO_2 sequestration by the orchards. These practices are listed in order of orchard life cycle, beginning from orchard planning and establishment till orchard rejuvenation or even re-planting. In each proposed practice an estimation is made on how much it may influence CO_2 sequestration on either a quantitative or qualitative basis, based on existing literature data, the easiness and cost of adopting the proposed practice, while at the same time the possible impact on farmer income is presented, based on predicted yield and inputs/outputs balance.

1. **High density plantations**

   The agricultural sector has moved during the last few decades from the extensive cultivation to more intensive planting systems, in order to get faster coverage of orchard floor by tree foliage and precocious yield. As CO_2 sequestration rate is higher during the early stages of growth of a tree (juvenile phase) and reduces as tree ages, it is considerably important for a tree to fill the allotted space as quickly as possible. The use of higher number of young trees during the first years of an orchard, by higher planting densities, is expected to increase CO_2 assimilation rates per soil area, as more orchard soil space will be covered by foliage in shorter time, while young trees are more efficient CO_2 assimilators than old ones. It must be noted though that a careful selection of both rootstock and cultivar is necessary as well as planting densities in order for the maximum exploitation of solar irradiance and thus CO_2 assimilation. Nowadays there are a lot of rootstocks with dwarfing properties in most of the fruit tree species investigated in this project, or even low vigor cultivars (in olive), which offer a wide range of choices. At the same time soil fertility should be taken into account as well as water supply and proper cultivation techniques should be adopted to preserve maximum solar irradiance exposure of foliage throughout the lifespan of the orchard.

Positive impacts: higher CO_2 sequestration during the early years of orchard planting, when young trees CO_2 absorption potential is higher. It is estimated that soil coverage by employing higher density plantations could be in average 60% higher under high density plantings compared to lower density plantings, during the first seven (7) years after planting, meaning that a respective increase of CO_2 assimilation is feasible.

Impacts for the grower: in general all the cultural management techniques will be executed more efficiently and cheaper, since the size of the trees will be severely reduced, facilitating thus any agricultural practice. Furthermore, cumulative yields under high density plantations during the first 5-7 years after planting can be 30-1000% (depending on the species) higher than the traditional or low density planting. Therefore, farmer enjoys a higher income during the first years, compensating sooner the investment made for the purchase of higher number of plants and any other equipment needed (supporting stakes etc). Higher planting densities can be easily adapted in Mediterranean countries, as long as there is an adequacy of water for irrigation. Nonetheless, the implementation of such practice may increase initial investment by three to four times (3-4x), depending on the species.

Impact on CO_2 sequestration – during the first 5-7 years	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	Medium	High	Medium

2. **Adaptation of training systems with higher solar interception**

The adaptation of training systems with higher exposure to solar irradiance is expected to increase photosynthetic rates and thus CO_2 assimilation. At the same time the more efficient assimilation will lead to higher product quality and yields, increasing even more the CO_2 sequestered in fruits, which at the end will be harvested and removed from the orchard. The old training systems such as vase, late vase or sphere, adopted in almost all five fruit tree species, have been gradually replaced by more efficient solar irradiance intercepting training systems such as palmette (oblique or horizontal), V shape or Y-trellis shape, slender spindle, central leader etc. Researches have revealed that solar interception and thus photosynthesis i.e. CO_2 assimilation, can be increased in a tree by adopting a Y-trellis training system compared to vase or delayed vase system, validating the importance of the correct choice of the training system to be adopted to the orchard.

Positive impacts: higher CO_2 rates throughout the lifespan of the orchard, higher yield efficiency, better fruit quality. It is estimated that the adaptation of a two-dimensional training system could lead to a two-fold increase of leaf area index, a 30-50% or even much higher light interception (approaching sometimes 130% increase), leading to a higher photosynthetic capacity per whole tree canopy, i.e. CO_2 assimilation. This elevated CO_2 assimilation can be estimated to be almost twice (2x) that of open vase or delayed open vase per farm area, assuming the right agricultural practices are applied.

Impacts for the grower: due to the better exposure of the leaves to sunlight, fruits are growing better, achieving better quality characteristics (such as color and total soluble solids, or oil content, in case of olive tree). Yield may increase slightly (approximately 5-15%) compared to similar training systems with lower light interception or reach an average of 50% (cumulative yield) compared to traditional training systems, such as vase or delayed vase. The system is easily implemented in Mediterranean countries, assuming adequate farmer skills on pruning and training techniques. The adaptation of this system does not require more money as an initial investment compared to similar trellis systems, but may need an initial increase by three to four times (3-4x) of the initial investment in case of crossing from open vase to Y-trellis.

Impact on CO_2 sequestration	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	Medium	Medium	Medium

3. **Use of mulching material (natural or not) on the planting row and fertigation**

The use of mulching materials on the planting row is expected to reduce water evaporation losses and thus the needs of replacing the water, which is lost to the atmosphere. The lower irrigation needs will reduce pumping needs and thus energy consumption for irrigating the orchard, reducing thus carbon footprint per irrigation event. Furthermore, the use of plastic sheets on the planting row inhibits weeds germination and growth, saving thus even more water as well as nutrients, necessary for orchard growth and production. The reduction of fertilizer loss is closely related to more judicious and economic use of fertilizers, reducing thus even more the carbon footprint of the orchard. At the same time, the installation of a fertigation system below the mulching material reduces the need of tractor use for fertilizer application-spreading and incorporation, as fertilization is performed through the irrigation system, being more efficient and environmentally friendly with lower CO_2 emissions, as two major cultivation practices (irrigation and fertilization) are performed at the same time. Furthermore, the plastic sheet or mulching material (organic or not) reduces the emergence of weeds, making thus the herbicide use on the row unnecessary, saving thus money and CO_2 emissions from both herbicide manufacturing, transport and use.

Positive impacts: lower needs for water, fertilizers and herbicides, reduction of emissions in the production, transport and application of fertilizers and herbicides, savings from farmer's side in the purchase and application of both. By the adaptation of mulch on the planting row the number of herbicide application on the row will be zero, compared to at least two applications on uncovered row. Water volume applied will be reduced by approximately 1/3 (this depending on soil properties and weather conditions of the region).

Impacts for the grower: reduced costs for herbicide application or weed cutting, reduced cost of water application (electricity needed for pump functioning) and savings of water supplies and more efficient use of fertilizers, reducing thus the production cost, by almost 10-30% while at the same time a minimum of 8-10% increase in yield may be achieved.

Impact on CO_2 sequestration	Implementation easiness	Application cost	Impact on yield – farmer income
Low	High	Medium	Medium

4. **Implementation of cover crops between planting rows.**

A permanent soil cover is able to maintain or even enhance the physico-chemical and microbiological fertility of the soil and the reduction of superficial erosion, which are extremely dangerous for soil loss and nutrient leaching. A temporary or even a perennial ground cover is suitable in areas where there is enough rainfall to support its growth without additional needs for irrigation. The biomass produced by the ground cover can be periodically shed and left on the ground, minimizing thus water loss, preserving soil structure and water holding capacity, while at the same time decreasing soil temperature and oxidation-degradation of soil organic matter (SOM). At the same time soil coverage permits tractor driving through the orchard with low soil compaction, which is desirable for a) the good aeration of the trees root system and b) a lower oxygen insertion though soil pores, which prevents SOM excessive oxidation and CO_2 soil emissions.

Positive impacts: lower SOM oxidation rate leading to higher SOM concentration, soil structure preservation, minor soil disturbance, reduction of soil erosion. An estimate of adapting cover crop is that they can sequester from 0 to 600 kg C/ha per year in dry and warm regions respectively, while at the same time may decrease herbicide use by 50-100% between rows or tillage needs by 50%.

Impacts for the grower: increase of soil organic matter and thus improved soil biological and physicochemical properties, aiding at a better plant nutrition and development and higher yields. Possible benefits for the farmer could be a reduction of approximately 5% on the overall cost of culture and a 5-10% increase in yield.

Impact on CO_2 sequestration	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	High	Low	Low

5. **Implementation of minimum tillage**

Soil organic matter is not homogeneous, and some SOM is quickly mineralised after entering the soil, while some persists for very long periods. Soil organic matter in the stable pool can be found in aggregates and/or adsorbed on mineral surfaces. It is widely recognized that long-term OM stabilization, possibly through organo-mineral associations, is promoted by interactions between microorganisms (fungi and bacteria) and soil-ecosystem. Furthermore, a high number of experimental studies have demonstrated that soil aggregation decreases the SOM mineralization rate and loss and that tillage or grinding increases SOM oxidation and thus CO_2 soil emissions, and this is proportional to the fineness of the grinding. Faster SOM mineralization rates have been determined after intense tillage, which mixes deeper soil horizons, which would otherwise being protected by oxidation and partly destroys the aggregation. No tillage management or conservative soil management has been found to increase soil organic matter pool in a short period of time, being this pool stable after that period.

Positive impacts: soil structure preservation, lower SOM oxidation, fast increase of soil organic carbon pool. It is estimated that conversion from conventional till to no-till farming reduces emission by 30 to 35 kg C/ha per season or in other words, the use of machinery for tillage can be reduced by 100% (assuming a minimum of two tillage events per year).

Impacts for the grower: increase of soil organic matter, improved soil biological and physicochemical properties, aiding at a better plant nutrition and development and higher yields. Possible benefits for the farmer could be a reduction of approximately 2-3% on the overall cost of culture due to lower fossil fuel consumption.

Impact on CO_2 sequestration	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	High	0	Low

6. **Implementation of deficit irrigation**

A lot of trees can be grown as rainfed orchards (olive, almond, etc) but there are also others where irrigation is necessary. The application of irrigation water is to cover the needs of evapotranspiration (ET), i.e. water losses through plant transpiration and soil evaporation. The application of water quantities below the evapotranspiration requirements is termed deficit irrigation (DI) and is applied during period of tree growth when a mild water stress does not have a significant impact on the forthcoming yield. Water quantities applied under DI are lower relatively to that needed to meet maximum ET. The farmer needs to know the level of water stress allowable per each fruit tree species and the time of DI application in order to achieve negligible losses in crop yields. By reducing irrigation events, significant gain of CO_2 emissions can be achieved, as many pumps run either by the use of fossil fuels or electricity, both responsible for CO_2 emissions in the atmosphere.

Positive impacts: water saving, less CO_2 emissions per growing period due to irrigation. Deficit irrigation at specific crop growth stages can reduce irrigation events by 20-30% depending on the species, without any negative impact on the yield.

Impacts for the grower: lower cost for irrigation without any significant loss of the yield. In terms of quantifying this impact an estimation of approximately 5% reduction of the cost of annual cultivation is considered realistic.

Impact on CO_2 sequestration	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Low	High	0	Low

7. **Monitoring climate and meteorological data for on time applications against fungi – resistant cultivars**

During the last decades intense interest has arisen in the use of prediction models for disease or pest appearance. The monitoring of meteorological data either in site with autonomous meteorological stations or through internet search, or the weekly-monthly monitoring of the state agricultural spray notification reports will improve pest and disease control by on-time spray applications. This will reduce unnecessary spray applications, which are usually executed by the use of tractor, emitting high amounts of CO_2 to the atmosphere. An alternative solution to efficient pest and disease control would be the selection of resistant or tolerant cultivars, which will minimize the number of spray applications and thus GHGs emissions. There are many examples on the use of tolerant cultivars, such as olive cultivars tolerant to olive leaf spot, apple cultivars tolerant to apple scab, pear cultivars tolerant to bacterial fire blight, etc.

Positive impacts: reduced use of pesticides, protection of the environment and farmer, reduced risk of pesticide residues, reduced use of tractor for pesticide application and thus CO_2 emissions. It is estimated that a pesticide program based on on-time applications against fungi may decrease phytosanitary products applications by at least 50% (depending on meteorological conditions of every single year). The use of tolerant or resistant cultivars may also decrease pesticide applications by 50-80% depending on the species and disease.

Impacts for the grower: reduced cost of pesticide applications and preservation of the healthy status of the orchard. An estimation of 10% reduction of the overall cost of annual cultivation can be achieved, depending on the disease pressure and climatic conditions.

Impact on CO_2 sequestration	Implementation easiness	Application cost	Impact on yield – farmer income
Low	High	Low	Medium

8. Monitoring or controlling pests with traps or bait applications

Nowadays the integrated pest management demands the use of environmentally friendly techniques to control pests. One of the easiest applied and effective technique is the use of traps, either to monitor or to control pests. The traps are hung on tree canopy and monitored every other day in order to assess the population of the pest. One way is to use the trap to monitor pest population in order to decide the optimum time of pesticide application for maximum efficacy, with minimum use of pesticides and consequently tractor use for their application. The other way is to use the traps to control the pest population without the need of pesticide application (massive trapping). Both ways result in reduced CO_2 emissions by limiting the use of tractor. Another way to control pests with minimum use of both pesticides and tractor is by bait applications, where only a small portion of tree canopy is sprayed with pesticides plus the suitable bait. Control of pests by traps or bait applications have been applied for many years in olive against olive fruit fly, in citrus trees against fruit fly and in apple against codling moth with high efficacy.

An estimation of the insecticide use reduction by adapting either monitoring of pest or mass trapping is presented in the following table:

Tree crop	Monitoring	Mass trapping
Olive	60%	70%
Orange	60%	90%
Apple	50%	50%
Peach	40%	50%
Almond	70%	30%

Positive impacts: reduced use of pesticides, protection of the environment and farmer, reduced risk of pesticide residues, reduced use of tractor for insecticide application and thus CO_2 emissions. It is estimated that the careful monitoring of major pests per species (i.e. codling moth, Mediterranean fruit fly, olive fruit fly, almond wasp etc) can reduce the insecticide applications by almost 50% or even more, depending on the climate conditions of the year, the tree crop and the enemy involved.

Impacts for the grower: reduced use of pesticides, lower cost of pest control. An estimation of 10% reduction of the overall cost of annual cultivation can be achieved, depending on the disease pressure and climatic conditions.

Impact on CO_2 sequestration	Implementation easiness	Application cost	Impact on yield – farmer income
Low	High	Low	Medium

9. **Pruning's residues used as compost or energy source**

Pruning a fruit tree is one of the most important cultural practices implemented, as it control or affects not only the form and the height of the tree, but also the yield quantity and quality. In some trees pruning is practiced annually (apple, peach, almond, etc) or can be practiced biannually or every three years (olive, orange, almond etc). The amount of biomass produced after pruning depends on the fruit tree species, the severity of pruning, the plant density etc. Nonetheless, in most Mediterranean countries pruning residues are usually burnt in the field, producing large amounts of CO_2 emissions to the atmosphere. An environmentally friendly approach is to use the residues, either as a mulching material after chopping them in the field (see section 3 above), or concentrate them in some part in or outside the field, make a compost and return it as fertilizer to the orchard. In the case of thick branches or even trunk, a suitable way to manipulate them is to use them as burning material instead of fossil fuel. This change of use of pruning residues results in a reduction in the use fossil fuels with a consequent reduction of CO_2 emissions in the atmosphere. The input of plant residues containing specific constituents (e.g. hemicellulose, suberin or phenolic compounds) that contribute to macro-aggregate stability of soil, contributes to the stabilization of soil organic matter as it reduces its mineralization and oxidation rates. Furthermore, the challenge for the 4 per 1000 initiative is to increase the size of the intermediate and stable C pools (by 0.4% or $4\%_0$), in order to maximize the sustainability of additional C storage, i.e. maximizing the residence time of this additional C in soil, contributing thus to less CO_2 emissions.

Positive impacts: increase of soil carbon (CO_2 sequestration into the soil), reduced use of herbicides, reduced CO_2 emissions from the use of fossil fuels. In case of using pruning residues as compost-organic fertilizer, addition to the orchard a net gain of approximately 1.5-2 tn CO_2/ha/year can be estimated.

Impacts for the grower: increased SOM will lead to an increased yield, due to improved soil fertility. The use of pruning material or by-products (in case of almond pericarp) can be easily applied in Mediterranean countries, by the use of a mulcher, for small diameter shoots. An estimation of 5% increase of yield can be accomplished, by increasing SOM of the orchard.

Impact on CO_2 sequestration	Implementation easiness	Application cost	Impact on yield – farmer income
Medium	High	Low	Low

10. **Use of renewable energy sources for electricity power for orchard equipment.**

Renewable energy sources (RES) can be efficiently used in the orchards, as most of them are located in places of high solar irradiance and/or mild-strong winds. Both solar energy panels and wind-power machines can be installed in the field to provide the necessary power for equipment used during orchard management. Pumps used for irrigation can work with the electrical power produced by RES, while during the last years a lot of battery driven tools have found application in orchard practices, such as pruning scissors, electrical chain saws, harvesting machines, weed trimming machines etc. Thus the use of the electrical power produced by RES located in the field reduces CO_2 emissions to the atmosphere, as they themselves have zero CO_2 emissions during operation, while at the same time saves fossil fuels needed for operating all the necessary orchard equipment.

Positive impacts: zero CO_2 emissions for energy production, minimization of fossil fuel use for orchard management.

Impacts for the grower: reduced cost for electricity of even 100 % can be achieved. There is no direct impact on the yield.

Impact on CO_2 sequestration	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	Low	High	Low

11. Use of alleviating products during the hotter months of the growing period

As climate change, plants experience during the summer months severe heat, solar irradiance and drought stress, which results in stomata closure and reduced photosynthetic rate. During the last decade intense interest has been arisen in the use of alleviating products, mitigating the adverse effects of summer stress, achieving higher CO_2 assimilation rates, shoot growth and yield. The application of such products (either of reflective, osmolyte or antioxidant nature etc) can increase CO_2 assimilation of plants and CO_2 storage and improve their production.

Positive impacts: direct higher CO_2 assimilation by tree leaves and higher yield, both quantitatively and qualitatively. An increase of CO_2 assimilation of 10-15% by means of photosynthetic capacity is feasible.

Impacts for the grower: yield increases (either quantitatively and/or qualitatively) can be estimated to range from 20-100%, this depending on the climatic conditions, the species and the cultivation practice implemented, regarding irrigation (i.e. rainfed or irrigated orchard- this refers mainly to olive).

Impact on CO_2 sequestration	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	High	Low	Medium

12. Rejuvenation of old, neglected olive orchards

During the lifespan of an orchard, the higher rate of CO_2 assimilation per leaf area is recorded during the juvenile phase, characterized by strong, vigorous vegetation. Olive tree lifespan exceeds 100 year while ancient olive trees and groves have been found in various Mediterranean countries with their age exceeding 1000 years. There are many neglected old olive groves in many olive producing countries, which could be rejuvanated by pruning, in order to get them back to production. During the first 3-5 years after rejuvenation pruning, the trees react with excessive vegetation, which is able to assimilate more CO_2 from the atmosphere than the old one, contributing thus to CO_2 sequestration to plant tissues. The branches pruned can be manipulated by means described earlier, either by using the thick ones as energy sources instead of fossil fuels, or by macerating them and use them as mulch on the orchard or compost them and return them as organic fertilizer to the soil, contributing thus in multiple ways to the reduction of CO_2 emissions and to the increase of soil organic carbon.

Positive impacts: increase of CO_2 sequestration in an old olive orchard with previously minimum CO_2 assimilation, improvement of soil structure and increase of soil organic carbon, reduction of the use of fossil fuels. The photosynthetic rate of juvenile leaves is much higher than that of mature leaves (estimated to be almost twice 2x that of mature leaves), while the annual growth rate of new shoots produced is many times higher than that of shoots on neglected olive trees (an average shoot length of 1.5 m against that of 1-2 cm). It could then be safely assumed that since the overall shoot growth of the rejuvenated tree is many times higher than that of a mature one, with simultaneously higher photosynthetic capacity, the assimilation rates per tree would be many times higher (during at least the first 3-5 years after rejuvenation pruning) than that of an old, neglected tree. A minimum of two fold (2x) increase of CO_2 assimilation per tree during the first 3-5 years is considered a logical assumption.

Impacts for the grower: the rejuvenated trees will re-enter the productive period in 3-5 years after pruning, yielding at least three-fold (3x) higher yields in the forthcoming years than the old neglected trees. Furthermore, the rejuvenated trees can be more effectively harvested, reducing thus harvest costs which accounts to almost 60% of the annual producing costs of an olive orchard, while at the same time the pruned brunches can be used as compost material or incorporated in the soil and the large ones as burning material, substituting fossil fuels.

Impact on CO_2 sequestration (for at least the first 3-5 years after rejuvenation)	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income (long term effects)**
Medium	High	Low	Medium

13. Different uses of leaves and stems in order to change their use as biosources and drive the production to different pathways forcing annual shoot production (oleuropein in leaves etc).

As stated above, young vegetation is able to assimilate CO_2 with greater rates than old leaves. Fruit trees are usually cultivated for their fruits and less for their foliage. If an alternative use of leaves and shoots of fruit trees could be found, a new industry could be evolved, exploiting the phytochemical profile of these tissues. A characteristic example is the presence of oleuropein in olive leaves, which has been found to confer anti-diabetic, anti-microbial, anti-cancer etc protection and has been used as nutritional supplement. If part of one tree cultivation is diverted to the exploitation of its leaves, then more severe pruning will be practiced, in order to induce every year vigorous vegetation, to be used for the extraction of the necessary phytochemicals. This annual young, vigorous vegetation will assimilate more CO_2 than the older one, conferring thus great CO_2 sequestration. Furthermore, as tree usage will change, the density of planting will change too, leading to more dense plantations with all the benefits described in section 1.

Positive impacts: increase of CO_2 sequestration by annual pruning, keeping the trees in a constant juvenile phase with higher CO_2 assimilation rates (about 1.5-2x that of mature leaves), new uses of tree tissues for pharmaceutical or cosmetic purposes.

Impacts for the grower: introducing to the markets unique products, less effort on keeping the fruit intact from pests and diseases, a new source of income.

Impact on CO_2 sequestration	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	Low	Low	Medium

In conclusion, many of the above described actions could be practiced at the same time (i.e. mulching, deficit irrigation, pest monitoring and control through traps, use of battery driven tools, etc), achieving thus a proportional sequestration of CO_2 in fruit tree cultivations.

Below three different scenarios are presented, based on the adaptation of more than one of the practices described above in existing orchards.

Basic scenario (limited interference with the cultural practices employed by the farmer).

This scenario is based on the minimum interference with the practices applied, in order to keep any annoyance to the farmer to the minimum.
The proposed practices are listed below:

- Deficit irrigation (the farmer needs only to reduce water volume applied and/or increase irrigation intervals).
- Getting information by the published agricultural notifications issued by the official agencies in his district, for on-time pesticides applications.
- Adopt minimal or no-tillage practice.

By adapting the three above mentioned cultural practices in his common orchard management the farmer will reduce unnecessary pesticides applications, will increase SOM and thus CO_2 sequestration in the soil while at the same time will reduce irrigation needs without any significant impact on the yield (both quantitatively and qualitatively).

Impact on CO_2 sequestration or CO_2 emissions	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Low	High	0	Low

Middle scenario (some actions are needed from the side of the farmer).
This scenario is based on the previously mentioned actions along with some more, needed to be taken by the farmer in order to increase orchards CO_2 sequestration capacity and his income at the same time. Beside the three above-mentioned practices, the following ones should also be implemented:

- Use of pruning residues by incorporating them in the soil and not burning them.

- Use of traps in order to either monitor pest population for on time pesticide application or to mass control major pests.
- Use of cover crops, in order to enhance SOM, improve soil physico-chemical and biological properties and CO_2 sequestration
- Implementation of fertigation, in order to reduce fertilizer cost (purchase, application), reduce soil contamination and enhance yield.

By adopting the aforementioned practices along with the three previously described ones the farmer

1. Increases SOM pools and soil physico-chemical properties for better yields,
2. reduces the cost of orchard management (by reducing needs for pesticides application, simultaneous irrigation and fertilization),
3. increases the yield and the CO_2 sequestered by the orchard (through the implementation of cover crops) while at the same time
4. reduces CO_2 emissions by reduced use of tractor for pesticides and fertilizer applications).

Impact on CO_2 sequestration or CO_2 emissions	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
Medium	Low	Medium	Medium

Advanced or optimum scenario (more advanced actions are needed from the side of the farmer).

This scenario is based on advanced practices implemented by the farmer and is divided into two sections, the first one in existing orchard and the second one in an orchard to be planted.

A) <u>In existing orchard</u>

Besides the practices mentioned above (in the two above scenarios) the farmer can implement further practices in order to maximize CO_2 sequestration and minimize CO_2 emissions. The following additional measures are proposed:

- Use of renewable energy sources to produce electricity needed for either the pump used for irrigation/fertigation and/or for battery charging for the battery-driven equipment (scissors, chain saws etc), or even selling the surplus energy produced. This investment will zero the electricity needs for orchard management, reducing thus CO_2 emissions produced during specific practices (such as irrigation, fertigation, pruning, weed trimming etc).
- Application of alleviating products in areas where severe summer stress is eminent. This will increase leaf photosynthetic capacity and increase yield and farmers income.

Impact on CO_2 sequestration or CO_2 emissions	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
High	Medium	High	Medium

B) <u>In an orchard to be established</u>

The following practices can be implemented in a new orchard in order to get the maximum benefits regarding CO2 sequestration and income for the farmer.

- Planting in high density and choosing the training system intercepting the highest solar irradiance in the region the orchard is going to be planted. For this to be effective, dwarf rootstocks should be used and/or cultivars suited for high density plantations and water supply should be adequate.
- Establishment of a soil cover on the row (natural, plastic or soil net) with simultaneous fertigation system in order to reduce herbicide and fertilizer application and increase fertilization efficiency. At the same time the implementation of cover crops between rows will zero the herbicide application needs. The fertigation system will allow the farmer to implement deficit irrigation, when needed, in order to reduce irrigation cost.

- Choose of resistant cultivars to the most significant pests and diseases for the fruit tree species and the region of orchard establishment, if such cultivars can be found and are profitable. This will severely reduce phytosanitary application needs as well as the cost for the farmer.
- Composting pruning material or incorporate them in the soil, to increase SOM content and physico-chemical properties with long term positive effects on tree performance.
- Monitoring meteorological data and placing traps in the orchard in order to achieve an on-time control of significant pests and diseases, which will reduce phytosanitary application cost.
- Establishment of a renewable energy source within the orchard to cover the needs for pump operation (irrigation/fertigation needs).

As a result of the implementation of all the above measures, a significant CO_2 sequestration potential is expected by the orchard as well as minimum GHGs emissions with simultaneous increase of yield and thus farmer's income.

Impact on CO_2 sequestration or CO_2 emissions	**Implementation easiness**	**Application cost**	**Impact on yield – farmer income**
High	Medium	High	High

C) <u>Additional policy measures</u>

Farmers of neglected olive groves would benefit from measures aiming on rejuvenating these trees while at the same time increasing plant density by planting young olive trees between the old ones, right after rejuvenation pruning.

Furthermore, measures aiming on diverting orchard cultivation from the production of fruits to the production of phytochemicals present in other parts of the tree (leaves, shoots etc) may lead to an increase of farmer's income and CO_2 sequestration as more trees will be planted per cultivated area, producing every year young, vigorous vegetation characterized by high capacity of CO_2 assimilation.

Indicative literature

Bar-Yosef, B., 1999. Advances in fertigation, Advances in agronomy. Elsevier, pp. 1-77.

Basheer-Salimia, R., Patakas, A., Noitsakis, V., Bosabalidis, A.M., Vasilakakis, M.J., 2005. Changes of morphological and physiological markers induced by growth phases in leaves of olive tree (Olea europaea L.). Journal of Biological Research 2, 105-114.

Basheer-Salimia, R.J., 2007. Juvenility, maturity, and rejuvenation in woody plants. Hebron University Research Journal 3, 17-43.

Boman, B.J., 1995. Fertigation versus conventional fertilization of flatwoods grapefruit. Fertilizer Research 44, 123-128.

Brilli, L., Lugato, E., Moriondo, M., Gioli, B., Toscano, P., Zaldei, A., Leolini, L., Cantini, C., Caruso, G., Gucci, R.J. 2019. Carbon sequestration capacity and productivity responses of Mediterranean olive groves under future climates and management options. Mitigation and Adaptation Strategies for Global Change 24, 467-491.

Brito, C., Dinis, L.-T., Silva, E., Gonçalves, A., Matos, C., Rodrigues, M.A., Moutinho-Pereira, J., Barros, A., Correia, C.J.S, 2018. Kaolin and salicylic acid foliar application modulate yield, quality and phytochemical composition of olive pulp and oil from rainfed trees. Scientia Horticulturae 237, 176-183.

Caruso, T., Guarino, F., Bianco, R.L., Marra, F.P., 2015. Yield and profitability of modified Spanish bush and Y-trellis training systems for peach. Hortscience 50, 1160-1164.

Glenn, D.M., Puterka, G.J., Drake, S.R., Unruh, T.R., Knight, A.L., Baherle, P., Prado, E., Baugher, T.A., 2001. Particle film application influences apple leaf physiology, fruit yield, and fruit quality. Journal of the American Society for Horticultural Science 126, 175-181.

Hampson, C.R., Quamme, H.A., Brownlee, R.T.J.H., 2002. Canopy growth, yield, and fruit quality of'Royal Gala'apple trees grown for eight years in five tree training systems. 37, 627-631.

Hampson, C.R., Quamme, H.A., Kappel, F., Brownlee, R.T., 2004a. Varying density with constant rectangularity: I. Effects on apple tree growth and light interception in three training systems over ten years. Hortscience 39, 501-506.

Hampson, C.R., Quamme, H.A., Kappel, F., Brownlee, R.T., 2004b. Varying density with constant rectangularity: II. Effects on apple tree yield, fruit size, and fruit color development in three training systems over ten years. Hortscience 39, 507-511.

Kongsager, R., Napier, J., Mertz, O., 2013. The carbon sequestration potential of tree crop plantations. Mitigation and Adaptation Strategies for Global Change 18, 1197-1213.

Lal, S., Sharma, O., Singh, D.J., 2017. Effect of tree architecture on fruit quality and yield attributes of nectarine (Prunus persica var. nectarina) cv.'Fantasia'under temperate condition. Indian Journal of Agricultural Science 87, 24-28.

Lal, R.J. 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304, 1623-1627.

Liguori, G., Gugliuzza, G., Inglese, P.J.T. 2009. Evaluating carbon fluxes in orange orchards in relation to planting density. The Journal of Agricultural Science 147, 637-645.

Martin-Gorriz, B., González-Real, M.M., Egea, G., Baille, A., 2020. Ecosystem respiration of old and young irrigated citrus orchards in a semiarid climate. Agricultural and Forest Meteorology 280, 107787.

Montanaro, G., Tuzio, A.C., Xylogiannis, E., Kolimenakis, A., Dichio, B.J. 2017. Carbon budget in a Mediterranean peach orchard under different management practices. Agriculture Ecosystems and Environment 238, 104-113.

Montanaro, G., Xiloyannis, C., Nuzzo, V., Dichio, B.J. 2017. Orchard management, soil organic carbon and ecosystem services in Mediterranean fruit tree crops. Scientia Horticulturae 217, 92-101.

Nardino, M., Pernice, F., Rossi, F., Georgiadis, T., Facini, O., Motisi, A., Drago, A. 2013. Annual and monthly carbon balance in an intensively managed Mediterranean olive orchard. Photosynthetica 51, 63-74.

Nuzzo, V., Dichio, B., Xiloyannis, C.J.A.H., 2002. Canopy development and light interception in peach trees trained to transverse Y and delayed vase in the first four years after planting. Acta Horticulturae 592, 405-412.

Robinson, T.L., 1996. Interaction of tree form and rootstock on light interception, yield and efficiency of'empire','delicious'and'jonagold'apple trees trained to different systems, VI International Symposium on Integrated Canopy, Rootstock, Environmental Physiology in Orchard Systems. Acta Horticulturae 451, pp. 427-436.

Vargas, O.L., Bryla, D.R., 2015. Growth and Fruit Production of Highbush Blueberry Fertilized with Ammonium Sulfate and Urea Applied by Fertigation or as Granular Fertilizer. Hortscience 50, 479.

Sofo, A., Nuzzo, V., Palese, A.M., Xiloyannis, C., Celano, G., Zukowskyj, P., Dichio, B., 2005. Net CO2 storage in mediterranean olive and peach orchards. Scientia Horticulturae 107, 17-24.

Vicente-Vicente, J.L., García-Ruiz, R., Francaviglia, R., Aguilera, E., Smith, P.J. 2016. Soil carbon sequestration rates under Mediterranean woody crops using recommended management practices: A meta-analysis. Agriculture Ecosystems and Environment 235, 204-214.

Warrington, I., Stanley, C., Tustin, D., Hirst, P., Cashmore, W.J. 1996. Light transmission, yield distribution, and fruit quality in six tree canopy forms of'Granny Smith'apple. Journal of Tree Fruit Production 1, 27-54.

Wu, T., Wang, Y., Yu, C., Chiarawipa, R., Zhang, X., Han, Z., Wu, L., 2012. Carbon sequestration by fruit trees--Chinese apple orchards as an example. PLoS One 7, e38883-e38883.

Zanotelli, D., Montagnani, L., Manca, G., Tagliavini, M., 2013. Net primary productivity, allocation pattern and carbon use efficiency in an apple orchard assessed by integrating eddy-covariance, biometric and continuous soil chamber measurements. Biogeosciences, 10, 3089–3108.