ORGANIC FARMING AND CLIMATE CHANGE: Literature Review Synthesis and Perspectives

ORGANIKO LIFE+ PROJECT

Revamping organic farming and its products in the context of climate change mitigation strategies

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Partner: Agricultural Research Institute

Author: Michalis Omirou

Contributors: Damianos Neocleous, Dionysia Fasoula, Panagiotis Dalias, Andreas Stylianou, Soteroula Ioannidou, Ioannis M. Ioannides

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AGRICULTURAL RESEARCH INSTITUTE

The Agricultural Research Institute was founded in 1962 with the assistance of the international Food and Agricultural Organization (FAO) as a center of Agricultural Excellence for the wider region, with the aim to lead Cyprus to a better future by strengthening rural development, improving the quality of life, and ensuring the sustainable use of natural and genetic resources. It is historically the first Research Organization in Cyprus and belongs to the Ministry of Agriculture, Rural Development and Environment.

His long and historic research tradition was duly recognized in 2000, when it was proclaimed an EU "Center of Excellence", receiving a substantial amount of competitive funding for its research and training activities. During its 54 years of existence, ARI has been consistently providing the Cyprus farmers with new and well-adapted varieties of cereals and legumes, improved livestock, novel fruit tree genetic material, advanced irrigation and hydroponics protocols, as well as offering valuable advice in a variety of plant protection, soil and water subjects.

In addition, ARI facilities include the national GeneBank, as well as the national Variety Testing Center. Further to its production and rural support activities, ARI scientist are continuously involved in student training, in collaboration with a great variety of EU, international, and local academic institutions.

EXECUTIVE SUMMARY

Σκοπός

Στόχος του παραδοτέου είναι η παροχή μια εκτεταμένης βιβλιογραφικής ανασκόπησης των τελευταίων ετών σε ότι αφορά τις επιδράσεις και τις επιπτώσεις που μπορεί να έχει η βιολογική γεωργία στην κλιματική αλλαγή στα πλαίσια της δράσης Α1. Ειδικότερα δόθηκε έμφαση σε περιοχές όπου υπάρχει σημαντική έλλειψη γνώσης έτσι ώστε να αποκαλυφθούν συγκεκριμένες ανάγκες για έρευνα με στόχο τη βελτίωση της περιβαλλοντικής επίδοσης του συστήματος σε ότι αφορά την κλιματική αλλαγή.

Αντίκτυπος

Για την ολοκλήρωση της έκθεσης πραγματοποιήθηκε ανασκόπηση της διεθνούς βιβλιογραφίας (58 εργασίες). Η ανασκόπηση αφορούσε τις επιπτώσεις στις εκπομπές αερίων του θερμοκηπίου εξαιτίας των κυριοτέρων πρακτικών που εφαρμόζονται όπως η θρέψη, η άρδευση, η κατεργασία του εδάφους καθώς και η παρουσία και χρήση μικροοργανισμών. Επιπρόσθετα, πραγματοποιήθηκε ανάλυση των ευκαριών και αδυναμιών που χαρακτηρίζουν τη βιολογική γεωργία ως στρατηγικές επιλογές για τον μετριασμό των επιπτώσεων των κλιματικών αλλαγών στη γεωργία.

Αποτελέσματα

Οι περισσότερες μελέτες αναδεικνύουν την αναγκαιότητα για την αειφόρων δράσεων προσαρμογής και αντιμετώπισης των κλιματικών αλλαγών έτσι ώστε να διασφαλιστεί η επάρκεια των τροφίων δεδομένης της αύξησης του Παγκόσμιου πληθυσμού. Πολλές μελέτες έχουν καταδείξει την υπεροχή του συστήματος της βιολογικής γεωργίας σε ότι αφορά την περιβαλλοντική απόδοση του συστήματος. Παρόλα αυτά όμως η κριτική που δέχεται η βιολογική γεωργία για την αντιμετώπιση των κλιματικών αλλαγών εντοπίζεται στην μειωμένη απόδοση του συστήματος. Η ανασκόπηση της βιβλιογραφίας και η ανάλυση αδυναμιών και ευκαιριών κατέδειξε ότι ο σχεδιασμός και εφαρμογή συγκεκριμένων και ειδικά προσαρμοσμένων στις τοπικές συνθήκες πρακτικών απότελεί πρόκληση και ένα από τα σημαντικότερα μέτρα για τον μετριασμό των κλιματικών αλλαγών με το σύστημα της βιολογικής γεωργίας.

Συμπεράσματα

Η βιολογική γεωργία ως σύστημα παραγωγής μπορεί να διαδραματίσει ένα πολύ σημαντικό ρόλο στο μετριασμό των επιπτώσεων στις κλιματικές αλλαγές. Ωστόσο οι προκλήσεις που αντιμετωπίζει ως σύστημα παραγωγής είναι πολλαπλές αφού είναι σημαντικό να αυξηθεί η απόδοση του συστήματος χωρίς την επιβάρυνση του περιβάλλοντος και ειδικότερα των εκπομπών αερίων που προκαλούν το φαινόμενο του θερμοκηπίου. Τέλος η εκπαίδευση των γεωργών και η βελτίωση των γνώσεων τους σε θέματα βελτιστοποίησης των καλλιεργητικών πρακτικών αναμένεται να συμβάλει θετικά.

Purpose

The aim of this deliverable is to provide a comprehensive study of scientific peer reviewed papers, emphasizing and identifying areas where fundamental information for organic farming practices that are related to climate change are missing. Also through this review we underline the special research needs for organic farming in order to increase the environmental performance of the system.

Outcome

For the completion of the deliverable, we reviewed 58 studies targeting the relationship between principle practices and components of the organic farming ecosystems (plant nutrition, irrigation, tillage, microbial communities) and GHG emissions. Moreover we identified opportunities and weakness of the system as a climate mitigation strategy.

Results

It is evident that sustainable mitigation and adaptation measures have to be taken in a way that food security issues will also be accounted. Indeed, it is expected that food needs will be doubled by 2050 according the increase rate of human population in Earth. To meet this need, crop yields must be substantially increased without rising up the negative environmental impacts of agricultural activity. Several studies revealed the superiority regarding the environmental performance of agricultural land managed under the scheme of organic farming However organic farming is criticized about the lower yields that are produced compared to that of conventional or integrated crop management systems. The literature review presented in the current report suggests that combined and complementary practices in organic farming might be useful for mitigating climate change.

Conclusions

Organic farming is a potential and promising climate change mitigation strategy. However increasing crop productivity without increasing the land use and reducing the emissions of greenhouse gases are challenges that must be faced. Changes, improvement and optimization of the current organic farming practices and knowledge transfer to the farmers are necessary to meet these needs and expected to contribute positively as a part of an integrated climate change mitigation policy.

FOREWORD

Climate change is a phenomenon that takes place now. Thousands of human beings are affected by the increase of temperature, the changes in the frequency and intensity of precipitation, the glaciers melting and the sea levels rising. All estimates and projections show that extreme weather events such as floods and prolong droughts will be more frequent and severe leading to additional adverse effects on public health, food production and ecosystem services.

Undoubtedly, climate change is related to the anthropogenic activity and in particular Greenhouse Gas (GHG) emissions that cause global warming. The last 50 years the average temperature of the earth increased by 0.8 ^oC and is projected to increase further. Just an increase of earth temperature by 2 ^oC compare to that before the industrial revolution will have major impacts on human well-being on earth as well as the functionality of ecosystems.

At the World Conference for Climate Change held in Paris in November 2015, International Community decided to take a series of measures in order to limit the increase in global temperature above 2 ^oC. The EU decided to drastically reduce GHG emissions that cause global warming by 80-95% by 2050 (compared to those observed in 1990).

Agricultural activity cannot be excluded by the efforts of reducing GHG emissions. According the last available data from EUROSTAT, the contribution of Agricultural Sector to GHG emissions in EU is accounted to 10% [1]. However Agricultural Sector is not only contributing to the climate change but is also affected by the environmental changes caused by climate change.

The main objective of LIFE + ORGANIKO is to highlight the superiority of organic farming on the environmental performance emphasizing the impact of this agricultural system on GHG emissions mitigating therefore climate change. This is a comprehensive study of scientific peer reviewed papers through which we want to emphasize and identify areas where fundamental information for organic farming practices that are related to climate change are lacking. Also through this review we underline the special research needs for organic farming in order to increase the environmental performance of the system.

INTRODUCTION

It is well recognized that climate change will adversely affect the quality of life of the people living in Mediterranean basin. The majority of the available studies, projects that, the climatic conditions over Mediterranean region will be increasingly drier and warmer [2]. This phenomenon is expected to be more severe during summer in Eastern and Western Mediterranean regions [3, 4]. The increase of temperature and reduced precipitation increases the threats for agriculture while at the same time creates environmental challenges that have to be faced. The agricultural model implemented globally during 20th century created risks and challenges that also have to be faced. Monocultures, deforestation, careless use of pesticides are practices resulted in a significant loss of ecosystem services. The interaction of these practices with climate change resulted in a serious environmental deterioration of agricultural ecosystems productivity both in terms of quality and quantity.

On the other hand, agricultural activity contributes from 10 to 15% of global anthropogenic GHG emissions while the inclusion of indirect sources this increases the contribution of the sector to more than 30%. The main GHG emissions are nitrous oxide, methane and carbon dioxide. According to Belarby et al (2008) the overall agricultural emissions are composed of about 41% nitrous oxide, 49% methane and 10% carbon dioxide. Nitrous oxide is considered the most important GHG and is derived from fertilized soils and manure management practices. Particularly, a part of the nitrogen applied to soils in emitted as nitrous oxide through microbial activity. Methane is mostly produced during enteric fermentation in ruminants and rice paddies while other minor sources of methane are manure management practices and biomass burning. Fossil fuel combustion and land use change are the main emission source of CO_2 in agriculture corresponding to 75 and 25% respectively [5].

Under these conditions it is evident that sustainable mitigation and adaptation measures have to be taken in a way that food security issues will also be accounted. Indeed, it is expected that food needs will be doubled by 2050 according the increase rate of human population in Earth [6].

To meet this need, crop yields must be substantially increased without rising up the negative environmental impacts of agricultural activity. Organic farming can meet these criteria since it is “a holistic production management (whose) primary goal is to optimize the health and productivity of interdependent communities of soil, life, plants, animals and people”. Several studies revealed the superiority regarding the environmental performance of agricultural land managed under the scheme of organic farming [7-10]. However organic farming is criticized about the lower yields that are produced compared to that of conventional or integrated crop management systems [11]. Indeed, the yields in organic farming systems are lower compare to that recorded in conventional fields and this response is considerably depended on crop types and species [12]. To overcome these losses and to achieve crop yields similar to those observed in conventional farming systems more land is needed. However, the use of new land for agricultural activity is not an environmental appropriate practice since tropical forests are destroyed and significant portion of biodiversity could be lost. Thus the great challenge is firstly to increase crop productivity without increasing the land use under organic farming systems and secondly to minimize the risks for environmental deterioration and in particular to reduce the emissions of greenhouse gases. The later is translated to a change or to an improvement of the current organic farming practices in a way that aforementioned criteria will be met.

ORGANIC FARMING AND CLIMATE CHANGE

Two main ways can be addressed as climate mitigation actions in Agricultural Sector. The first is the reduction of GHG emissions during crop productivity and the second is the sequestration of carbon in agricultural ecosystems. Short food chains and local markets can also be addressed as another important marketed oriented ways for the reduction of the global warming potential of agriculture. The production of food commodities and their transportation in long distances results in a significant increase of GHG emissions. The underpinnings of Organic Farming Systems and the implemented practices can considerably mitigating therefore climate change.

The realized standards in EU, on the basis of which Organic Farming products are certificated and labeled, greatly affects the agroecosystem resource use efficiency and inevitably, climate change related indicators. Typically in Organic Farming systems diversified crop rotation schemes are implemented, the plant nutrition and irrigation strategies are based not only in seasonality, but also in local operating characteristics, which determines the use of green and animal manures, composts and other organic materials. The use chemical pesticides are prohibited and alternative methods or biopesticides are applied. All these peculiarities and differences during crop production process largely affect GHG emissions compare to those observed in conventional farming systems.

Below we report via a comprehensive review the existing knowledge regarding the relationship between principle components of the organic farming ecosystems and GHG emissions in an attempt to identify opportunities and weakness of the system.

Plant Nutrition and GHG emissions

The ban of using chemical fertilizers in organic farming results in a major reduction in GHG emissions from this system. This is due to the fact that the emissions during the production process, transport and application of fertilizers are avoided (Figure 1). Wang [13] calculated that only for nitrogenous fertilizers the global warming potential ranged from 2.6 to 9.7 kg CO_2 eq/kg N produced. The high variability is related with the type of fertilizer and the production process. The production and transport of high soluble nitrogenous fertilizers such as ammonium nitrate resulted in GHG emissions equal to 9.7 kg CO_2 eq/kg N. In Cyprus the average consumption of N fertilizers was 4000 tns during 2013 while the European average was almost 11 million tns. Despite the fact that a decrease on N fertilizers was achieved since 1992 (Figure 2), the average Gross Nitrogen Surplus per ha in the period 2009-2012 was the highest among the EU-28 member states and accounted to 195 kg N/ha [1]. Thus any reduction of fertilizer use without losing plant productivity will favor environmental performance, particularly for GHG emissions and increase nitrogen use efficiency.

Plant nutrition is one of the major factors influencing the sustainability and the performance of organic farming systems [14]. Since the use of chemical fertilizers is prohibited, alternative methods and management practices are used to meet crops requirements. Under Mediterranean semi-arid conditions, crop nutrient management in organic farming is derived exclusively from external resources such as composts, animal and green manures as well as other organic residues in the basis of a crop rotation scheme. The necessary nutrients are provided to the crop through the mineralization of the organic matter that is introduced in the system. Thus understanding the factors influencing the mineralization rate is essential to avoid deficiencies or surplus of the available nutrients especially for nitrogen. Nitrogen is the most difficult nutrient to manage under organic farming schemes since its inorganic forms are extremely prone to leaching, volatilization and denitrification posing serious environmental and economic risks for the farmers. On the contrary, soil incorporation of organic amendments has a great impact on carbon sequestration [15] that is a main mitigation strategy for climate change. The interaction and the interrelation of these processes are crucial in order to achieve the desired result without organic farming systems losing their productivity. Thus it is imperative to identify and understand the mechanisms governing these processes that are related to GHG emissions in order to design optimized plant nutritional schemes.

Organic matter mineralization is not consistent through the year and plant nutrient demand must be matched with nutrient release from mineralization (Figure 3). Mineralization rates depends on the inherent properties of the introduced material (C:N ratio, lignin content), the environmental conditions (soil type, temperature, moisture) and the incorporation technique [16-19]. These factors are also affecting soil GHG emissions and the challenge is to design plant nutrition strategies that are maximizing plant performance at the minimum environmental cost. Particularly, failure to synchronize N mineralization with plant uptake can lead to plant deficiencies and subsequently to yield losses. Moreover, excessive amount of N inorganic forms will be accumulated creating serious environmental risks. Indeed, several studies demonstrated equal or even higher N_2O and CO_2 emissions after soil incorporation of organic residues compare with those measured in fallow fields or treated with chemical fertilizers [20-22].

Soil incorporation of fresh organic residues (animal or green manure) enhances microbial activity and at least temporarily increases microbial biomass. The rapid decomposition of these materials results in an accumulation of inorganic forms of nitrogen such as NH_4^+ and NO_3^- increasing the risk for NO_3^- leaching and N_2O emissions. These materials are usually characterized by low C:N ratio and their mineralization rate is high. On the contrary, organic amendments such as composts, with high C:N ratio and lignin content have slower decomposition rates [23] resulting therefore in reduced inorganic N forms in the soil. Incorporation of organic matter low in N content and high lignin concentration resulted in reduced $N\text{-}NO_3^-$ in soils and 33% lower N_2O emission rates compare with non-treated soils [21].

Besides the use of external sources of organic amendments, specific and diversified crop rotations are needed in order to increase nitrogen use efficiency in organic farming systems minimizing the same time GHG emissions. This is not an easy task and site-specific solutions are needed. In particular for semi-arid conditions like that occurring in Cyprus specific rotational schemes should be designed aiming at reduced GHG emissions and increasing NUE of the system. Under rainfed conditions in Mediterranean region a fallow-barley 2-year rotational scheme is implemented. The inclusion of legumes in this scheme usually improves system sustainability but this is not the common or the baseline practice at least for Cyprus in conventional farms. On the contrary in organic farming soil incorporation of vetch is a common practice in a three-year rotational scheme (vetch-barley-fallow). Emissions of nitrous oxide from legumes during the process of nitrogen fixation are negligible [24]. However, GHG emissions during the growing season should be taken into account either when the legumes are used as green manures or harvested for hey or seed. It could be therefore claimed that during a three-year rotational scheme a combination of high C:N ratio organic materials and fresh green manures will result in lower GHG emissions while the productivity of the system will be constant. So far multifunctional design of crop rotations didn't take into account the risks associated with GHG emissions and mitigation of climate change while the use of external organic amendments have been overlooked.

Irrigation and GHG emissions

Hot and dry summer is typical under Mediterranean conditions and water availability governs crop performance. In Cyprus, water is usually collected during winter in dams and distributed during summer or whenever is needed to agricultural areas through a well-organized irrigation network. Data regarding the emissions caused during water transferring are not available but is expected to be high due to the energy that is needed for water transportation. Ground water is also used for crop irrigation. In semi arid regions of China, ground water pumping is the biggest emission source accounting for 61% of the total irrigation emissions [25].

In disturbed Mediterranean type climates the "Birch" effect take place [26-28]. This is the peak of N_2O and CO_2 emissions caused by microbial activity that is stimulated during soil rewetting and when aerobic conditions are dominant and temperature is optimum. However GHG emissions of irrigation activities depends largely on water use efficiency of the crops. Several studies showed increased N_2O emissions in irrigated soils of semi-arid regions [29-32]. Drip irrigation favors a steady low level N_2O flux during the growing season while small peaks of N_2O emissions are measured after the irrigation event [33, 34]. Denitrification and the amount of N_2O emitted during the irrigation event are related with soil oxygen prevailing conditions. Increase of water filled pore space higher than 80% stimulates the emission of N_2 that is an inactive form in terms of greenhouse emissions.

Irrigation is not a stand-alone practice but is closely related to plant nutrition and crop genotype that is detrimental for the efficient utilization of the resources. Imbalanced nutrition and ecotypes susceptible to drought and water stress will reduce the water use efficiency of the crop leading to increased GHG emissions per ha or per product kg. Thus improving water use efficiency of the cultivated crops is an important tool to reduce GHG emissions.

Water use efficiency and GHG emissions are highly related with the irrigation methods employed. Several studies showed that drip irrigation reduces N_2O emissions compare to furrow methods [33-35]. Drip irrigation is broadly extended in Cyprus and is the main irrigation method implemented. Through drip irrigation, surface evaporation and runoff as well as deep percolation are reduced. This is also related to plant nutrition and the use of practices that are able to enhance plant productivity without increasing GHG emissions. The use of compost extracts during irrigation could be an alternative for irrigated crops in organic farming such as vegetables and orchards. Using this approach, we can achieve optimum nutritional status under optimal water regimes increasing therefore further the crop water use efficiency. However no data are available and this practice is unknown to the farmers.

The situation in rainfed systems like that of barley is completely different. Due to the high redox potential observed in these systems N_2O pathway is suppressed and the emissions are significantly suppressed. In such systems GHG emissions are observed usually after a precipitation event or during the incorporation of green manures or other organic amendments derived from external resources. Under these conditions, water availability should be examined in relation with that of organic carbon of soils and the mineralization rates of the introduced organic matter. Recently, the pathway of nitrifier denitrification was recognized as a significant route for N_2O emissions when soil water availability is in levels sub-optimal to denitrification [36] and in particular to Mediterranean conditions [34] this pathway could be the major route of N_2O emissions from soils.

Tillage practices and GHG emissions

The results concerning the impact of tillage practices in GHG emissions and in particular for N_2O are contradictory. Some research has shown that conservation tillage and in particular no-tillage, results in greater amounts of N_2O emissions than those measured in intensively tillage soils [37-39]. The phenomenon was attributed to the amount of plant residues left, keeping this way the soil wetter and providing energy to the denitrying soil community. However other studies indicated that intensive tillage methods such as moldboard ploughing induced N_2O emissions [40]. This was related to the increased organic C decomposition of soils treated and the higher temperatures prevailed after intensive tillage. Conservation tillage approaches like that of chisel are adopted by the farmers in order to maintain higher moisture levels and surface soil organic matter. However these conditions may increase NO_3^- levels and reduce the redox potential of soil favoring an increase of N_2O emissions.

Tillage is a common practice both in organic as well as conventional farming system and its effect is related with soil nutrient and water availability. For organic farming and especially during the conversion period, tillage is the only method to suppress weed competition since herbicides are prohibited. No data are available regarding the GHG emissions during this period. In addition most of the research performed regarding the effect of tillage on GHG emissions has focused on conventional farms and on comparisons between traditional plowing with conservation tillage. Recently, Campbell et al [41] showed that the no-tillage treatment resulted to lower N_2O emissions than the conservation treatments only in one of the two locations tested suggesting that besides tillage other factors are also involved. Tillage is a practice that is closely related to organic matter incorporation in soils and for organic farming this is a detrimental factor for nutrient management and in this context should be examined.

Organic Farming Breeding and GHG emissions

The challenge for producing more using less is a task that has to be achieved not only in organic farming, but also in low-input agricultural and conventional systems. Plant breeding is a valuable tool for achieving this task and historically this has been proven many times. Nowadays, 40% of the crop production globally comes from the 16% of irrigated good agricultural land. However, due to climate change as well as the increase in construction activities, the available utilizable good agricultural land declines. Thus, the task today is to create genotypes with specific traits that contribute to sustainable farming, including increased nutrient use efficiency, drought and pest tolerance without reducing crop productivity. Targeting plant breeding for organic farming systems can contribute in the same manner to reduce the observed yield gap. Development of cultivars adapted to organic farming conditions can be successfully achieved when plant breeding programs combine the selection of progeny in organic farming environments [42-44] and when selection emphasizes specific traits described below.

The adaptation and mitigation of climate change can be enhanced through specific strategies during the plant breeding process. The reduction of N_2O emissions can be achieved by selecting lines with increased nitrogen use efficiency. This will allow significantly less nitrogen inputs and increase nitrogen assimilation and uptake reducing therefore the prone to N_2O emission forms of nitrogen. Genetic variation in nitrogen use efficiency has been recognized in several plant species, while genomic regions associated with this trait have been identified in barley [45].

The ability of plants to establish efficient and competitive symbiotic relationships with functional microbial communities in soil is another very suitable trait in organic farming. For example, mycorrhizal fungi exhibit an important ecological role in soil fertility which is tightly related with the plant genotype. Increased micronutrient uptake was observed in winter wheat [46], while an increase of water use efficiency was documented in watermelon [47]

Another important factor for mitigating climate change is the enhancement of carbon sequestration. Key plant traits possibly influencing carbon sequestration are root characteristics such as depth, structure, and architecture. Allocation of photosynthates in root system will increase the amount of carbon remains in soil.

Microbial communities and GHG emissions

Nutrient cycling and the biogeochemical processes in terrestrial ecosystems are supported and governed by soil microbial communities. It is also well known that soil GHG emissions are mainly microbial driven (Figure 4). However, the importance of soil microbial communities to GHG emissions has been overlooked mainly due to the general assumption that microbial communities have little relevance to large-scale ecosystem models. This is further supported by the lack of the theoretical background of linking microbial assemblages to ecosystem functioning [48]. The majority of the studies concern the response of microbial communities to climate change and not how these assemblages are contributing to GHG emissions in different agricultural systems. It is well established that in organic farming systems the microbial community structure is more diverse. In particular, the abundances of genes that are related with C and N cycling in soils are higher in organic farming systems than in the conventional [49]. This was attributed to the increased amount of organic amendments that are incorporated into the soil. The high availability of rich organic substrates increases microbial diversity richness by promoting copiotrophic organisms [50].

In organic farming, biofertilizers could also be an alternative tool for crops nutrient managements. The use of specific microbial functional groups such as arbuscular mycorrhizal fungi, symbiotic nitrogen fixing bacteria and plant growth promoting bacteria is increasing [47]. The available data in literature regarding the impact of using these functional groups in GHG emissions are limited.

Arbuscular mycorrhizal fungi induce colonizes more than 80% of the terrestrial plants and their presence induces changes in soil structure, soil-water relations and the availability and quality of labile carbon [51-53]. Recently Bender et al. (2014) [54] showed that N_2O emissions were largely dependent on AMF presence. Reduced abundance of AMF resulted in an increase of N_2O emissions by 33% than treatments with higher AMF abundance. The abundance of AMF was also positively correlated with the expression of genes that are related to N_2O emissions indicating that the regulation of these emissions might be partially governed by AMF-induced changes in the denitrifying soil community. However this trend has to clarified and measured under field conditions.

Inoculation of legumes with efficient nitrogen symbionts is an important tool to increase nitrogen use efficiency of the crops and to reduce their dependence to nitrogenous inputs mitigating this way climate change. However, in agricultural ecosystems where legumes are included in crop rotation schemes, N_2O is also emitted from the degradation of root nodules [55]. Some *Bradyrhizobium* strains have in their molecular cascade *nosZ* gene which encodes N_2O reductace resulting therefore to the production of N_2. Characterization, isolation and inoculation of legumes with these strains could lead to a reduction of N_2O emissions and be a valuable mitigation tool for climate change [56, 57]. In addition, soil monitoring regarding the presence of this gene in the autochthonous nitrogen fixing populations will help us for a targeted implementation of such biofertilizers. No data are available regarding the expression of these genes in organic farming systems to reveal any differences at systems level (conventional vs organic) or to clarify the factors affecting the selection of such populations in Mediterranean climates.

Similarly, the use of plant growth promoting bacteria (PGPR) enhances nitrogen use efficiency of the plants while other studies showed an increase in CO_2 assimilation via increased photosynthetic activity [58]. The increase of nitrogen use efficiency of crops can allow the reduction of nitrogen inputs in the system reducing therefore N_2O emissions. The impact of using PGPR in organic farming has been overlooked in general while the study of GHG emissions in PGPR inoculated crops under controlled or field conditions are not available. Thus research is needed in order to evaluate the importance of these inoculants to global warming potential when used.

Terrestrial microbial biodiversity is a tremendous pool for the isolation of microbial stains that can be eventually used for the mitigation of climate change. Particularly for organic farming and the well-recognized need of increasing nutrient use efficiency biofertlizers could be another one valuable tool for the increase of yields without increasing inputs. In these circumstances the use of microbial inoculants may reduce GHG emissions from soils. To reach this point research and field trials are needed especially for Mediterranean region in order to quantitate the impact of this implementation in GHG emissions.

OPPORTUNITIES AND WEAKNESS FOR ORGANIC FARMING SYSTEMS

Opportunities for Organic Farming Systems as a mitigation strategy for climate change

It is now evident that further reduction of GHG emissions from agricultural sector should be take place. So far it is well established that organic farming can be an environmental friendly agricultural system that can reduce GHG emissions and meet the IPCC requirements. The key and the arising opportunity is the fact that multifunctional crop rotations should be carefully design using the available scientific knowledge. This will eventually lead to the sustainable use of green manures, biofertilizers, animal manures while GHG emissions will diminished. Besides GHG emissions, organic farming stores more carbon while the use of the pesticides and chemical fertilizers are prohibited. Longer rotations including legumes are supporting a more diverse microbial community structure enhancing this way ecosystems services while the capacity of the system to withstand drought increases.

The aforementioned opportunities however are strictly linked with scientific excellence and the close collaboration of key players of the sector. There is a tremendous gap in terms of research needs of organic farming that are related to GHG emissions as well as the adaptation of the organic farming practices to a changing environment. The behavior and the system performance in terms of GHG emissions under specific practices remains a great challenge and in particular for Mediterranean climates a lot remain to be clarified. The response and the resilience of the system that is also related with microbial communities is a black box. Understanding fundamental microbial mediated processes under organic farming systems is an opportunity to reveal its environmental superiority. However the greatest opportunity remains the increase of yields without deteriorating environment and in particular to reduce GHG emissions.

Common Agricultural Policy fosters the inclusion of organic farming in the Rural Development Plan. Thus organic farmers have the opportunity to be economically supported through subsidies and partially enhance the feasibility their enterprises. The use of subsidies is a tool that can be effectively used to increase organic farming production and thus reduce GHG emissions.

Weakness for Organic Farming Systems as a mitigation strategy for climate change

The major weakness of organic farming systems that are related with climate change is the lack of adequate production of knowledge. Particularly, the quantification of GHG emissions in specific rotational schemes is limited while there is strong evidence that global warming potential of wrong designed practices might be equal to that noticed in conventional farming systems.

Transportation of organic products from one region to another is another significant source of GHG emissions, further contributing to the global warming potential of organic food sector. Distribution of organic products locally is an option that has to be included in strategic design of the development of organic farming sector that is in general missing since the economic importance of the sector for Cyprus is limited. Another obstacle to achieve this goal is the inability of the farmers to provide a wide variety of organic products to the consumers continuously. This is attributed to the difficulties faced and is related to organic farming production as well as the farm small scale.

CONCLUSIONS

The importance of organic farming on GHG emissions under semi-arid conditions has to be verified. The literature review presented in the current report suggests that combined and complementary practices in organic farming might be useful for mitigating climate change. The use of improved irrigation systems like that of drip irrigation and the controlled nitrogen inputs might not be accompanied by increased N_2O emissions. This has to be verified through a specifically designed multifunctional crop rotational schemes.

A main barrier for the development of organic farming is the inability of Cypriot farmer to produce and provide to the market a wide variety of products continuously. Thus inter-allia specific technical solutions and practices should be developed in order to overcome these obstacles. However, the increase of organic farming systems productivity should not accompanied by an increase of GHG emissions. The latter has to be proven by scientific evidence and through a comprehensive life cycle analysis.

Issues related with organic products transportation is another important issue that has to be taken into account in terms of GHG emissions. Opportunities and available tools should be developed in order to enhance and support the operation of local markets.

ANNEX

Figure 1. The soil/plant nitrogen cycle; From Cameron, 2013 [59]

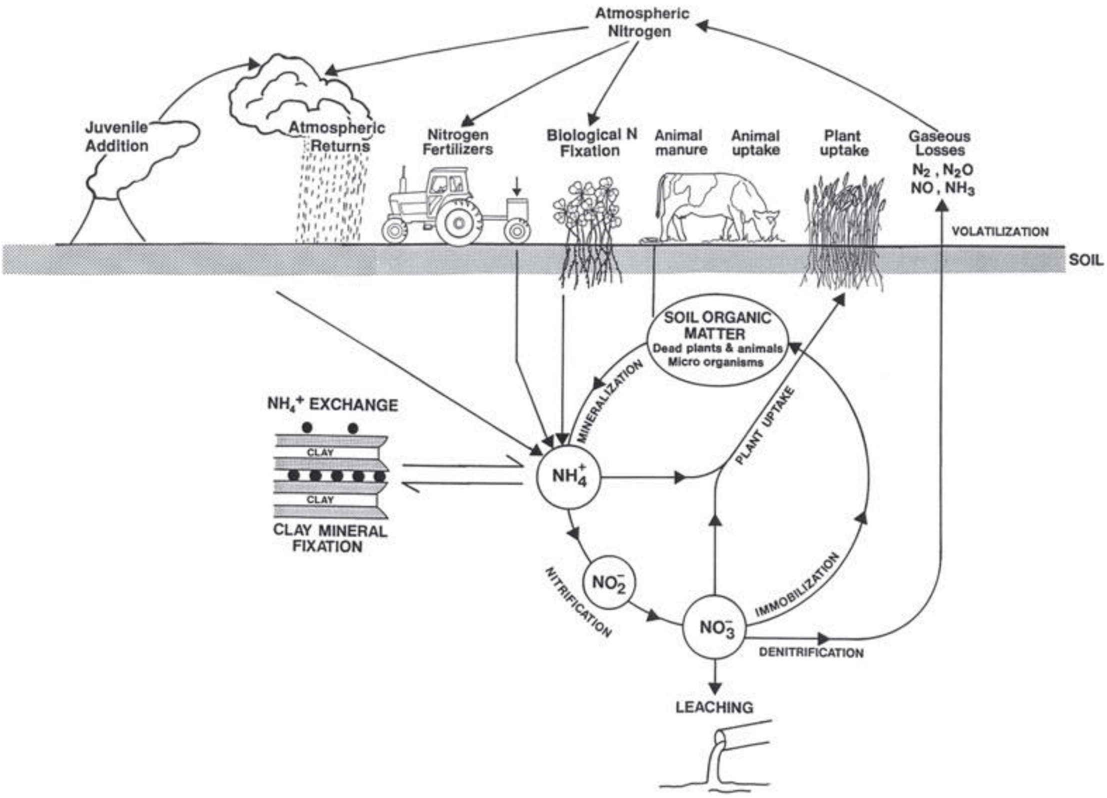


Figure 2. Imports of N fertilizers in Cyprus (1992-2012)

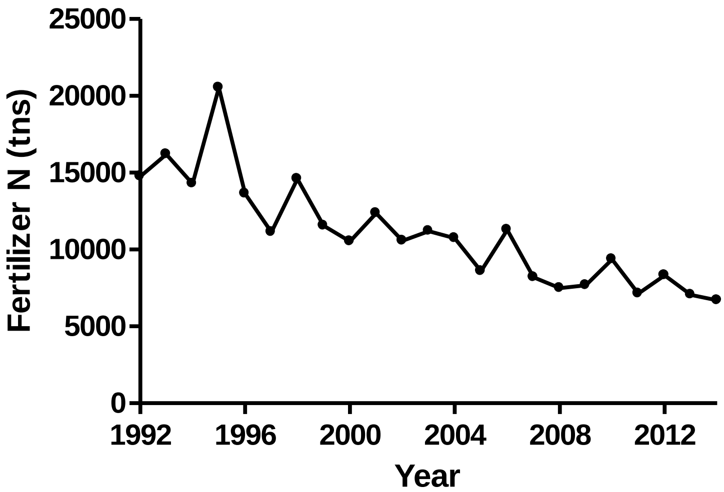


Figure 3. The synchronization concept in organic farming systems. Rapid release from organic sources with a low C:N ratio may supply nutrients more rapidly than the plant's demand (A). An organic material with a high C:N ratio may not release nutrients sufficiently rapid to meet the need of growing plants (B).

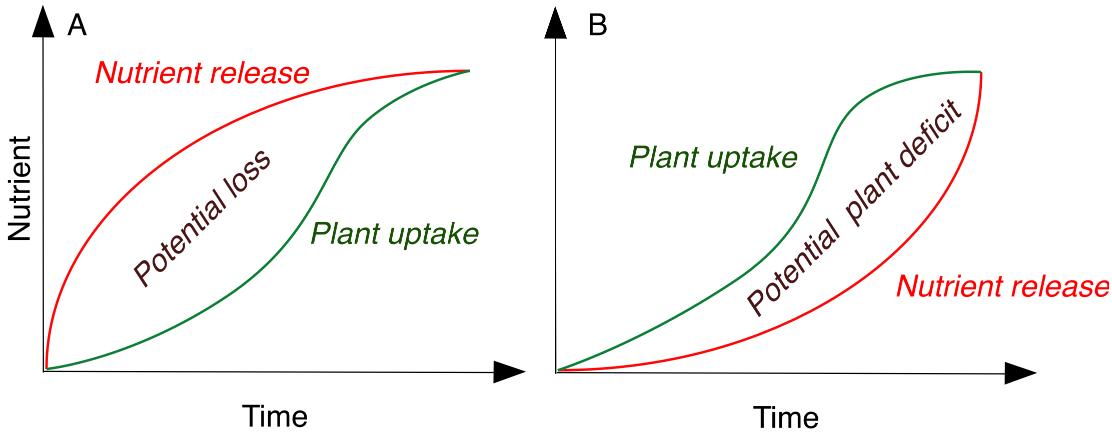
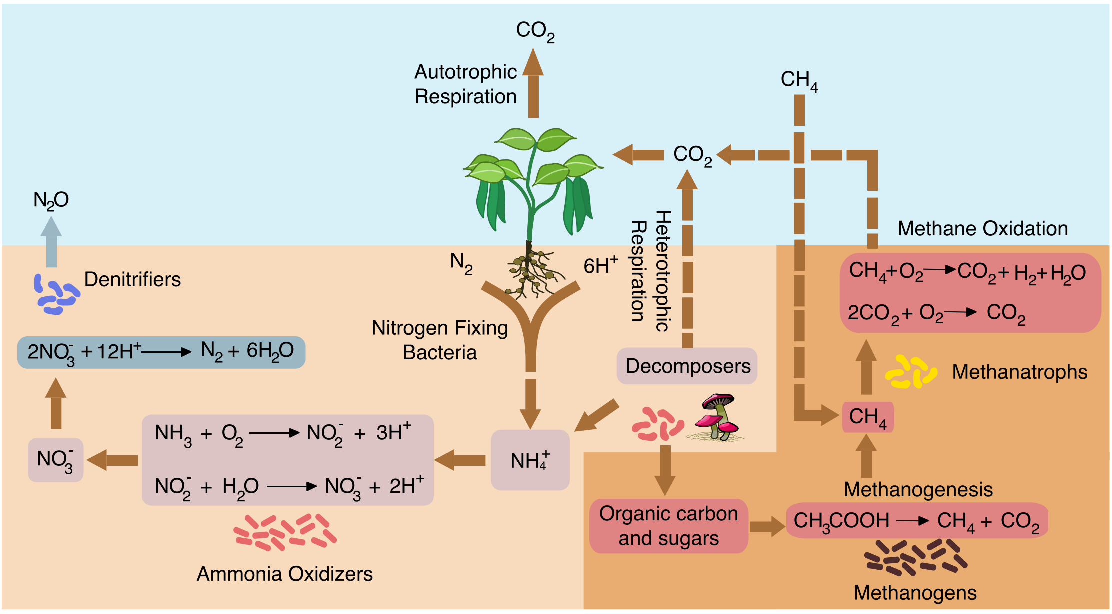


Figure 4. Emissions of N_20, CO_2 and CH_4 driven by biological proccesses



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