Climate mitigation performance assessment based on agronomic and environmental indicators

ORGANIKO LIFE+ PROJECT

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

Action C2, Activity 2.1

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FINDINGS AT A GLANCE

Plant Available N is higher in conventional systems

Soil quality differs among the agricultural systems

Farming system significantly affected soil carbon stocks !!!

Incorporation of farmyard manure and compost in soil results in a significant increase of soil organic carbon!!!

In the long term exclusion of organic amendments in organic farming systems results in a substantial reduction of soil carbon stocks!!!

Executive Summary

Σκοπός

Σκοπός της παρούσας έκθεσης είναι να παράσχει λεπτομερή στοιχεία σχετικά με τους βασικούς περιβαλλοντικούς δείκτες του εδάφους από μονάδες βιολογικής και συμβατικής παραγωγής κριθαριού και μήλων όσο και από τις πιλοτικές μονάδες του ΙΓΕ. Η έκθεση αυτή εντάσσεται στη Δράση C2 "Climate mitigation performance assessment based on agronomic and environmental indicators" και ειδικότερα στο πλαίσιο της δραστηριότητας C2.1

Αντικτυπος

Οι φυσικοχημικές ιδιότητες του εδάφους εξετέστηκαν από το 2015. Οι κύριοι δείκτες που μετρήθηκαν είναι ο συνολικός N, οι διαθέσιμες μορφές N, το pH, το EC, ο P-Olcen και το CaCO3. Εφαρμόστηκε τεχνολογία NGS για την αξιολόγηση της επίδρασης των συστημάτων καλλιέργειας στη μικροβιακή κοινότητα του εδάφους. Επιπλέον, η αποθήκευση C αξιολογήθηκε στα πειραματικά αγροκτήματα του ΙΓΕ μέσω της εφαρμογής του μοντέλου ICBM.

Αποτελέσματα

Παρατηρήθηκαν σημαντικές διαφορές μεταξύ οργανικών και συμβατικών συστημάτων σε όλες τις καλλιεργητικές περιόδους. Στα συμβατικά συστήματα, η περιεκτικότητα του εδάφους σε NO3- και NH4 + ήταν σημαντικά υψηλότερη. Αντίθετα, η περιεκτικότητα σε οργανικό C καθώς και του P-Olsen ήταν υψηλότερη στα συστήματα βιολογικής καλλιέργειας. Οι κοινότητες των βακτηρίων διέφεραν μεταξύ των καλλιεργειών αλλά όχι μεταξύ των γεωργικών συστημάτων. Παράγοντες όπως ο οργανικός C και το pH είναι οι σημαντικότεροι παράγοντες του εδάφους που επηρεάζουν την βακτηριακή κοινότητα στα υπό εξέταση εδάφη. Τέλος, η εφαρμογή του μοντέλου ICBM έδειξε ότι το ο οργανικός C αυξάνεται και θα μπορούσε να διατηρηθεί χωρίς μείωση μακροπρόθεσμα, όταν εφαρμόζονται οργανικη ουσία κάθε χρόνο.

Συμπεράσματα

Τα ευρήματά μας δείχνουν ότι υπάρχει σημαντική διαφορά μεταξύ συστημάτων συμβατικής και βιολογικής καλλιέργειας όσον αφορά την ποιότητα των εδαφών. Επιπλέον, ο τύπος της καλλιεργείας και η καλλιεργητική περιόδος είναι κρίσιμοι παράγοντες που ελέγχουν την ποιότητα των εδαφών. Τα οργανικά εδάφη είναι σε θέση να διατηρήσουν τα αποθέματα C του εδάφους λόγω των εφαρμοζόμενων στρατηγικών διαχείρισης θρεπτικών ουσιών. Η αύξηση και η συμπερίληψη οργανικών τροποποιήσεων στα συμβατικά συστήματα αναμένεται να βελτιώσει σημαντικά οργανικό C του εδάφους. Τέλος, η ποικιλότητα των βακτηριακών κοινοτήτων καθορίζεται από τους χημικούς παράγοντες του εδάφους που επηρεάζονται από τις πρακτικές διαχείρισης του εδάφους.

Executive Summary

Purpose

The aim of this report is to provide detailed data regarding baseline environmental soil indicators in both in pilot organic systems of ARI as well as farmers agricultural land that is under the monitoring program of ARI. This report is under Action C2 "Climate mitigation performance assessment based on agronomic and environmental indicators" and particularly within the Activity C2.1 "Monitoring environmental metrics related with climate mitigation and agro-ecosystem services".

Outcome

Soil chemical and physical characteristics were monitored since 2015. The main indicators measured are total N, available N forms, pH, EC, P-Olcen and CaCO3. Soil DNA was extracted and sequencing analysis was performed to evaluate the impact of farming systems on soil microbial community. In addition, C sequestration was evaluated in the pilot farms of ARI through the implementation of ICBM model.

Results

Clear differences between organic and conventional systems have been noticed in all growing seasons. In conventional systems, the amount of NO3- and NH4+ soil content was substantially higher. On the contrary, organic C as well as P-Olsen content was higher in organic farming systems. The bacterial communities differed among crops but not agricultural systems. Factors like organic C and pH are the most important soil factors shipping the bacterial communities in the soils surveyed. Finally, ICBM modelling showed that soil C increases and could be maintained without reduction in the long term when organic amendments are applied every year.

Conclusion

Our findings suggest that there is a significant difference between conventional and organic farming systems regarding environmental metrics. Additionally, the effect of crop and growing season are critical factors controlling the quality of soils. Organic soils are able to sustain C stocks of the soil due to the nutrient management strategies implemented. The increase and the inclusion of organic amendments in conventional systems is expected to substantially improve the sustainability of C stocks of the soil. Finally, the diversity of the bacterial community is driven from soil chemical factors that are affected from soil management practices.

Introduction

Green revolution led to a progressive loss of soil fertility and caused environmental pollution.

The green revolution in agriculture introduced new practices based on the intensive use pesticides, chemical fertilizers and improved crop varieties (Robertson et al., 2014). The intensive agricultural activity and the monocultures promoted to and adopted from the farmers globally, led to a progressive loss of soil fertility and biodiversity (FAO, 2013). This intensification is expected to increase further due to the demand for food at global scale and will degrade even further soil quality. Moreover, climate change is also expected to significantly exacerbate the already negative impacts of high-input agricultural activities. For example, extreme weather phenomena, prolonged drought and the outbreak of pests and diseases are expected to significantly reduce the productivity of agricultural ecosystems.

Climate change is affecting the productivity of agricultural ecosystems

It is therefore important to implement practices and adopt production systems that maintain natural resources and to cause the least possible environmental burden. Organic farming has been proposed by many scientists as a system that can improve the environmental performance of agriculture (Robertson et al., 2014). In particular, the implementation of the rules and practices of organic farming, causes an improvement of the soil quality, enhances biodiversity and contributes positively to the ecosystem services. Particularly for soil, the design and the implementation of plant nutrition management is based on the addition and preservation of soil organic matter. However, although the application of organic amendments to the system, the yields in organic farming are significantly lower than those of conventional agriculture (De Ponti et al., 2012; Ponisio et al., 2015). This gap in production is due to soil nutrients availability and the pressure from enemies and diseases since in conventional agriculture, chemical pesticides

Nutritional value of organic and conventional products are used. The production gab between conventional and organic farming systems creates doubt in the scientific community and policy makers for the ability of organic farming system to be used as a sustainable solution to meet the challenges of food security in a climate changing environment.

The knowledge of temporal changes in soil carbon is crucial as a GHG mitigation indicator. Indeed, early studies and in particular, Article 3.4 of the Kyoto Protocol indicates that carbon sequestration in agricultural soils can be of great importance for balancing global CO_2 emissions. Previous studies showed that organic farming practices could increase soil organic carbon (Niggli et al., 2009). However, previous studies showed no or no consistent effects of organic farming on soil organic C (Friendel et al., 2000; Marinari et al. 2006). Unfortunately, there are no studies in Cyprus regarding soil carbon dynamics within barley and apple orchard systems to enable extension services to provide accurate advice on soil carbon management and particularly how to manage soils to sustain and increase soil carbon content. In this Appendix we present the impact of management practices on soil organic carbon changes in experimental fields using ICBM model.

There is lack of comparative studies in Cyprus

Several models have been used to explain, predict and simulate carbon dynamics in soils like RothC (Farage et al., 2007), Century (Kamoni et al., 2007) and APSIM (Agricultural Production Systems Simulator) (Micheni et al., 2004). These models are describing carbon dynamics using complex sub-models and are trying to simulate carbon pool changes over time and have been tested in numerous climatic conditions throughout the world. For practical reasons, simple and accurate models are necessary to evaluate the impact of several agricultural practices on carbon dynamics in soils. The Introductory Carbon Balance Model (ICBM) is a simple

Model taking into account one rapid and one slow carbon pool (Andren and Katterer, 1997) and has been parameterized to a long-term field trial in Sweeden. Besides, ICBM was developed as a minimum approach for calculating soil carbon balances in a 30-year perspective (Andren et al., 2004). It uses daily weather station data into a climate factor reflecting the impact of climatic conditions on soil biological activity.

So far, in Cyprus the yield gabs between organic and conventional farming system have not been studied. Yet, the effect of the farming system on soil parameters has also not been studied. In particular there is a lack of knowledge regarding the chemical and biological profile of soils in Cyprus managed under organic and conventional systems.

The aim of this report is to present a comparative study of organic and conventional farming systems in terms of the yields in apple orchards and barley crops from Cyprus farmers. In addition, we are presenting an extensive comparative analysis between organic and conventional farming systems regarding soil chemical and biological properties. Finally we integrated ICBM method under Cyprus conditions, we can relatively estimate the potential soil organic carbon decomposition rates and reveal the potential of organic farming practices to sequestrate organic carbon taking into account systems productivity.

Materials and Methods

National Survey Analysis

Surveyed farms

In the current project we collected samples all around Cyprus from fields that are under the control of Certification bodies for organic farming as well as fields where conventional farming practices are implemented. Totally, we receive samples and data from 35 barley livestock free farms (under organic and conventional farming schemes total area: 323 ha) and from 15 apple orchards (under organic and conventional farming schemes, total area: 75 ha). The lowest number of the apple field samples was due to the fact that the certified area of organic apples orchards in Cyprus is very low (less than 0.7% of the total utilized agricultural area under organic farming).

Soil sampling and analysis

To detect spatial differences in chemical and biological soil properties, soil samples were collected from 15 sampling points in each field. The samples from each sampling point were pooled and transferred to the lab for analysis. . From these samples, EC, soil pH in H2O, soil moisture, soil organic matter fraction,TKN, NO_3^-, NH_4^+, P-Olsen, $CaCO_3$ were determined. Prior to analyses samples were homogenized and sieved through a 2 mm grid to remove coarse components like roots, stones and coarse litter. The standard operation procedures for the methods used are available in the Appendix of the current report.

DNA extraction and Next Generation Sequencing

DNA was extracted from 250mg soil from each replicate samples for all treatments before, 5 and 34 days after the application of the treatments. The 16S rRNA gene V4 variable region PCR primers 515/806 with barcode on the forward primer were used. Sequencing was performed on a MiSeq following the manufacturer's guidelines. Sequence data were processed using QIIME analysis pipeline (Caporaso et al., 2010) which utilizes the Ribosomal Database Project (RDP) classifier and the

Greengenes database. Operational taxonomic units (OTUs) were defined by clustering at 3% divergence (97% similarity) using USEARCH algorithm in QIIME. Alignment to the reference database in QIIME was performed using the PyNAST algorithm.

Statistical analysis

All statistical analyses were performed using RStudio commercial software (Version 1.1.456). Mixed effect models have been used to examine the impact of the growing season and the agricultural system on the several parameters examined. The analysis was performed using lmer4 package while pair multiple comparison of the marginal means have been examined using emmeans package. Multivariate analysis was used to assess the differences between the different soil variables during time. Data from 2015-2016 were excluded from the analysis but presented because of different sampling time.

Shannon Diversity Index was calculated to assess the diversity of the bacterial community. Non-metric multidimensional scaling (NMDS) based on the Bray-Curtis dissimilarity index was used to visualize the distribution patterns of bacterial soil assemblies in relation to the implemented treatments. Significantly correlated environmental parameters with the bacterial composition of each treatment were calculated using envfit function of Vegan package (v.2.5–4) (Oksanen et al., 2017). The response of individual taxa to the different treatments and their dissimilarities were evaluated using PERMANOVA as implemented in the adonis algorithm of the R package Vegan.

Implementation of ICBM model

Experimental design, meteorological data and soil analysis

Daily meteorological data are available from the meteorological station of Agricultural Research Institute, of Acheleia where the organic pilot farms are located. The data were used to calculate the main components of the model and are described in detail elsewhere (Bolinder et al. 2007; Andren et al., 2007).

Three different crop species suited for the rain-fed conditions of Eastern Mediterranean region were examined under organic and conventional agricultural practices and under 3 different rotational schemes in a spit-plot design.

The barley cv Achna was sown at the seed rate of 120 kg/ha, while a local cultivar of vetch and pea were sown at the seed rate of 150 kg/ha. The organic managed experimental field was subjected to alternative N nutrient management strategies: i) goat composted manure (MAN) was applied at the rate of 1.2 tn/ha (101 kg N/ha) at the end of November each year and ii) compost (COM) derived from plant residues was applied at the rate of 1 tn/ha (111 kg N/ha) at the end of November each year. The conventional managed experimental field received ammonium nitrate (F) at the rate of 180 kg/ha (60 kg N/ha). In vetch-seeded plots, the biomass was incorporated into the soil during flowering using rotavator. Before incorporation, the biomass produced in 1 m2 was weight and a subsample of 300 g was used to determined N and dry biomass. Additional plots without the application of any external nitrogen input were used as negative control (C) treatments for all crops under study. The calculation of carbon sequestration was performed using soil organic carbon stock (tn/ha) and carbon sequestration rate (tn/ha/year). Soil carbon stock was calculated using the following equation:

SOCstock = BD x SOCconc x D

Were BD is soil bulk density (tn/m^3), SOCconc is the concentration of soil organic carbon (mg/kg) and D is the soil layer thickness (m) Bulk density was calculated according to previous findings (Post and Kwon, 2000)

C sequestration rate= (Ctx – Ct0)/t

Where Ctx and Ct0 are the soil carbon stocks (tn/ha) at each sampling period. So far, the data presented in this report covers the years 2015 to 2019.

At harvest, crop yields were measured on the entire experimental plot (15 m2). Total C determined using the Dumas method and the biomass of the crop residue was determined using the harvest index (HI= 0.45 for barley) and shoot to root ratio (S/R) according to field measurements (Barley S/R=7.12, vetch S/R=1.23, chickpea S/R= 1.43).

Model Description and Assumptions

ICBM is a five-parameter model that has two pools of carbon: young and old soil carbon. The five parameters are ***i*** (carbon input), ***h*** (humification coefficient), ***Ky*** (decomposition rate constant for young soil organic carbon), ***Ko*** (decomposition rate constant for old soil organic carbon) and ***re*** (climate factor affecting the decomposition of young and old soil organic carbon).

A decomposition rate modifier ***re*** is calculated on a daily basis and then aggregated to annual values to reflect the climatic and hydrological conditions at a site, which influence biological activity. A detailed description of the calculation of ***re***, which includes a bucket model for the soil water balance and estimates of soil temperature derived from air temperature, can be found in Fortin et al. (2011) and papers cited therein. In the current work we calculated the ***re_clim*** using available daily meteorological data (PER, temperature and precipitation).

The annual input of carbon (***i***) in the system is calculated as the sum of inputs from each treatment. In the system, hay and grain yield from plots cultivated with barley were removed from the system and only stables and roots remained in the plots. In vetch treated plots, all the above ground biomass was incorporated into the soil. In all treatments, we assume that 65% of the root biomass was added into the soil during the growing season (Bolinder et al., 2007). The external carbon input in plots compost and manure treated plots was calculated according the carbon content of these material as determined in Agricultural Research Institute.

Statistics

The data collected from each treatment within and between the agricultural systems were processed by univariate ANOVA with fixed model using STATISTICA 7.0. Simple Excel spreadsheet was used for the ICBM simulations according the procedures described in (Andren et al., 1997).

Results and Discussion

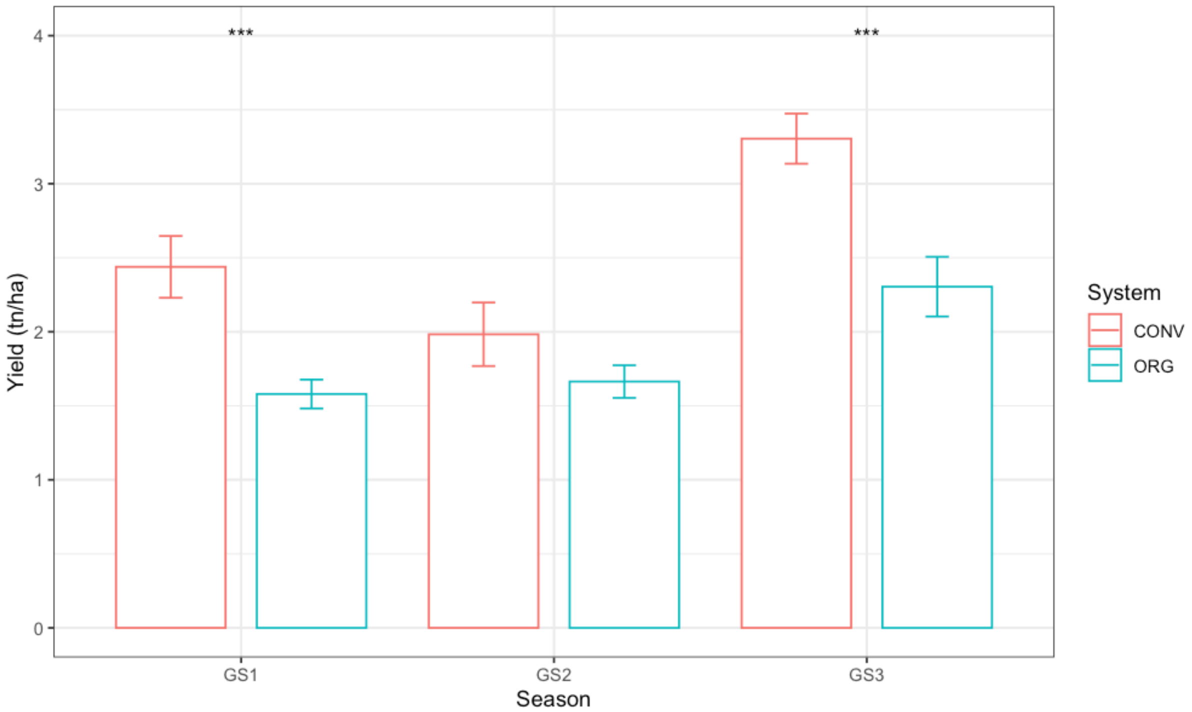
National Survey Analysis

Yield gap between organic and conventional systems

Barley

In the current report we are presenting a comparative analysis between organic and conventional barley farming systems. Mixed linear models demonstrated significant main and interaction effects of growing season as well agricultural system. Pair comparison of the different agricultural

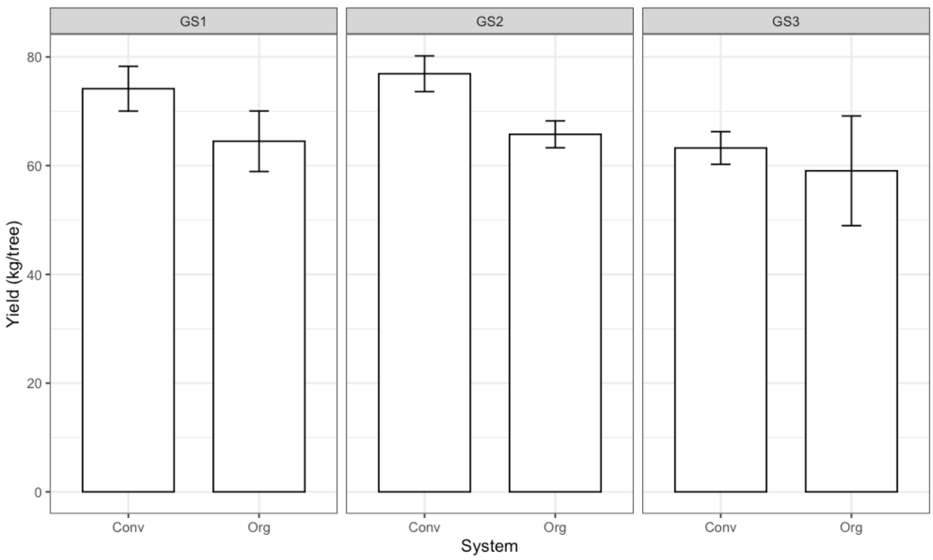
Figure 1. Yield of barley (tn hay/ha) grown under different farming systems in Cyprus in three growing seasons (GS1, GS2 and GS3)



systems showed that conventional farms produce more than barley farms under the organic farming scheme except growing season 2017-2018. During the first (2016-2017) and the third (2018-2019) the gab between conventional and organic farming systems was 36 and 31% respectively. Barley yield, irrespectively the farming system, was substantially higher during the third growing season compared to the first and the second growing season due to the higher rainfall occurred. These findings are in accordance with previous reports showed the superiority of the conventional to organic farming system (Knapp and van der Heijden, 2018; Ponisio et al., 2015). Similar findings have been noticed in the pilot of ARI only when compost from green wastes was included in the nutrient management scheme of the system. Instead, in the pilot farm of ARI when organic manure was used, the productivity of the organic compared to conventional farming systems was similar. It is evident that environmental conditions significantly affected barley yields under organic and conventional farming systems. Particularly for organic farming, farmers are heavily rely on the productivity of green manures as well as the . For example, during the first growing season 2017-2018 the productivity of these crops was low due to low rainfall thereby affecting the productivity of the subsequent crop which in our case is the barley.

Apple

The overall productivity of conventional apple orchards was higher compared to that of organic farming orchards. However, there are farms in which organic farming results in similar to conventional farming yields. This is related with several agronomical and genetic characteristics that are



related to the apple variety. For example, in more dense apple orchards i.e grown under a trellis system, the total yield of organic farming systems is higher or similar with that of conventional farming system where a free style pruning system is implemented. In detail, the productivity of apple trees in the LIFE+ORGANIKO pilot farms in the different nutrient management schemes implemented ranged from 51 to 89 kg/tree depending on the nutrient management scheme established, in a Pink Lady variety grown in a trellis system. On the contrary in a Starking variety, the yield per tree ranged from 38 to 89 kg with a grand average of 60 kg/tree. The average production of conventional apple orchards was 72 kg/tree and was 17% higher than that of organic systems and similar with that of organic apple trees cultivated under trellis system.

Variability of soil parameters between the systems

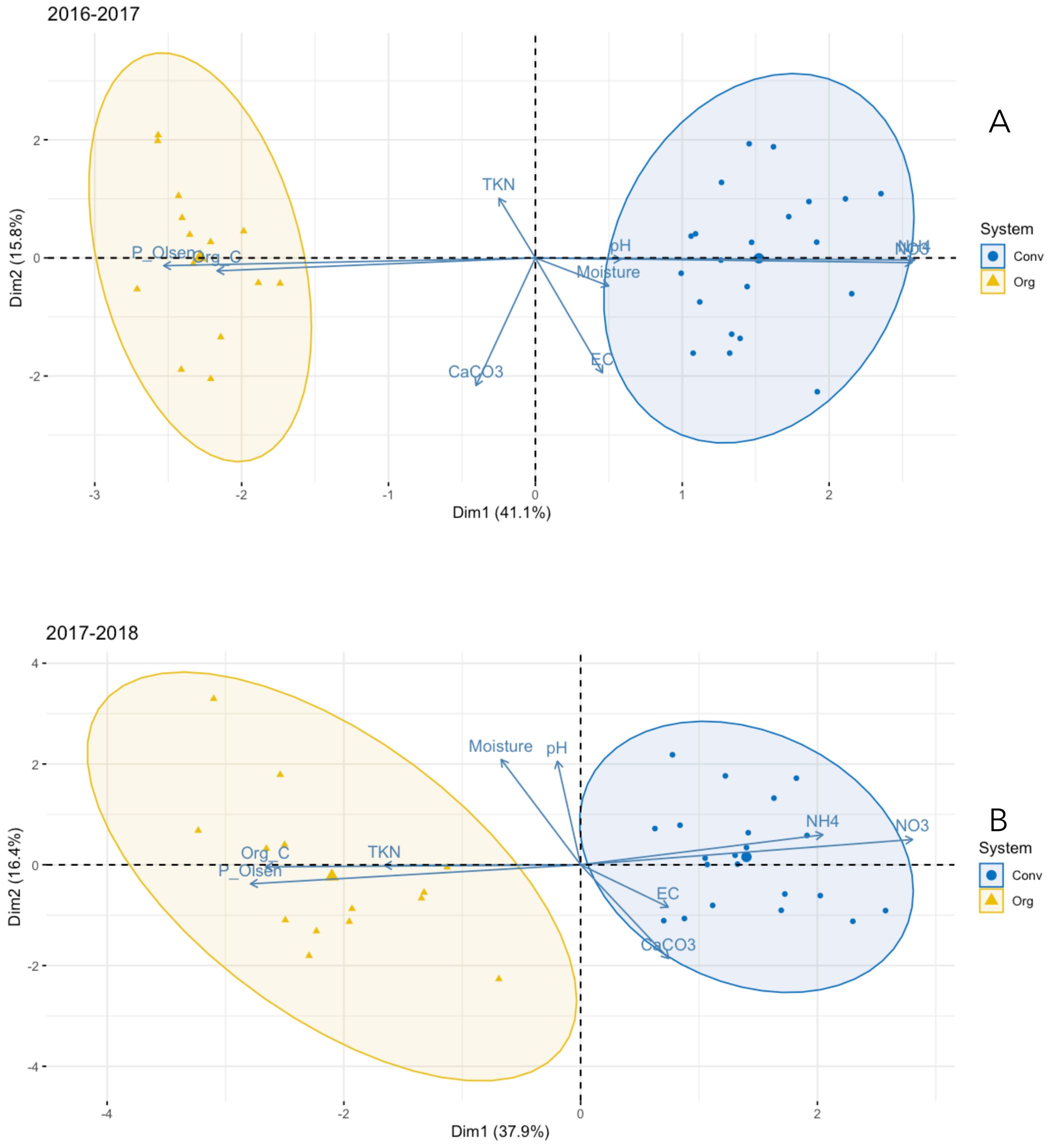
Barley

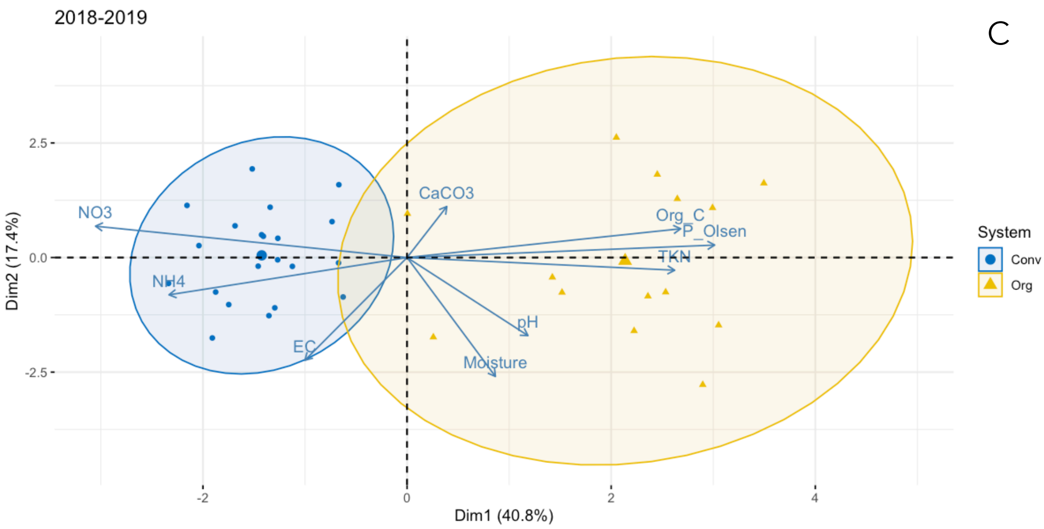
Average values of environmental variables obtained from the conventional and organic farming systems are summarized in the Appendix of the current deliverable.

Clear differences between organic and conventional systems have been noticed in all growing seasons. Multivariate analysis revealed differences between system in all growing seasons (Figure 1A, B and C). The separation to the different Principal Components, between the agricultural systems, was due to the differences on specific soil parameters. For example, in conventional systems, the amount of NO_3^- and NH_4^+ soil content was substantially higher (Figure 2). Higher concentrations of available N in conventional farming systems are possibly related to the highest amount of available nitrogen that is applied into the system chemical fertilizers. Previous studies showed that the amount of available N in conventional soil is higher than that measured in organic farms (Calleja-Cervantes et al., 2015; Nautiyal et al., 2010; Reidsma et al., 2018; Sekiguchi et al., 2008; van Diepeningen et al., 2006). These findings are similar with those observed in the pilot farms of ARI at Acheleia Paphos.

On the contrary, organic C as well as P-Olsen content was higher in organic farming systems (Figure 3). The higher content of organic C and available P found in the organic farms suggest that the inputs from green manure and or other organic amendments are affecting these parameters. The addition of animal manures for example reduces the binding cites for phosphates due to the chelation of Fe and Al of the soils, thereby resulting in an accumulation of available P in the soil solution (Jiao et al., 2007). Several other studies showed an increase of P availability in the soil which is in line with the findings in Cyprus organic soils monitored during LIFE+ ORGANIKO (Cooper et al., 2018; Jiao et al., 2007; Marinari et al., 2006; Melero et al., 2006). The increase of organic C during the addition of organic amendments is expected and is of major advantage of organic farming.

Figure 1. Principle Component Analysis of soil environmental parameters variability in organic and conventional barley crops during 2016-2017 (A), 2017-2018 (B) and 2018-2019 (C).





Several studies, presented that the addition of organic amendments had a significant positive effect of C-pools of soils. In the current, survey the organic C in organic barley fields ranged from 0.96 to 3.15%. The coefficient of variation ranged from 12 to 35% indicating the high variability within the different farms. On the contrary, in conventional farms, the coefficient of variation ranged from 5 to 11%. The latter shows that the differences between the management practices and particularly the addition of organic amendments into the system. For organic farming, the the high CV shows that also there are differences among farmers about the use of organic amendments.

Figure 2. Soil NO3 and NH4 concentration of organic and conventional barley farming systems

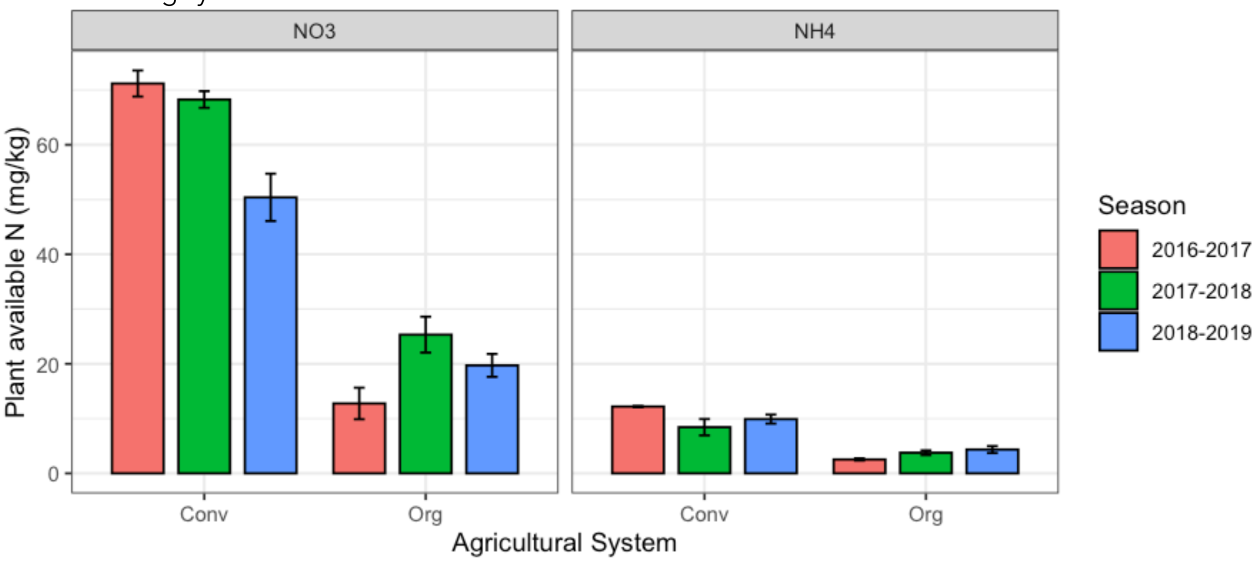
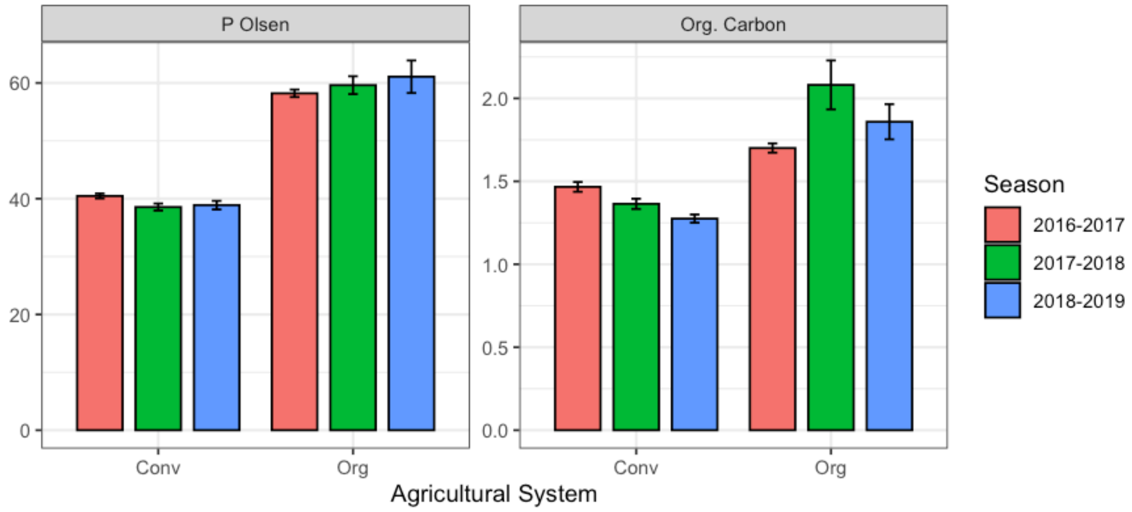


Figure 3. Levels of P - Olsen and Organic C of organic and conventional barley farming systems

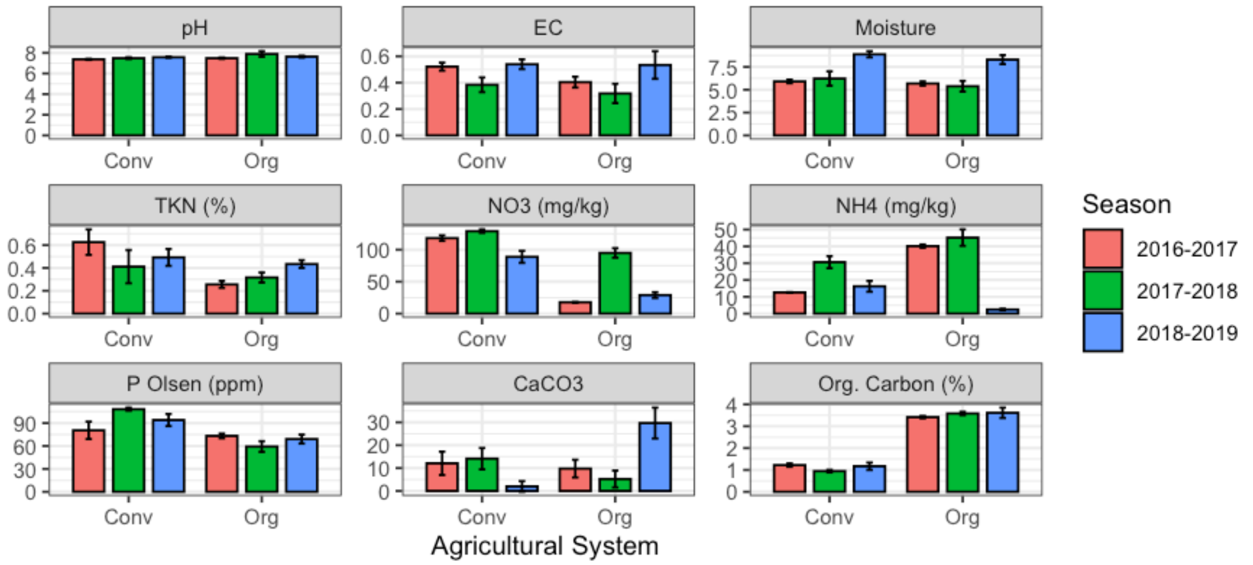


Apple orchards

Average values of environmental variables obtained from the conventional and organic farming systems are summarized in the Appendix of the current deliverable.

Clear differences between organic and conventional systems have been noticed in all growing seasons. Multivariate analysis revealed differences between system in all growing seasons (Figure 4A, B and C). The separation to the different Principal Components, between the agricultural systems, was due to the differences on specific soil parameters. In all growing seasons, organic farming orchards separated from conventional orchards according to the dimension of the first principal component. The data explained a substantial part of the variability and ranged from 59 to 67 % in the first and the second principle component. The soil organic carbon was substantially higher in organic farming orchards which is in line with the overall concept of increased organic matter and accumulation in organic managed soils. Previous studies showed that the nutrient management strategies followed in organic farming apple orchards increased the organic matter of the soil due to the increased amount of compost and manures applied as well as the integrated and sustainable floor management of the orchard. Under the conditions of Cyprus orchards

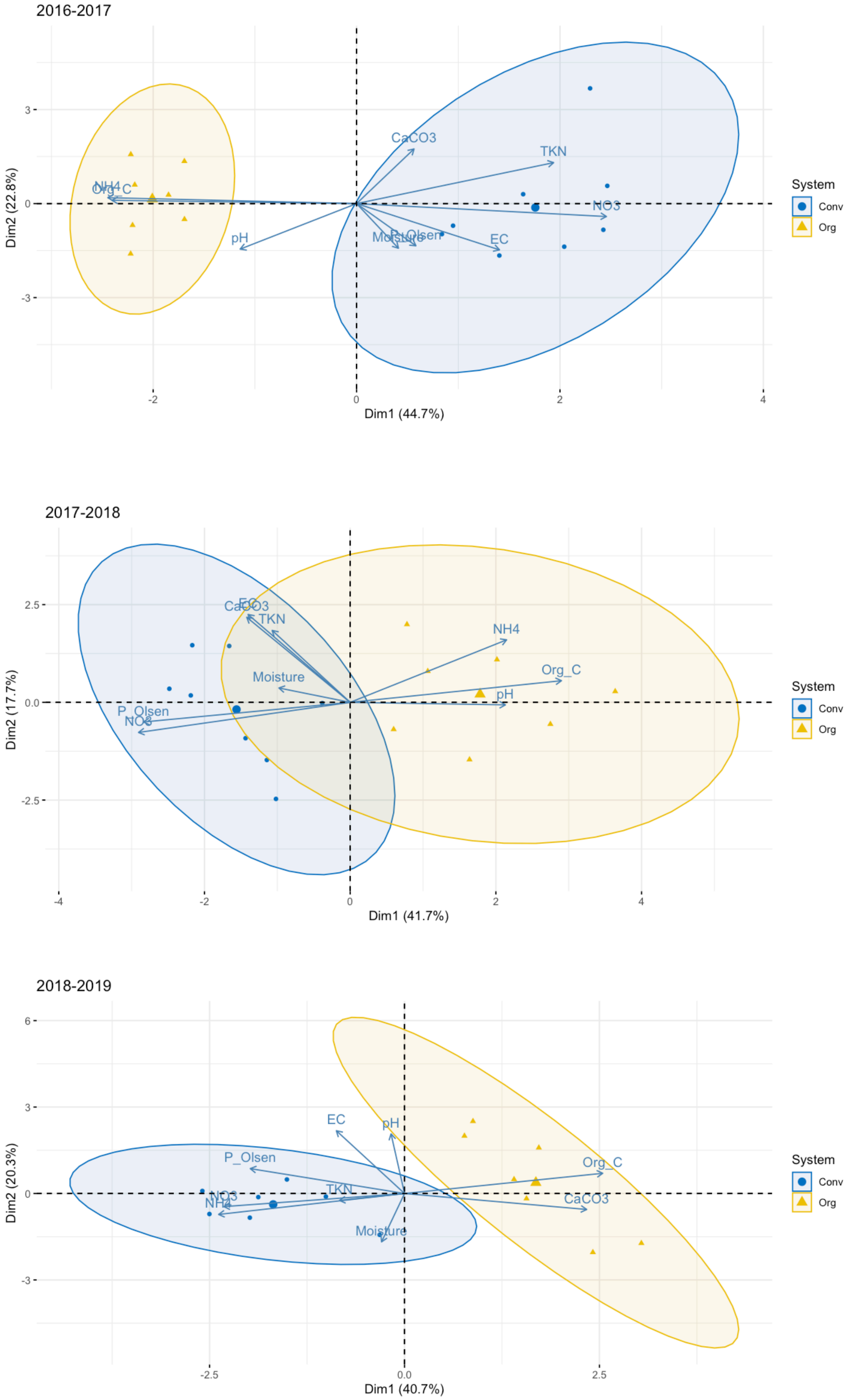
Figure 4. The content of different soil parameters in organic and conventional apple orchards



farmers are not using the practice of green manuring and the inclusion of legumes as a cover crop during winter and the incorporation of the above ground biomass into the soil or its usage as a mulch during summer. The use of barley straw in the pilot farms of LIFE+ORGANIKO resulted in a substantial increase of organic C during time. It is unknown whether under Cyprus conditions, mulching with legumes above ground biomass will increase soil organic carbon. In temperate regions, floor management is a fundamental practice for organic farmers resulting in a significant improvement of the soil fertility.

Under Easter Mediterranean conditions, the amount of NH_4 was higher in soils managed under organic farming schemes (Figure 5). This is probably related to the amount organic N that undergoes mineralization process. On the contrary, the amount of NO_3 and total N was higher in conventional apple orchard soils. The higher availability of NO_3 in conventional systems suggests that under this system the possibility of NO_3 leaching into the groundwater resources could be higher. However more detailed studies are needed to explore the fate of NO_3 as well as NH_4 in both organic and conventional systems under the environmental and climatic conditions of Cyprus.

Figure 5 Principle Component Analysis of soil environmental parameters variability in organic and conventional apple orchards during 2016-2017 (A), 2017-2018 (B) and 2018-2019 (C).



Bacterial communities in Cyprus systems

Composition of bacterial communities

The soil microbial composition of organic and conventional farming systems in barley fields and apple orchards are summarized at phyla level, and depicted in Figure 6. Overall, a total of 16 phyla from Bacteria domain, 34 classes, 74 orders, 94 families and 135 genera were found within the soil samples. Irrespective of systems or crop type, bacterial communities were dominated by Proteobacteria (36.9%), Bacteroidetes (7.72%), Acidobacteria (7.52%), Actinobacteria (24.90%), Firmicutes (1.94%), Verrucomicrobia (3.35%), Planctomycetes (9.44%), Gemmatimonadetes (2.92%) and Chloroflexi (3.66%). Other phyla were represented by a relative abundance less than 1%. The relative abundance of the Phyla identified in the different farming systems and crops is shown in Figure 6.

General linear regression using negative polynomial transformation was used to evaluate differences between organic farming systems and crops. The abundances of most of the Phyla examined were not significantly affected either from the agricultural system however the abundance of the different microbial Phyla were different between apple orchard and barley fields. Details for the absolute abundance of the different phyla examined are presented in Figure 7 and 8 for apple orchards and barley fields respectively.

Impact of agricultural system on soil microbial diversity

To investigate changes in microbial diversity in different farming systems and crops, we used taxonomic and phylogenetic metrics approaches like Faiths PD, Shannon Index and Observed biodiversity. The results are depicted in Figure 9. Regarding a-diversity, our findings showed a weak superiority ($p<0.1$) of the organic farming system compared to conventional in both crops. Further analysis showed that the within system variation was high suggesting that other factors are shaping the microbial diversity within each crop. For example the differences on organic carbon, phosphorus and potassium in apple orchard soils are associated with the abundance and the diversity of the bacterial community found.

Figure 6 Relative abundance of bacteria at Phylum level in organic and conventional apple orchards and organic and conventional barley cultivated crops.

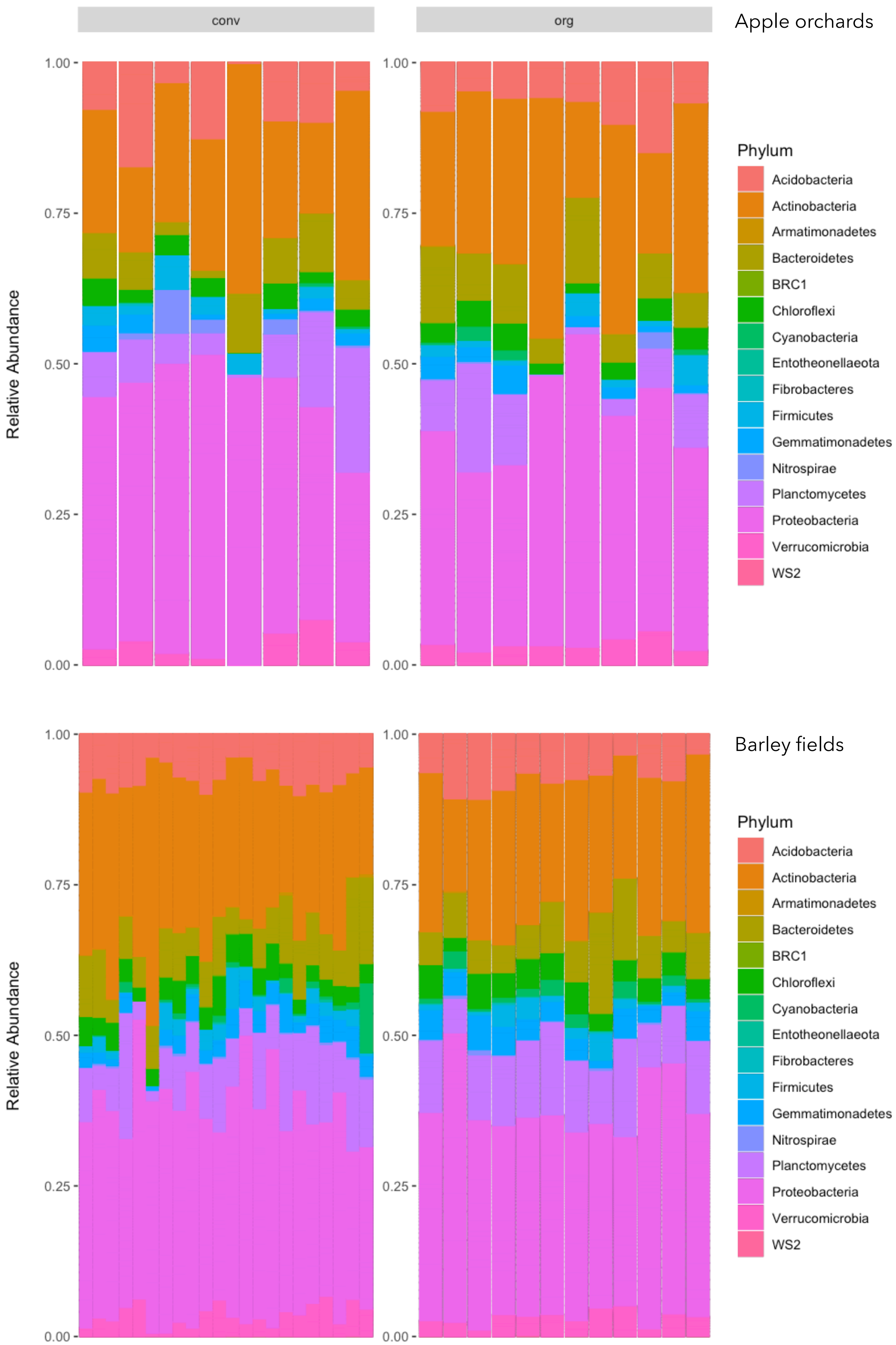
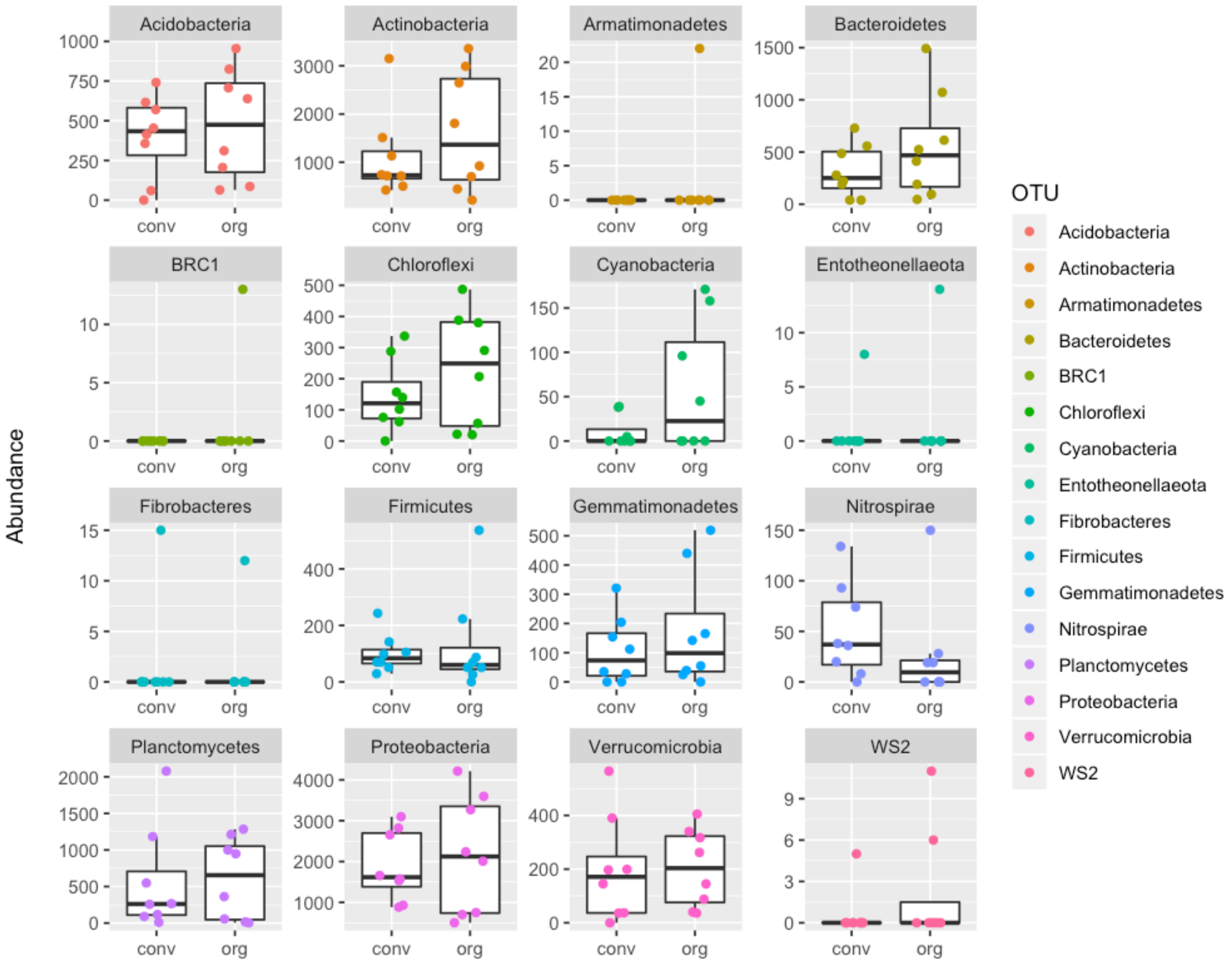


Figure 7 The abundance of bacteria at Phylum level in organic and conventional apple orchards.



To determine whether microbial community variability (estimated by beta-diversity based on taxonomic and phylogenetic dispersions) were altered by farming systems, we used the Bray-Curtis distance metric associated with ADONIS and pairwise comparison. The results showed that the centroids between the communities are different between crops (F=3.01, p=0.002) but not between systems (F=0.66, p=0.72). However, the dispersion of the bacterial community within the crops is significant meaning that the bacterial communities within crops are heterogeneous. This is related with environmental factors, soil type and climatic conditions. For example pH and organic carbon are the most important factors shaping the bacterial community when all samples are included in the analysis data set (Figure 9). These finding clearly suggest that specific surveys are critical for the discrimination and evaluation of the impact of agricultural systems on soil microbial diversity and functioning.

Figure 8 The abundance of bacteria at Phylum level in organic and conventional barley fields.

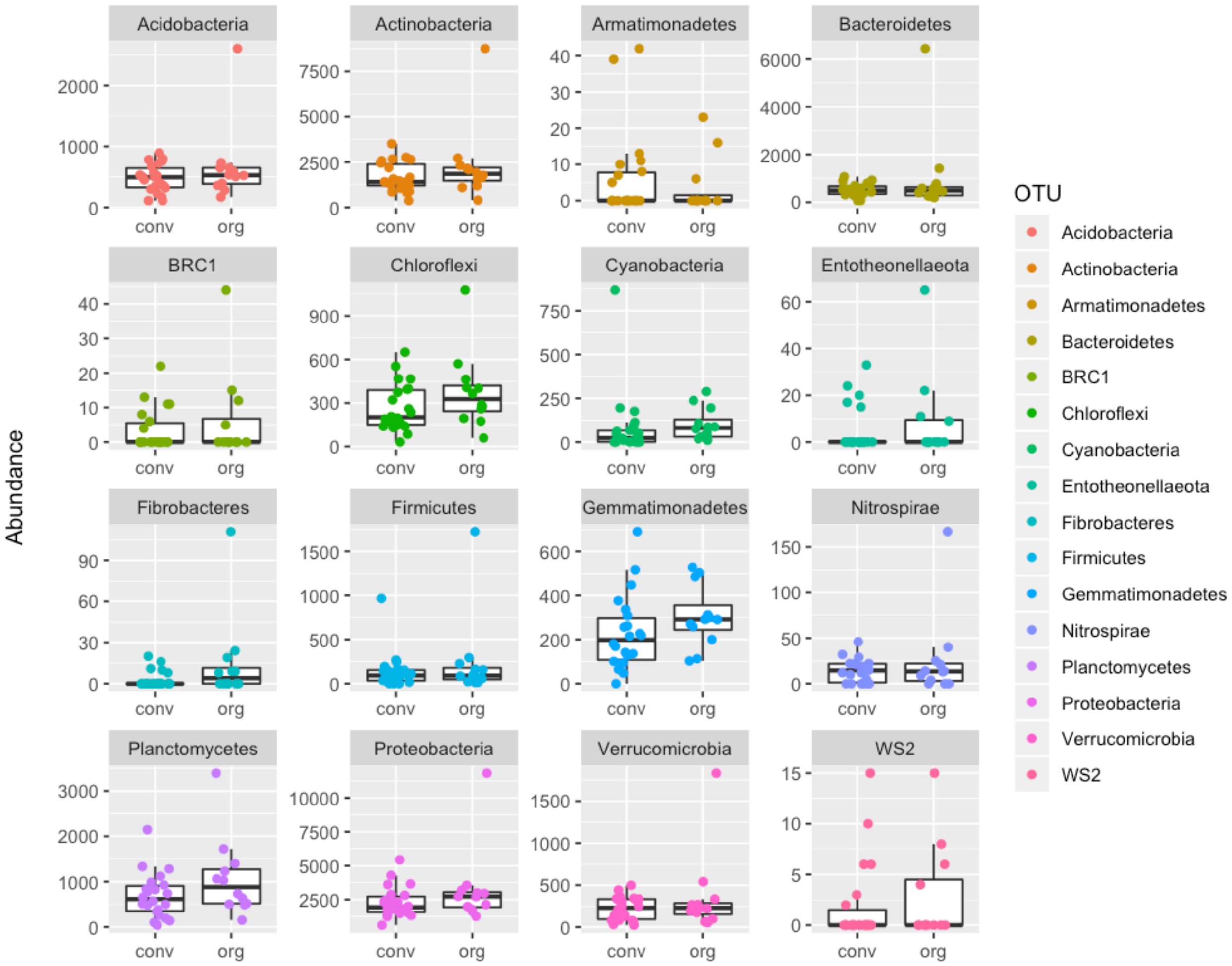
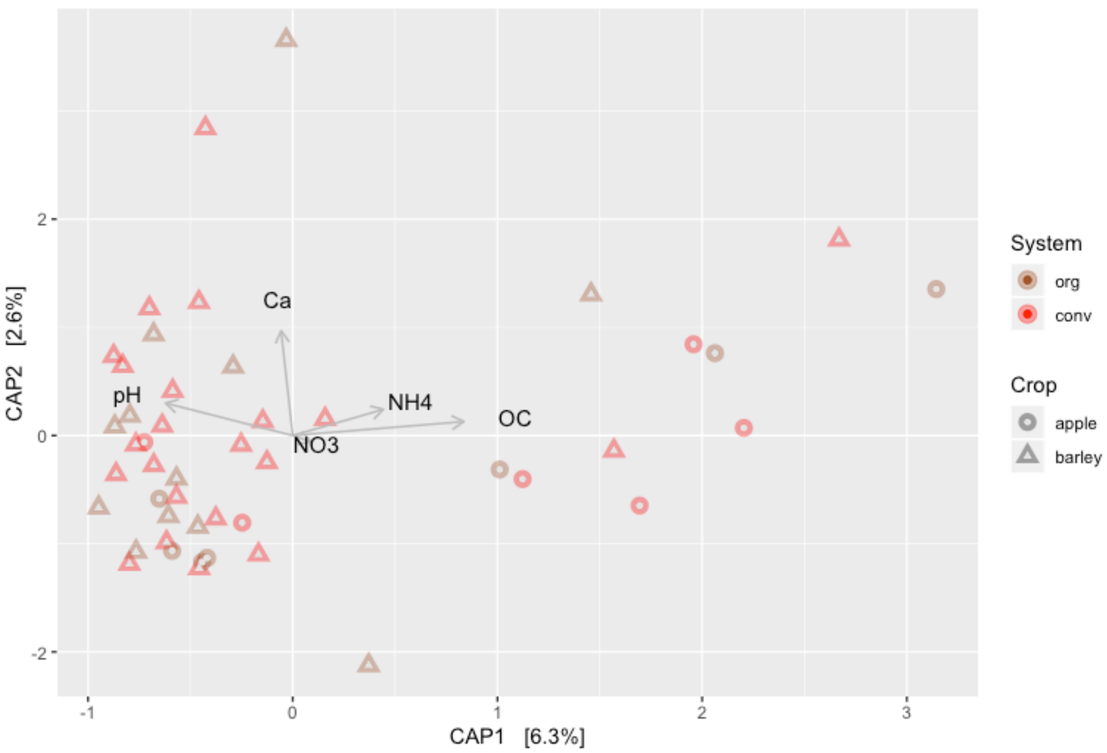


Figure 9 Canonical Constraint Analysis of bacterial communities in organic and conventional apple orchards and barley fields. Arrows represents significant driving soil factors shaping the bacterial composition in the soil.



Implementation of ICBM model

The magnitude of the annual C inputs to soil is one of the crucial factors for SOM modeling (Andren et al. 2008). Annual C inputs to soil are typically calculated from information on above ground plant production and root biomass measurements. In the current pilot farm we found that farming system significantly affected soil carbon stocks however nutrient management scheme determined the amount of soil carbon in the field (Table 1). In the experimental station of Achelia at Paphos area we are implementing organic farming practices since 2002.

The soil organic carbon in the organic managed plots is slightly higher compared to the conventional managed plots. In particular before the establishment of the pilot farms in the frame of ORGANIKO project, the mean amount of soil organic carbon in organic plots was 30.49 ± 0.16 tn/ha while in conventional managed plots was 29.14 ± 0.11 tn/ha. After the first two years of the established rotational schemes the amount of SOC sequestration is presented in Table 1 and was not significantly affected in conventional system. In conventional system, rotation A and B caused a slight but not significant increase of carbon stocks in the soil while rotation C exhibited a reduction of carbon pool in soils. In organic farming managed plots, incorporation of farmyard manure and compost in the system resulted in a significant increase of soil organic carbon. The sequestration rate within the manure treated plots ranged between 139.4 to 256.5 kg/ha/year. In compost treated soils the carbon sequestration rate was slightly higher compared to manure but this was not significantly different. Plots received composted material had a sequestration rate ranging from 273.3 to 348.2 kg/ha/year. Carbon sequestration was not different between conventional and organic managed plots without any organic input (Table 1).

These findings highlight the importance of organic amendments on carbon sequestration. The low values noticed in organic plots received no input is due to the lower biomass production of the cultivated crops and the absence of the external input.

Table 1. Soil Carbon Stock in different rotational schemes and nutrient management schemes

		Initial SOC (tn/ha)	C Seq (tn/ha)	C Seq Rate (tn/ha)
Nutrient Management Strategy		Conventional farming system		
Chemical	Rotation A	29.47±0.18	0,05	25,6
	Rotation B	29.45±0.11	0,07	33,7
	Rotation C	29.56±0.15	-0,16	-78,4
		Organic farming system		
Manure	Rotation A	30.64±0.97	0,51	256,5
	Rotation B	30.62±0.16	0,51	255,5
	Rotation C	30.73±0.24	0,28	139,4
Compost	Rotation A	30.45±0.37	0,55	273,3
	Rotation B	30.77±0.48	0,57	285,0
	Rotation C	30.63±0.42	0,70	348,2
No input	Rotation A	30.15±0.14	0,07	36,9
	Rotation B	30.16±0.27	0,04	20,9
	Rotation C	30.27±0.22	-0,03	-15,7

To evaluate longer carbon cycling dynamics of the system, we implemented the ICBM model. We adapted the model parameters (***Re_clim***) to the local conditions, using long-term available meteorological data from the experimental station of ARI at Acheleia. In detail, the Re_clim according the available daily climate data for 2016 was 2.09 indicating that the decomposition rate of organic carbon in Acheleia area is 2.09 times higher compared to that of Central Sweden where the model was calibrated. Figure 10 depicts the data for ***Re_clim*** since 2010 showing that the climatic conditions in the area are quite stable.

The average annual carbon inputs to soil from barley residues was 0.748 tn/ha, from vetch 2.01 tn/ha and 2.3 tn/ha from chickpea. The carbon input derived from manure and compost incorporation was 1.22 tn/ha and 2.60 tn/ha respectively. The inert amount of carbon in organic managed fields was the half of that measured in plots without any organic input and that was similar with that of not treated experimental plots located in conventional managed fields.

In particular, the amount of inert C was 23.16 tn/ha. The humification coefficient h, determines the proportion of "young" soil carbon that becomes old soil carbon has been set to 0.13 while the default values of Ky (0.800) and Ko (0.006) were used. Our simulations showed a substantial reduction of soil organic carbon stocks both in conventional and organic farming pilot plots received no inputs after 30 years (Figure 2). On the contrary when manure and compost are included in the carbon stock balance of the field then a slight increase of the soil carbon pool is notice (Figure 3). Despite the fact that, the model needs to be corrected for the agricultural system and practices implemented and validated under real soil carbon measures there is a clear indication that manure and compost inputs will increase in the long term soil carbon stocks. This is particularly important for semi-arid regions where limited water availability, prolonged drought conditions, high temperature as well as soil erosion are factors negatively affecting carbon cycling in agricultural ecosystems. Interestingly, green manure in organic farming is not increasing carbon sequestration in both systems. This is related to the inherent characteristics of these inputs and particularly to the low lignin content and the easily degradable carbon of plant fresh residues.

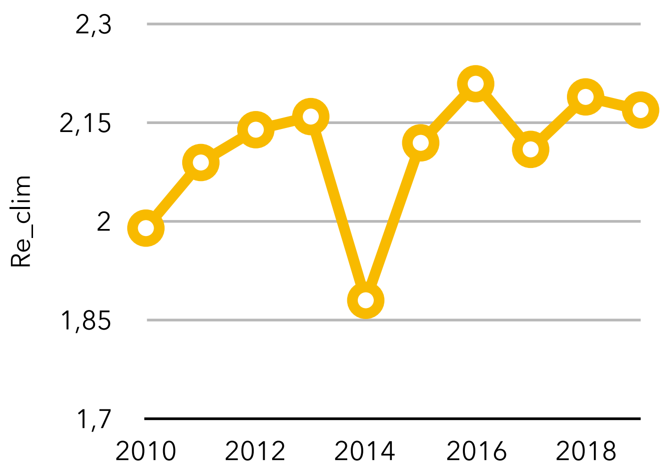


Figure 10. The climatic factor that controls the decomposition of soil organic carbon under the Cyprus environmental conditions at the experimental station of Acheleia, at Paphos.

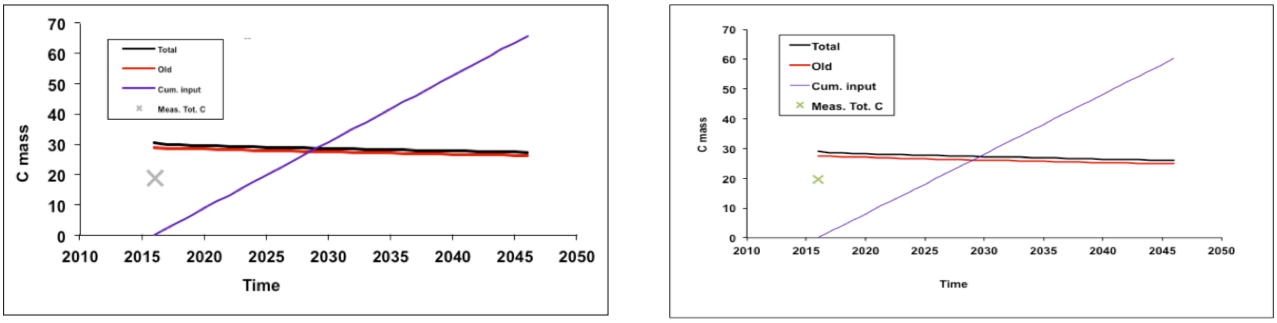


Figure 11 Long-term carbon mass projection of conventional managed plots (left) treated with fertilizers (Mean carbon input year 1.66 tn/ha and initial carbon amount 29.49 tn/ha) and organic managed plots treated (right) with no additional organic amendments (Mean carbon input year 1.66 tn/ha and initial carbon amount 30.19 tn/ha)

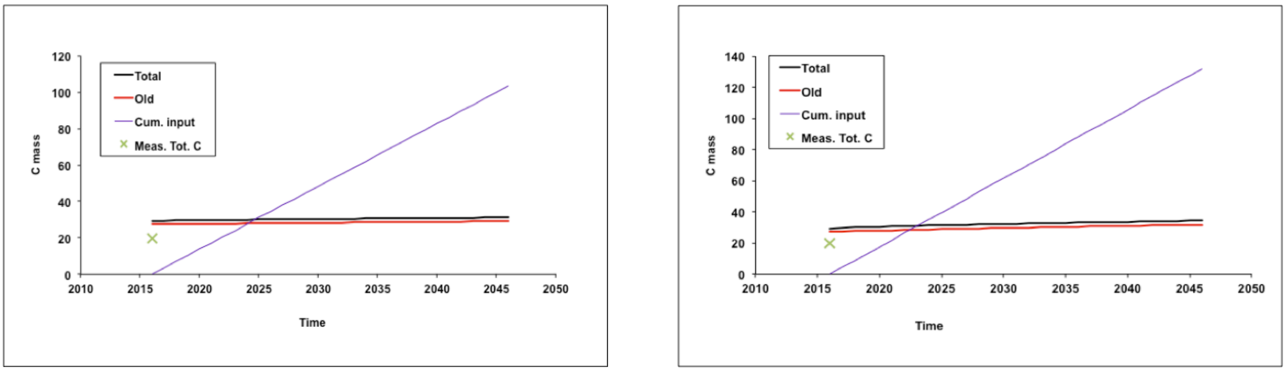


Figure 12 Long-term carbon mass projection of organic managed plots (left) treated with manure (Mean carbon input year 3.45 tn/ha and initial carbon amount 30.66 tn/ha) and organic managed plots treated with compost (Mean carbon input year 4.81 tn/ha and initial carbon amount 30.62 tn/ha)

Conclusions

Altogether our results indicate that conventional and organic farming systems had a major influence on soil quality and the ability of soils to maintain carbon stocks while the general notion that "organic farming increases soil microbial diversity" should not be adopted as a generalised conclusion. The response of microbial community to farming systems is diverse and complex. Our results clearly showed that the shape and the structure of bacterial community is driven from soil chemical characteristics i.e organic C and pH which are tightly related with nutrient management practices as well as soil type. For example, the amount of organic C in soils managed under organic farming schemes was higher than the conventional farming systems. Similarly, the conventional managed soils had higher content of N available forms which in turn are partially affecting bacterial diversity. On the contrary soil pH is mainly driven from the ontology and the structure of the soil. These findings suggest that changes in bacterial diversity are important but it is not known whether the implementation of conventional farming systems lead to diversity losses. The latter was not the case for the survey performed during LIFE+ORGANIKO.

The implementation of organic amendments results in an increase of soil organic C. This improves substantially the C stocks in soils and ICBM modelling demonstrated that soil C could be sustained in the long term. However to sequestered significant amount of C into the soil the amount of C that should be added is high and will increase the N2O emissions. Therefore policy makers should take into account the trade-off between C stock maintenance and N2O emissions. For conventional farming systems however, the inclusion in farmers practices of organic amendments will substantially improve the C stock of the soil and reduce the risks associated to soil organic C losses.

Altogether our results indicate that conventional and organic farming systems had a major influence on soil diversity and composition of microbial communities while the effects of the SHTs were of smaller magnitude. Organic farming system promoted beneficial effects on biotic aspects regarding to microbial diversities, richness and community heterogeneity. However, the response of microbial community to farming systems is diverse and complex, and simple conclusions like "organic systems increased the soil biodiversity" may not be directly synonymous with concomitant increase in soil health and plant productivity. Furthermore, impact of the diversity losses in conventional system is not yet known; it is not clear how microbial diversity is related to ecosystem function and whether the changes in diversity we observed are reversible and the long-term consequences remain to be unexplored. Moreover, we detected that there is a legacy of the SHT which selects for treatment-specific microbial members that are consistent with the existing knowledge, but the limited phylogenetic and functional information precludes more definite conclusions about the beneficial impact of individual taxonomic groups with soil suppressiveness. However, the observed shifts in microbial diversity, community structure and individual taxon bring novel insights into the potential of managing the microbial community for sustainable agricultural productivity.

References

Calleja-Cervantes, M.E., Fernández-González, A.J., Irigoyen, I., Fernández-López, M., Aparicio-Tejo, P.M., Menéndez, S., 2015. Thirteen years of continued application of composted organic wastes in a vineyard modify soil quality characteristics. Soil Biology and Biochemistry 90, 241-254.

Cooper, J., Reed, E.Y., Hörtenhuber, S., Lindenthal, T., Løes, A.-K., Mäder, P., Magid, J., Oberson, A., Kolbe, H., Möller, K., 2018. Phosphorus availability on many organically managed farms in Europe. Nutrient Cycling in Agroecosystems 110, 227-239.

Jiao, Y., Whalen, J.K., Hendershot, W.H., 2007. Phosphate Sorption and Release in a Sandy-Loam Soil as Influenced by Fertilizer Sources Abbreviations: DOC, dissolved organic carbon; OM, organic matter; TSP, triple superphosphate. Soil Science Society of America Journal 71, 118-124.

Knapp, S., van der Heijden, M.G.A., 2018. A global meta-analysis of yield stability in organic and conservation agriculture. Nat Commun 9, 3632.

Marinari, S., Mancinelli, R., Campiglia, E., Grego, S., 2006. Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy. Ecological Indicators 6, 701-711.

Melero, S., Porras, J.C.R., Herencia, J.F., Madejon, E., 2006. Chemical and biochemical properties in a silty loam soil under conventional and organic management. Soil and Tillage Research 90, 162-170.

Nautiyal, C.S., Chauhan, P.S., Bhatia, C.R., 2010. Changes in soil physico-chemical properties and microbial functional diversity due to 14 years of conversion of grassland to organic agriculture in semi-arid agroecosystem. Soil and Tillage Research 109, 55-60.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2015. Diversification practices reduce organic to conventional yield gap. Proc Biol Sci 282, 20141396.

Reidsma, P., Janssen, S., Jansen, J., van Ittersum, M.K., 2018. On the development and use of farm models for policy impact assessment in the

References

European Union – A review. Agricultural Systems 159, 111-125.

Sekiguchi, H., Hasegawa, H., Okada, H., Kushida, A., Takenaka, S., 2008. Comparative Analysis of Environmental Variability and Fungal Community Structure in Soils between Organic and Conventional Commercial Farms of Cherry Tomato in Japan. Microbes and Environments 23, 57-65.

van Diepeningen, A.D., de Vos, O.J., Korthals, G.W., van Bruggen, A.H.C., 2006. Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. Applied Soil Ecology 31, 120-135.

Appendix

A. 2015-2016	Barley					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	7.90	0,211	2,7	7.96	0,221	2,8
EC (dS/m)	2.44	0,330	7,4	2.31	0,214	6,3
Moisture	3.67	1,210	32,9	3.77	1,325	35,1
TKN (%)	0.16	0,023	14,1	0.17	0,011	6,3
N-NO_3 (ppm)	37,30	17,92	48,0	35,77	16,928	47,3
N-NH_4 (ppm)	0.11	0,491	442,3	2.345	3,693	157,5
P-Olsen (ppm)	42.03	21,23	50,5	56.38	11,23	19,9
$CaCO_3$ (%)	23.03	11,12	48,3	18.69	10,98	58,7
Organic C (%)	834	0,105	12,6	855	0,126	14,7

B. 2016-2017	Barley					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	8.19	0,23	2,81	8,01	0,24	3,00
EC (dS/m)	0.43	0,22	51,1	0,49	0,24	48,98
Moisture	3.83	2,01	52,5	3,45	1,78	51,59
TKN (%)	0.19	0,08	42,1	0,21	0,06	28,57
N-NO_3 (ppm)	68.25	2,35	3,44	15,36	1,87	12,17
N-NH_4 (ppm)	12.35	0,58	4,69	2,16	0,87	40,28
P-Olsen (ppm)	40.96	1,69	4,13	57,71	2,17	3,76
CCO_3 (%)	29.24	19,7	67,3	32,02	20,37	63,62
Organic C (%)	1.46	0,17	11,6	1,72	0,21	12,21

C. 2017-2018	Barley					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	8,09	0,21	2,60	8,08	0,32	3,96
EC (dS/m)	0,42	0,33	78,57	0,47	0,57	121,28
Moisture	3,57	2,08	58,26	3,68	2,02	54,89
TKN (%)	0,16	0,04	25,00	0,25	0,08	32,00
N-NO_3 (ppm)	61,35	3,58	5,84	24,87	2,81	11,30
N-NH_4 (ppm)	10,48	0,98	9,35	3,81	1,35	35,43
P-Olsen (ppm)	38,35	2,58	6,73	61,87	5,84	9,44
$CaCO_3$ (%)	31,20	18,47	59,20	31,02	21,79	70,25
Organic C (%)	1,35	0,08	5,93	2,14	0,47	21,96

D. 2018-2019	Barley					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	8,07	0,11	1,36	8,15	0,21	2,58
EC (dS/m)	0,49	0,11	22,45	0,33	0,47	142,42
Moisture	7,41	1,18	15,93	8,14	1,30	15,97
TKN (%)	0,16	0,02	12,54	0,22	0,04	18,18
N-NO_3 (ppm)	45,41	5,11	11,25	16,31	6,43	39,42
N-NH_4 (ppm)	8,75	3,18	36,34	4,55	1,84	40,44
P-Olsen (ppm)	38,08	4,32	11,34	58,57	9,07	15,49
$CaCO_3$ (%)	35,28	13,22	37,47	36,72	12,01	32,71
Organic C (%)	1,27	0,10	7,87	2,05	0,71	34,63

A. 2015-2016	Apple orchards					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	7,187	0,95	11,7	7,49	0,342	4,6
EC (dS/m)	1,395	0,065	4,7	2,32	0,154	6,6
Moisture	4,236	0,52	12,3	3,73	0,954	25,5
TKN (%)	0,201	0,014	7,0	0,310	0,024	7,7
$N\text{-}NO_3$ (ppm)	46,001	4,25	9,2	63,19	6,31	10,0
$N\text{-}NH_4$ (ppm)	0	0	0	2.5*	7,070	282,8
P-Olsen (ppm)	72,35	29,32	40,5	79,01	62,05	78,5
$CaCO_3$ (%)	3,056	0,984	32,2	19,890	21,384	107,5
Organic C (%)	0,911	0,160	17,6	1,538	0,252	9,9

B. 2016-2017	Apple orchards					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	7,37	0,15	2,04	7,48	0,18	2,41
EC (dS/m)	0,52	0,09	17,31	0,4	0,11	27,50
Moisture	5,91	0,55	9,31	5,68	0,61	10,74
TKN (%)	0,63	0,32	50,79	0,26	0,08	30,77
$N\text{-}NO_3$ (ppm)	118,18	12,23	10,35	17,77	1,34	7,54
$N\text{-}NH_4$ (ppm)	12,57	0,53	4,22	40,14	2,55	6,35
P-Olsen (ppm)	80,51	32,28	40,09	73,2	8,18	11,17
CCO_3 (%)	12,08	14,43	119,45	9,77	10,23	104,71
Organic C (%)	1,22	0,22	18,03	3,42	0,15	4,39

C. 2017-2018	Apple orchards					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	7,48	0,24	3,21	7,89	0,7	8,87
EC (dS/m)	0,38	0,16	42,11	0,32	0,19	59,38
Moisture	6,23	2,21	35,47	5,38	1,53	28,44
TKN (%)	0,41	0,41	100,00	0,32	0,12	37,50
N-NO_3 (ppm)	129,07	7,63	5,91	94,98	19,73	20,77
N-NH_4 (ppm)	30,6	10,14	33,14	45,19	12,94	28,63
P-Olsen (ppm)	108,21	5,73	5,30	59,24	18,42	31,09
$CaCO_3$ (%)	14,12	13,2	93,48	5,22	9,73	186,40
Organic C (%)	0,95	0,17	17,89	3,58	0,21	5,87

D. 2018-2019	Apple orchards					
	Conventional			Organic		
	Mean	SD	CV (%)	Mean	SD	CV (%)
pH	7,57	0,13	1,72	7,63	0,25	3,28
EC (dS/m)	0,54	0,1	18,52	0,53	0,28	52,83
Moisture	8,88	0,89	10,02	8,3	1,3	15,66
TKN (%)	0,49	0,2	40,82	0,43	0,09	20,93
N-NO_3 (ppm)	88,87	24,78	27,88	28,92	11,94	41,29
N-NH_4 (ppm)	16,24	8,54	52,59	2,43	1,29	53,09
P-Olsen (ppm)	93,99	20,97	22,31	69,09	15,52	22,46
$CaCO_3$ (%)	1,97	6,18	313,71	29,68	17,84	60,11
Organic C (%)	1,17	0,45	38,46	3,61	0,63	17,45