The impact of agricultural practices on soil organisms: lessons learnt from market-gardens

Abstract
The aim of this study was (i) to establish a typology of farming practices in vegetables cropping systems in Guadeloupe and (ii) to determinate a relationship between these cropping systems and soil fauna. Based on the analysis of cropping systems of an initial set on the whole territory, we selected a representative subset of 18 farms located on vertisols in Grande-Terre. On these 18 farms, we performed a PCA and a HCA. These methods allowed us to build a typology in which farms were distributed between two types. In type A, farmers are using conventional agricultural practices while in type B, farmers are using alternative farming practices. In a second step, we collected soil fauna, from December 2016 to January 2017 in type A and type B farms. The results showed no significant difference between soil fauna abundance in both types. However, the number of species richness was higher in type B. Our results also showed that the abundance of litter transformers was significantly higher in type B. Soil fauna activity in type A was probably affected by the use of synthetic fertilizers and herbicides. Taxonomic richness and soil fauna functional diversity thus strongly depend on agricultural practices in vegetables cropping systems in Guadeloupe.

Keywords: Vegetables cropping systems, Agroecology, Survey, Soil fauna, Functional diversity.

1. Introduction

Intensive agriculture relied heavily on the use of synthetic inputs and low genetic diversity [1,2,3]. It is well recognized that conventional intensive agriculture had negative impact on natural resources such as soil (soil pollution, erosion), water quality (pollution of rivers, lakes and streams), biodiversity loss and human health (inadequate use of pesticides) [4,5,6,7,8,9] . Therefore, such unsustainable models need to be modified to agroecosystems that can optimize ecological functions while maintaining high productivity [9] . Since 1990s, there was a growing interest in developing alternative sustainable farming strategies. All of these strategies share the same objective in term of minimizing the use of synthetic inputs (or even non-use at all), enhancing organic matter recycling and improving agroecosystems health, while maintaining a high production level [10,11,12]. These strategies are part of the field of agroecology as they promote the development of practices based on the mobilization of natural regulations. According to Pretty (2008) [13], sustainable agriculture jointly produce food and goods for farmers and the environment.

In 2017, worldwide agricultural production of vegetables was 182 million metric of tomatoes, 97 million metric of onions, 83 million metric of cucumbers and gherkins, 71 million metric of cabbages and other brassicas and 52 million metric of eggplants [14]. China, India and the United States of America were the main producers in 2017 [14]. Market-gardening has a major place in agriculture production and in human health due to the providing of compounds such as vitamin A and C, minerals, folic acid and fibers [15,16].

In Guadeloupe, agriculture is one of the most important economic sectors. It is a major source of exported goods mainly based on the agroindustrial models developed with banana and sugarcane. The surface of agriculture land decline mainly due to urban construction (e.g. from 57 385 ha in 1981 to 30 965 ha in 2013 [17]. However, it still occupies one third of the area of the archipelago. In 2016, the island's main crops were sugarcane (590 299 tones) and banana (66 208 tones). The others crops were vegetables (28 841 tones) and tubers (4 370 tones) [18]. Sugarcane and banana were the main studied cropping systems in Guadeloupe [19,20] as they represent agricultural dominant systems, because of the engagement of farmers in market channels and professional and public organizations. Sugarcane and banana also benefit from major public subsidies, which helped farmers to invest and maximize their production. By contrast, we have few informations on vegetables cropping practices though they are models of alternative diversified systems, assumed less dependent on chemical inputs. Therefore, the study concentrated on identifying agricultural practices in vegetables farming systems in Guadeloupe. As we know agricultural practices have an influence on soil fauna activity; however, we wanted to know what kind of alternative practices are used in vegetable cropping systems and in what extent those practices affect soil biota. We hypothesized that there was a positive correlation between practices quality developed in vegetables cropping systems and soil organisms. Soil is then considered as a indicator of the quality of the practices. Considering the lack of scientific kwnowledge on vegetables cropping systems influence on soil organisms, this article intends to fill this gap by providing consistent informations on the functioning of such agroecosystems. Thus, this paper aims at: (i) identifying the practices developed in vegetables cropping systems and explaining their degree of ecologization. (ii) On this basis, a typology of cropping practices in these agrosystems in Guadeloupe was established. (iii) Using this typology, we demonstrate the relationship between cropping systems and the quality of soils proxied by biological indicators (abundance and diversity of soil fauna).

2. Materials and Methods

2.1 Research area

The study was carried out in Guadeloupe (French West Indies), which is a part of the Winward islands,in the eastern Caribbean Sea. This archipelago includes two main islands with distinct environment. Basse-Terre (848 km^2) is dominated by a mountain chain oriented North-West to South-East. The annual temperature is comprised between 20.1 and 31.9 °C (France Meteorological Service, http://www.meteo.gp). This island is characterized by a humid tropical climate and a variety of soil types: ferralsols, nitisols, andosols and vertisols [20]. The mean annual rainfall in Basse-Terre is comprised between 1400 mm and 3500 mm (France Meteorological Service, http://www.meteo.gp). At the opposite, Grande-Terre (586 km^2) is characterized by a slightly undulating surface, and the relief rarely exceed 40 m [20]. The climate is tropical, with a mean annual rainfall between 1300 mm and 1600 mm, and soils are mostly vertisols.

2.2 Farm surveys and typology

To collect data on the practices declined in vegetables cropping systems, a survey was carried out between September and November 2016. 49 farms were randomly sampled: 21 in Grande-Terre and 28 in Basse-Terre. We only targeted farms, which have all or a part of their productions devoted to vegetables cropping systems.We visited those farmers to observe their practices. In the survey, we used variables that best described and discriminated farms. Some variables are intangible (i.e. soil type) while others depend on farmers strategies: crops rotation, soil tillage, irrigation, use of pesticides, weed control, use of synthetic fertilizer or organic amendment, mulch, and management of crop residues. Based on cropping systems of the initial set of 49 farms on the whole territory, we selected a representative subset of 18 farms developed on vertisols in Grande-Terre. This selection was due to the fact that in Guadeloupe, vegetables cropping systems are mostly concentrated on vertisol [21]. Indeed, these soils are rich in calcium, magnesium, potassium and they maintain a pH neutral to slightly basic [22] . In addition, the large diversity of soils in Basse-Terre makes it difficult to build a typology.

On the 18 farms, we performed a PCA and a HCA. These methods allowed us to build a typology, by gathering farms based on their characteristics and practices. This analysis was realized by using the following variables: (i) soil tillage separated farms into 3 classes: deep, superficial and manual tillage ; (ii) the type of pesticides divided farms in 3 classes: chemical pesticides, pesticides used in biological agriculture or no pesticides; (iii) the use of synthetic herbicides distributed farms in 3 classes: intensive, intermediate and occasional; (iv) weed control separated farms in two classes: mechanical or manual; (v) amendment divided farms in 4 classes: application of synthetic fertilizer, application of organic matter, application of both, and no fertilization; (vi) the use of the mulch practice separated farms in 2 classes: presence or absence; (vii) the management of crop residues divided farms in three classes: removed from the field, incorporated into the soil, and left in the plot; (viii) the application of slash-and-burn practices distributed farms in two classes: with or without slash-and-burn practices; (ix) finally, the observation of soil biodiversity on the surface separated farms in four classes: high, medium, low and no activity.

2.3 Soil fauna

From December 2016 to January 2017, in each selected farms on Vertisol, five soil samples of 25 cm (length) × 25 cm (width) × 20 cm (deep) were taken for soil macrofauna extraction using TSBF method [23] . Each sample was separated at least 200 m from the others, and was collected 1 km far away from any road and walking path. Animals were collected in alcohol, counted and identified at the taxonomic level under a dissecting microscope. The following taxonomic groups of soil fauna were identified: Oligochaeta, Formicidae, Isoptera, Isopoda, Diplopoda, Dictyoptera, Coleoptera, Diptera, Lepidoptera, Gasteropoda, Homoptera, Orthoptera, Heteroptera, Arenaidae, Chilopoda, Dermaptera, Turbellaria, Insects larvae, and Other insects. They were gathered in different functional groups: litter transformers, predators and ecosystem engineers, and we calculated the taxonomic richness. This functional approach can provide information on soil framework and vegetation quality [24,25].

2.4 Data analysis methods

To establish a typology of farming practices in vegetables cropping systems, a principal component analysis (PCA) was performed. PCA is a multivariate data analysis that based on projection methods. It is a useful technique for reducing the dimensionality of such datasets, increasing interpretability but at the same time minimizing information loss [26]. Base on the PCA, a hierarchical cluster analysis (HCA) was performed. HCA build a tree diagram, which identify groups of similar observations in a dataset. These analysis were realized with R statistical software (http://www.r-project.org/) using R Commander package (Rcmdr). For the relationship between the two types of farming practices and soil fauna, we used Welch's t-test. This test was carried out using R software.

3. Results and discussion

3.1 Characterization of vegetables cropping systems

3.1.1 Description of 49 farms based on surveys

The survey showed the diversity of agricultural practices in vegetables cropping systems in Guadeloupe. In Basse-Terre and in Grande-Terre, we saw similar crops such as lettuce, zucchini, tomatoes, melon, chili pepper, and eggplant. In addition, in Basse-Terre, we also observed cucumber, pumpkin, cabbage, ochra and chives. We also observed various types of cropping systems, from monoculture to polyculture, and a wide range of practices, from conventional to agroecological.

Farming practices are mainly territorially anchored. Tillage is used to ameliorate soil conditions in relation to the water balance and crop growth, to loose upper soil layers to prevent soil compaction, to diminish weed growth and to prepare the seedbed ([27, 28, 29, 30]. Our results showed that in Grande-Terre, most farmers used deep tillage (76%) compared to superficial tillage (24%). In this region, vertisols which are clay rich soils which are extremely hard when they dry with cracks and polygonal structures [31] are dominant. Deep tillage is thus used to prepare field for the next culture, by moving and mixing the topsoil with crop residues, which are incorporated into the soil [28]. On the contrary, farmers from Basse-Terre used superficial tillage (71%) rather than deep tillage (29%), due to the type of soils met in this region. Ferralsols have loose and friable fragments [22]. Nitisols are very similar to ferralsols but are an early stage. Finally, andosols are slightly sticky and friable to very friable [32] . Tillage reduced soil organic matter availability by accelerating decomposition and by increasing soil erosion and soil degradation [33]. Moreover, it has a detrimental effect on environmental quality because of it impact on greenhouse gas emissions [34, 35]. Soil disturbance such as tillage has a strong influence on soil fertility and water availability [36]. At the opposite, by minimizing mechanical disturbance of soil and macro-aggregate destruction, reduced tillage strongly decrease soil erosion [37,38] and improve water use efficiency [39]. Reduced tillage has thus positive effects on nutrient cycling and soil biodiversity [40.41].

During the survey, we observed that use of synthetic pesticides was widely spread among the different farms. In Guadeloupe, crop yield was subjected to pest damage and diseases mainly during rainfall season. Farmers usually prevent economic loss due to pest by spreading heavy pesticides treatments [42]. Additionally, the application rate of herbicides depended on the area. Farmers from Grande-Terre combined herbicides and deep tillage. The mixture of those two methods regulated the abundance of weed species in field [43]. In fact, Chauhan and Johnson (2008) [44] showed that when seeds are deeply buried, the emergence rate was very low.

33% of farmers in Grande-Terre and 11% of farmers in Basse-Terre applied mineral fertilizers. Agricultural production has increased, since 1950s, due to the large input of mineral fertilizers [45]. However, the intensive use of mineral fertilizers has a negative impact on soil fertility (soil acidification) and yield production [46]. 25% of farmers applied organic matter in Basse-Terre and 24% in Grande-Terre. Organic fertilizers are used as an alternative to synthetic ones, in order to restore or ameliorate soil physical, chemical and biological properties [47]. Organic matter is not only a source of plants nutrients in soils, but also, it has an important role in preserving soil fertility, reducing soil erosion, nutrient cycling, water retention and disease suppression [48, 49]. During the study, we noticed that in most cases, farmers mixed organic matter and mineral fertilizer together, 54% in Basse-Terre compared to 33% in Grande-Terre. A meta-analysis, across sub-Saharian Africa, demonstrated that the use of both input types leads to a greater crops production [50] . Other studies have reported that organic input prevents the rapid leaching of nitrogen fertilizer by immobilizing the nitrogen temporarily [51, 52, 53].

For the management of crops residues, most farmers left crops residues in the plot (68% and 52% for Basse-Terre and Grande-Terre respectively). Some farmers removed crop residues from the field, 29% in Grande-Terre and 18% in Basse-Terre, or incorporated them into the soil (19% and 14% for Grande-Terre and Basse-Terre respectively). Crop residues can serve as a nutrient source for soil organisms [54]. Moreover, crop residues can ameliorate soil structure, increase organic matter in soil and reduce evaporation [55]. At the same time, we did an observation of soil biodiversity activity on soil surface (observation of ant nests and earthworm casts), and most farms had an activity between high and medium.The presence of ant nests and earthworn casts may be an indicator of soil health.

3.1.2. Typology of farms located on vertisols

We realized a typology on 18 farms located on vertisol in Grande-Terre based on PCA and AHC. The first two components of PCA explained nearly 43.85% of the total variation (Figure 1 a). Axis F1 has a positive correlation with organic matter, soil biodiversity and slash-and-burn. At the opposite, axis F1 has a negative correlation with herbicides and synthetic fertilizer. Axis F2 opposed plots with biological pesticides to plots using weed control.

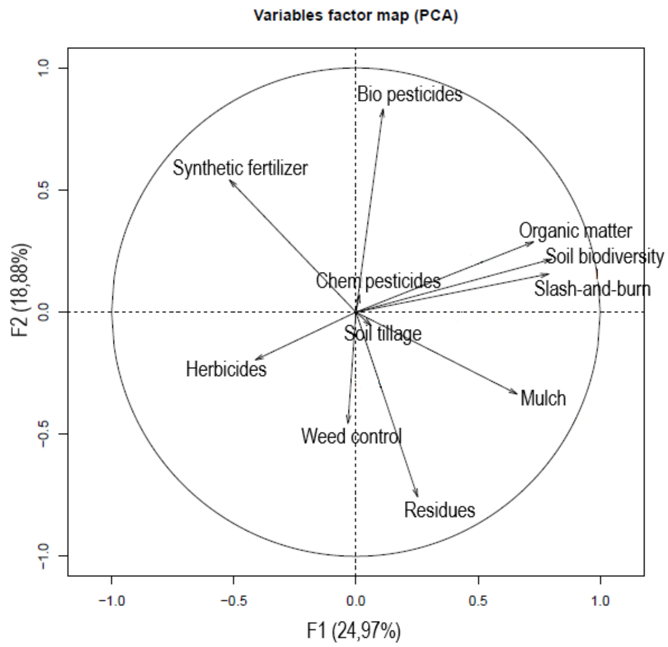
Our results showed that farmers from type A are using conventional agricultural practices. These farms are the most numerous in Grande-Terre (Figure 1c) and are characterized by an intensive to medium application of synthetic fertilizers and herbicides. In this type, farmers do not used mulch and slash-and-burn methods. The observation on the soil activity showed low biodiversity (Figures 1a, 1b, 1c). At the opposite, farmers from type B are using alternative agroecological farming practices. In particular, these farms are characterized by application of organic matter, the use of biological pesticides or no pesticides, slash and burn and mulch. The residues are usually left on the field. The observation on soil activity showed a rich biodiversity (Figures 1a, 1b, 1c).

In our study, farmers from type A applied mineral fertilizer, which globally, improve crop yields and food security [56, 57]. Nevertheless, the overdose of mineral fertilizer contributed to soil deterioration, water pollution, and soil biodiversity through soil acidification [58, 59, 60] . Farmers from type A also applied high amount of herbicides which also had a negative effect on fauna, by reducing soil fauna abundance or fitness, due to the destruction of habitat and food resources [61]. On the contrary, in type B, the application of organic matter had a beneficial effect on diverse biological processes by being a food resource for various ecological groups in the community [62, 63]. In addition, farmers of type B applied slash-and-burn, an alternative method. By using this method, farmers can actually maintain carbon stock and increase biodiversity [64, 65, 66, 67]. Mulching also had a major impact on soil fauna abundance and diversity. Mulching is a form of cover crops that remains on the surface of the soil. It can be inorganic or organic material (plastic, straw, cover crop residues or live plant) and it is used to prevent soil erosion, increase water retention, pest control and weed control [10, 68, 69, 70]. However, a few number of surveyed farmers are using this method. Farmers, who were using cover crop method, had a positive feedback based on their crops production. Though, farmers, who used plastic, have trouble to recycle the plastic and they are planning to go to an ecological method.

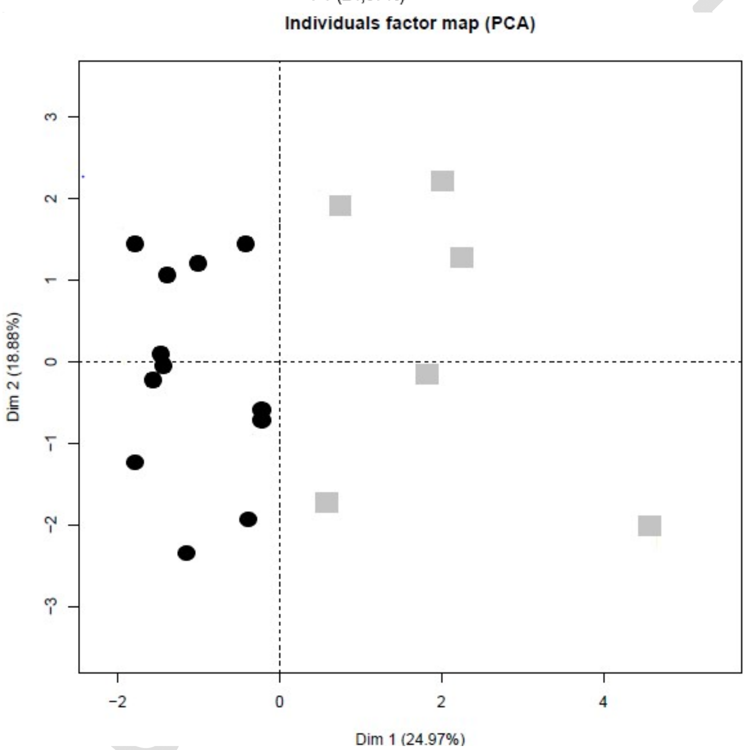
Our results showed the impact of farming practices on soil biodiversity. In order to confirme this observation with quantitative data, we performed a soil macrofauna extraction on farms.

Figure 1 (a) Projection of the variables used to elaborate the farm typology with Principal Component Analysis (PCA), (b) Representation of farms classified by type based on the components of the PCA (● Type A and ■ Type B), and (c) Dendrogram chart obtained for the Agglomerative Hierarchical Clustering analysis (AHC) performed on components of the PCA, n represents the number of farms for each type. These analyses were carried out using R software.

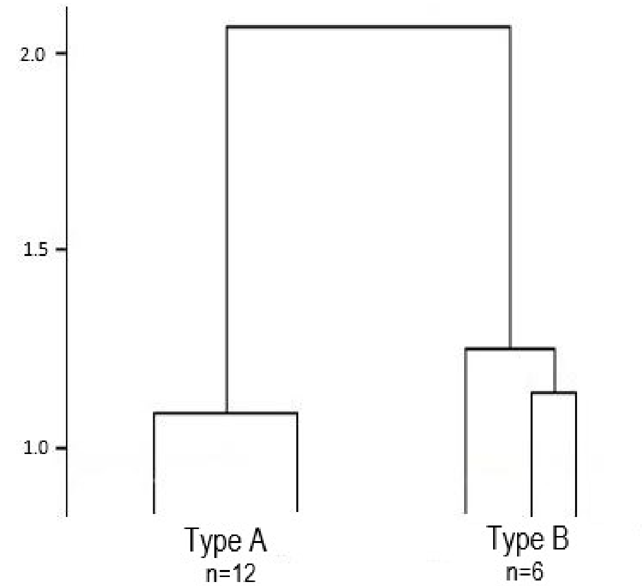
a


Variables factor map (PCA)
Bio pesticides
Synthetic fertilizer
Organic matter
Soil biodiversity
Slash-and-burn
Chem pesticides
Soil tillage
Herbicides
Mulch
Weed control
Residues
F2 (18,88%)
F1 (24,97%)
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0

b


Individuals factor map (PCA)
Dim 2 (18.88%)
Dim 1 (24.97%)
3
2
1
0
−1
−2
−3
−2
0
2
4

c



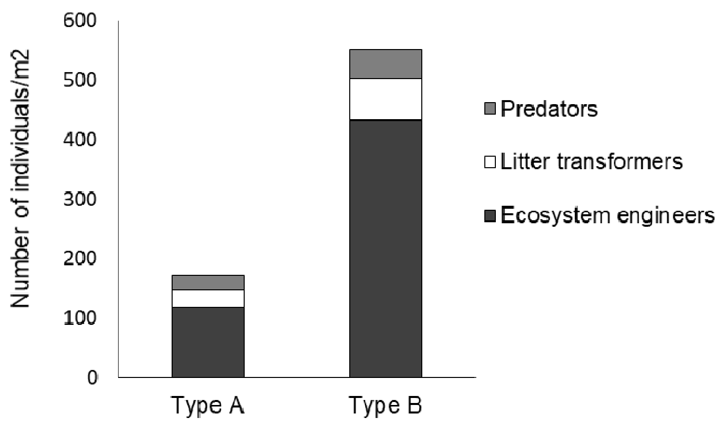
3.1.3. Soil macrofauna on farms located on vertisols

Soil macrofauna were collected on selected farms. We found 171 ± 52 (mean ± SE) individuals.m^{-2} in type A, and 554 ± 239 individuals.m^{-2} in type B. The abundance of soil fauna was slightly higher in type B (Figure 2b). However, there was no significant difference in soil fauna abundance between both types (t-test Welch; P = .13). In general, ecosystems engineers were more abundant than litter transformers and predators (Figure 2a). In type B, the amount of ecosystem engineers (432 ± 229 individuals.m^{-2}) and predators (48.8 ± 16.88 individuals.m^{-2}) was slightly higher than in type A (ecosystem engineers: 116 ± 41 individuals.m^{-2}, biological regulators: 24 ± 6 individuals.m^{-2}). However, there was no significant difference between the quantity of ecosystems engineers and predators between type A and type B (t-test Welch; P = .21 and P = 0.15). On the other hand, the quantity of litter transformers was significantly different between the two types (t-test Welch; P = .02) (Figure 2a). The amount of litter transformers was higher in type B (72 ± 18 individuals. m^{-2}) than in type A (30 ± 10 individuals. m^{-2}). Also, in Figure 2c, the taxonomic richness was significantly higher in type B (11 ± 0.4 taxonomic richness) compared to type A (6.5 ± 0.61taxonomic richness) (t-test Welch; P < .001).

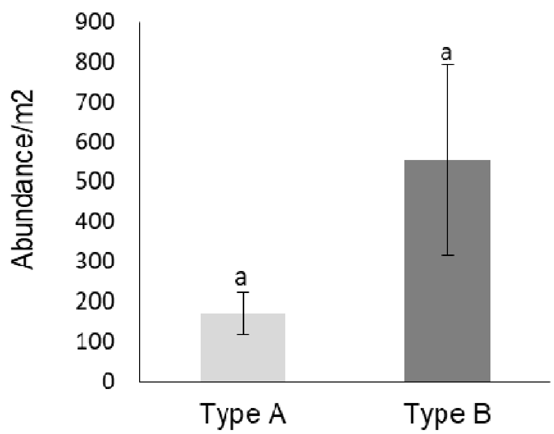
Soil macrofauna may be used as bioindicators of soil health and contributed to ecosystems services [25]. Soil macrofauna play an important role in soil organic matter decomposition (litter transformers), regulations of pests (predators), formation of stable aggregates, water regulation and erosion control (ecosystems engineers) [71]. Our results showed that soil macrofauna may be directly or indirectly impacted by agricultural practices. In type A, we observed a number of conventional agriculture practices (deep tillage, application of high amounts of chemical pesticides, synthetic fertilizer, and herbicides), which are well known to have a negative impact on soil biodiversity [59]. Our study showed that litter transformers are strongly impacted by these conventional practices. They had an essential role in soil carbon sequestration [72]. As a consequence, by decreasing the quantity of litter transformers, conventional agriculture may have profound effects on climate change. On the contrary, by decreasing the input of synthetic fertilisants and herbicides, by reducing the rate of tillage and by increasing the application of organic matter, farmers in type B are stabilizing their soil. Moreover, type B applied mulching, which can have a positive effect on soil habitat. Mulching helps to preserve the ecosystem by reducing the rate of tillage. Sustainable agriculture also had a beneficial impact on soil physical and chemical proprerties, such as, aggregation and nitrogen content [73, 74], which indirectly impacted soil fauna abundance and diversity. In order to overcome the impacts of conventional agriculture, sustainable agriculture methods have been developed to minimize environmental footprints and sustain natural environments and resources [75, 30]. Our study showed that in Guadeloupe, farmers are looking for alternative agriculture practices in vegetables cropping systems. In order to better understand the impact of those new agroecological practices, further physical, chemical and soil fauna analyses should be realized.

Figure 2 (a) Soil fauna abundance in 9 farms (type A and type B) in Guadeloupe (Grande-Terre).(b) Soil fauna abundance in type A and B in Guadeloupe. (c) Taxonomic richness abundance in type A and type B in Guadeloupe. Values with similar letters are not significantly different (Welch t-test). These analyses were carried out using R software

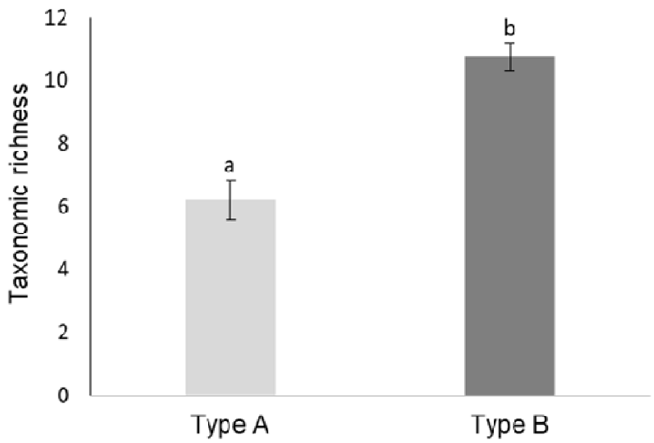
a



b



c



Conclusion

Agricultural systems are continually re-design based on a variety of parameters: climatic changes, consumers demand, land reform and advances in technologies and sciences [76]. In our study, we wanted to know what kind of alternative practices are used in vegetables cropping systems in Guadeloupe and if these methods affect positively soil biota. As expected, intensive practices have a negative impact on soil biodiversity. Alternative agroecological farming strategies are in constant development, in order to improve agroecosystems health by minimizing intensive practices as application of massive pesticides or deep tillage. Our study showed in Guadeloupe, sustainable agriculture is present in vegetables cropping systems and is still in progress.

References

1. Trewanas Antony. Malthus foiled again and again. Nature. 2002 ; 418 : 668-670.

2. Gliessman Stephen R. Agroecology. The Ecology of sustainable food systems. Second edition, CRC Press Taylor & Francis Group, Florida ; 2007.

3. Nair PKR. Grand Challenges in Agroecology and Land Use Systems. Front Environ Sci. 2014 ; 2 : 1-3.

4. Pimentel D. Environmental and economic costs of the application of pesticides, primarily in the United States. Environ Dev Sustain. 2005 ; 7 : 229-252.

5. Halweil B, Mastny L, Assadourian E, Flavin C, French H, Gardner G, Nierenberg D, Postel S, Renner M, Sarin R, Sawin J, Vickers A. State of the World. W.W. Norton & Company ; 2004.

6. Castillo LE, Martinez E, Ruepert C, Savage C, Gilek M, Pinnock M, Solis E. Water quality and macro invertebrate community response following pesticide applications in a banana plantation, Limon, Costa Rica. Sci. Total Environ. 2006 ; 367 : 418-432.

7.Kendall P, Petracco M. The current state and future of Caribbean agriculture. J. Sustain. Agric. 2009 ; 33 : 780-797.

8. Chappell M, LaValle LA. Food security and biodiversity: can we have both? An agroecological analysis. Agric Human Values. 2011 ; 28 : 3-26.

9. Bommarco R, Kleijn D, Potts SG. Ecological intensification: harnessing ecosystem services for food security. Trends Ecol Evol. 2013; 28 : 230–238.

10. Altieri MA. The ecological role of biodiversity in agroecosystems. Agric Ecosyst Environ. 1999; 74 :19-31.

11. Andres C, Bhullar G. Sustainable Intensification of Tropical Agro-Ecosystems: Need and Potentials. Front Environ Sci. 2016 ; 4 : 1-10.

12. Meynard JM. L'agroécologie, un nouveau rapport aux savoirs et à l'innovation. Tropical Issue. 2017 ; 24.

13. Pretty JN. Agricultural sustainability: Concepts, principles and evidence. Phil. Trans. R. Soc. B. 2008 ; 363 : 447-465.

14. The Statistics Portal. 2019. Accessed 10 March 2019. Available: https://www.statista.com/statistics/264065/global-production-of-vegetables-by-type/.

15. Lester GE. Environmental regulation of human health nutrients (ascorbic acid, carotene, and folic acid) in fruits and vegetables. HortSciences. 2006 ; 41 : 59-64.

16. Slavin JL, Llyord B. Health benefits of fruits and vegetables. Advances in Nutrition. 2012 ; 3(4) : 506-516.

17. AGRESTE.Enquête sur les pratiques phytosanitaires sur les légumes en 2013. 2013. Accessed 23 March 2019. Available: http://daaf.guadeloupe.agriculture.gouv.fr/IMG/pdf/breve_1_-_pklegumes_2013_cle81ed6e-1.pdf.

18. AGRESTE. Mémento de la statistique agricole. 2017. Accessed 25 March 2019. Available: http://daaf.guadeloupe.agriculture.gouv.fr/Memento-Agricole-Guadeloue-2017.

19. Clermont-Dauphin C, Cabidoche YM, Meynard JM. Effects of intensive monocropping of bananas on properties of volcanic soils in the uplands of the French West Indies. Soil Use Manage. 2004 ; 20 : 105-113.

20. Sierra J, Causeret F, Diman JL, Publicol M, Desfontaines L, Cavalier A, Chopin P. Observed and predicted changes in soil carbon stocks under export and diversified agriculture in the Caribbean. The case study of Guadeloupe. Agric. Ecosyst. Environ. 2015 ; 213 : 252-264.

21. Bulletin de santé du végétale (BSV). Retrouver les bilans par filière de l'année 2016. 2016. Accessed 12 March 2019. Available: http://daaf.guadeloupe.agriculture.gouv.fr/IMG/pdf/BSV971_ToutesFilieres_Bilan2016_cle492392.pdf; 2016.

22. Sierra J, Desfontaines L. Rapport : Les sols de la Guadeloupe. Genèse, distribution et propriétés. 2018. Accessed 26 February 2019. Available: https://www6.antilles.inra.fr/astro/Ce-que-nous-savons-sur/No-6-Les-sols-de-la-Guadeloupe

23. Anderson JM, Ingram JSI. Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Wallingford ; 1993.

24. Brussaard L. Soil fauna, guilds, functional groups and ecosystem processes. Appl Soil Ecol. 1998 ; 9 : 123-135.

25. Turbé A, Toni DA, Benito P, Lavelle P., Lavelle P, Ruiz N, Wim HVdP, Labouze E, Mudgal S. Soil biodiversity : functions, threats and tools for policy makers. Bio Intelligence Service, IRD, and NIOO, Report for European Commission (DG Environment) ; 2010.

26. Jolliffe IT, Cadima J. Principal component analysis: a review and recent developments. Phil. Trans. R. Soc. A. 2016 ; 374 (2065).

27. Wall HD, Bardgett RD, Behan-Pelletier V, Herrick JE, Jones H, Ritz K, Six J, Strong DR, Van der Putten WH. Soil ecology and Ecosystem services. Oxford University Press, New York ; 2012.

28. Welbaum GE.Vegetable Production and Practices. Virginia Tech University, USA ; 2015.

29. Gómez JA, Orgaz F, Gómez-Macpherson H, Villalobos FJ, Fereres E. Tillage, In: Villalobos FJ, Fereres E, editors. Principles of Agronomy for Sustainable Agriculture, Cham: Springer International Publishing ; 2016.

30. Stavi I, Bel G, Zaady E. Soil functions and ecosystem services in conventional, conservation, and integrated agricultural systems. A review. Agron Sustain Dev. 2016 ; 36: 32.

31. Baize D, Girard, MC. Référentiel pédologique. Quæ Editions ; 2008.

32. Baize D, Girard MC. A Sound Reference Base for Soils: The "Référentiel Pédologique". Quæ Éditions ; 1998.

33. Gliessman Stephen R. Agroecology. The Ecology of sustainable food systems. Third edition, CRC Press Taylor & Francis Group, Florida ; 2015.

34. Schneider UA, Smith P. Energy intensities and greenhouse gas emission mitigation in global agriculture. Energy Effic. 2009 ; 2 : 195-206.

35. Ji Q, Wang Y, Chen XN, Wang XD. Tillage effects on soil aggregation, organic carbon fractions and grain yield in Eum-Orthic Anthrosol of a winter wheat-maize double-cropping system, Northwest China. Soil Use Manag. 2015 ; 31 : 504-514.

36. Adimassu Z., Alemu G., Tamene L. Effects of tillage and crop residue management on runoff, soil loss and crop yield in the Humid Highlands of Ethiopia. Agric Syst. 2019 ; 168 :11-18.

37. Six J, Bossuyt H, Degryze S, Denef K. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Tillage Res. 2004 ; 79 : 7–31.

38. Liu, E., Teclemariam SG, Yan C, Yu J, Gu R., Liu S, He W, Liu Q. Long-term effects of no-tillage management practice on soil organic carbon and its fractions in the northern China. Geoderma. 2014 ; 213 : 379-384.

39. Li L, Huang G, Zhang R, Bill B, Guangdi L, Kwong YC. Benefits of conservation agriculture on soil and water conservation and its progress in China. Agric. Sci. China. 2011 ; 10 : 850-859.

40. Lal R. Restoring soil quality to mitigate soil degradation. Sustainability. 2015 ; 7 : 5875-5895.

41. Pareja-Sánchez E, Plaza-Bonilla D, Ramos MC, Lampurlanés J, Álvaro-Fuentes J,Cantero-Martínez C. Long-term no-till as a means to maintain soil surface structure in an agroecosystem transformed into irrigation. Soil Till Res. 2017 ; 174 : 221–230.

42. National Research Council.. Sustainable Agriculture and the Environment in the Humid Tropics. National Academy Press., Washington; 1993.

43. Mishra JS, Singh VP. Tillage and weed control effects on productivity of a dry seeded rice–wheat system on a Vertisol in Central India. Soil Till Res. 2012 ; 123 : 11-20.

44. Chauhan BS, Johnson DE. Germination Ecology of Southern Crabgrass (Digitaria ciliaris) and India Crabgrass (Digitaria longiflora): Two Important Weeds of Rice in Tropics. Weed Sci. 2008 ; 56 : 722-728.

45. Cai A, Xu M, Wang B, Zhang W, Liang G, Hou E, Luo Y. Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. Soil Till Res. 2019 ; 189 : 168-175.

46. Zhu Q, Liu X, Hao T, Zeng M, Shen J, Zhang F, De Vries W. Modeling soil acidification in typical Chinese cropping systems. Sci Total Environ. 2018 ; 613-614 : 1339-1348.

47. Celestina C, Hunt JR, Sale PWG, Franks AE. Attribution of crop yield responses to application of organic amendments: A critical review. Soil Till Res. 2019 ; 186 : 135-145.

48. Loveland P, Webb J. Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. Soil Till Res. 2003 ; 70 : 1-18.

49. Murphy, BW. Impact of soil organic matter on soil properties–a review with emphasis on Australian soils. Soil Res. 2015 ; 53 : 605-635.

50. Chivenge P, Vanlauwe B, Six J. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. Plant Soil. 2010 ; 342 : 1-30.

51. Vanlauwe B, Diels J, Aihou K, Iwuafor ENO, Lyasse O, Sanginga N, Merckx R. Direct interactions between N fertilizer and organic matter: evidence from trials with 15N-labelled fertilizer. In: Vanlauwe B, Diels J, Sanginga N, Merckx R, editors. Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice. CAB International; 2002.

52. Bekunda MA, Nteranya S, Woomer PL. Restoring soil fertility in sub-sahara africa. Adv Agron. 2010; 108 : 183–236.

53. Pincus L, Margenot A, Sixc J, Scowd K.. On-farm trial assessing combined organic and mineral fertilizer amendments on vegetable yields in central Uganda. Agric Ecosyst Environ. 2016 ; 225 : 62-71.

54. Feng Y, Balkcom KS. Nutrient Cycling and Soil Biology in Row Crop Systems under Intensive Tillage. In: Al-Kaisi MM, Lowery B, editors. Soil Health and Intensification of Agroecosystems. Academic Press Elsevier Inc.; 2017.

55. Liang S, Li X,Wang J. Advanced Remote Sensing. Elsevier Inc ; 2012.

56. Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. Agricultural sustainability and intensive production practices. Nature. 2002 ; 418 : 671-677.

57. Boli N, Mingzhu L, Shaoyu L, Lihua X,Yanfang W.. Environmentally friendly slow-release nitrogen fertilizer. J Agric Food Chem. 2011 ; 59 : 10169-10175.

58. Tilman D, Fargione J, Wolff B, D'Antonio C, Dobson A, Howarth R, Schindler D, Schlesinger WH, Simberloff D, Swackhamer D. Forecasting agriculturally driven global environmental change. Science. 2001 ; 292 : 281-284.

59. Clermont-Dauphin C., Blanchart E, Loranger-Merciris G, Meynard JM. Cropping systems for soil biodiversity and ecosystem services: prospects and research needs. Sustainable Agriculture Reviews . 2014 ; 14 : 117-158.

60. Smith LED, Siciliano G. A comprehensive review of constraints to improved management of fertilizers in China and mitigation of diffuse water pollution from agriculture. Agriculture. Ecosyst. Environ. 2015 ; 209 : 15-25.

61. Prosser RS, Anderson JC, Hanson ML, Solomon KR, Sibley PK. Indirect effects of herbicides on biota in terrestrial edge-of-field habitats: A critical review of the literature. Agric Ecosyst Environ. 2016 ; 232 : 59-72.

62. Roger-Estrade J, Anger C, Bertrand M, Richard G. Tillage and soil ecology: Partners for sustainable agriculture. Soil Till Res. 2010; 111 : 33-40.

63. Ayuke FO, Brussaard L, Vanlauwe B, Six J, Lelei DK, Kibunja CN, Pulleman MM. Soil fertility management: Impacts on soil macrofauna, soil aggregation and soil organic matter allocation. Appl Soil Ecol. 2011; 48 : 53-62.

64. Bruun TB, Neergaard A, Lawrence D, Ziegler AD. Environmental consequences of the demise in swidden cultivation in southeast asia: carbon storage and soil quality. Hum Ecol. 2009 ; 37 : 375-388.

65. Padoch C, Pinedo-Vasquez M.. Saving slash□and□burn to save biodiversity. Biotropica. 2010 ; 42 : 550-552.

66. Ziegler AD, Fox JM, Webb EL, Padoch C, Leisz SJ, Cramb R, Mertz O, Bruun TB, Vien TD. Recognizing contemporary roles of swidden agriculture in transforming landscapes of southeast asia. Conserv. Biol. 2011 ; 25 : 846-848.

67. Lopes Thomaz E. Dynamics of aggregate stability in slash-and-burn system Relaxation time, decay, and resilience. Soil Till Res. 2018 ; 178 : 50-54.

68. Saxton K, Chandler D, Stetler L, Lamb B, Clairborn C, Lee BH. Wind erosion and fugitive dust fluxes on agricultural lands in the Pacific Nothwest. Trans. ASAE. 2000 ; 43 : 623-630.

69. Gonzalez-Martin C, Teigell-Perez N, Valladares B, Griffin DW. The global dispersion of pathogenic microorganisms by dust storms and its relevance to agriculture. Adv. Agron. 2014 ; 127 : 1-41.

70. Quintanilla-Tornel MA, Wang KH, Tavares J, Hooks CRR. Effects of mulching on above and below ground pests and beneficials in a green onion agroecosystem. Agric Ecosyst Environ. . 2016 ; 224: 75-85.

71. Lavelle P, Decaëns T, Aubert M, Barot S, Blouin M, Bureau F, Margerie P, Mora P, Rossi JP. Soil invertebrates and ecosystem services. Eur. J. Soil Biol. 2006 ; 42 : 3-15.

72. Angst Š, Mueller CW, Cajthaml T, Angst G, Lhotáková Z, Bartuška M, Špaldoňová A, Frouz J. Stabilization of soil organic matter by earthworms is connected with physical protection rather than with chemical changes of organic matter. Geoderma. 2017 ; 289 : 29-35

73. Caviglia OP, Andrade FH. Sustainable intensification of agriculture in the Argentinean Pampas: capture and use efficiency of environmental resources. Am. J. Plant Sci. Biotechnol. 2010 ; 3 : 1-8.

74. Lal R, Reicosky DC, Hanson JD. Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil Tillage Res. 2007 ; 93 : 1-12.

75. Liu G.B. Soil conservation and sustainable agriculture on the Loess Plateau: challenges and prospects. Ambio. 1999 ; 28 : 663-668.

76. Altieri MA, Funes-Monzote FR, Peterson P. Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. Agron Sustain Dev. 2012 ; 32 : 1-13.