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AUTOREFERÁT DISERTAČNÍ PRÁCE
DISSERTATION'S SUMMARY

Title:

Effect of Organic and Conventional System of Farming on Greenhouse Gases Emissions from Selected Crops and Their Environmental Efficiency

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Declaration

I declare that I am the author of this graduation thesis and that I used only sources and literature displayed in the list of references in its preparation.

In České Budějovice in November 2024

Signature

Abstrakt

Klimatické změny a globální oteplování se v posledních letech staly velmi diskutovaným tématem. Zemědělství přispívá významným podílem emisí skleníkových plynů (GHG), které způsobují až 17 % přímé změny klimatu prostřednictvím zemědělských činností a dalších 7–14 % prostřednictvím změn ve využívání půdy. Různé zemědělské postupy mají také různé účinky na emise skleníkových plynů a další účinky na životní prostředí. Konvenční systémy hospodaření mají negativní dopad na ekosystém, protože jsou založeny na používání syntetických a minerálních hnojiv a pesticidů, což vede ke znečištění podzemních vod a emisím skleníkových plynů. Ekologické zemědělství je často navrhováno jako řešení ke snížení negativního dopadu zemědělství na životní prostředí kvůli nižším rizikům vzlhedem k omezeným chemických vstupů, což může snížit dopady na složky životní prostředí a snížit příspěvek ke globálnímu oteplování a obecné degradaci ekosystémů. Za jejich hlavní nevýhodu jsou však považovány nižší výnosy systémů ekologického zemědělství. Používání živných organických doplňků a hnojiv může zvýšit výnosy plodin, ale je třeba je pečlivě zvážit. Např. koncept hodnocení životního cyklu (LCA) je v tomto smyslu často používaná metoda ke zkoumání dopadů jakékoli činnosti na životní prostředí v průběhu celého jejího životního cyklu. V tomto ohledu byly hodnoceny environmentální dopady některých běžných postupů obělávání půdy v různých systémech s různou intenzitou, včetně implementace zeolitu, kompostu, vermikompostu, hnoje, slámy nebo biouhlu. Celý proces hodnocení životního cyklu se řídil směrnicemi ISO 14040 a ISO 14044. Pro výpočet byl použit software openLCA a jako charakterizační model byla použita metodika ReCiPe Midpoint (H). Čtyři primární kategorie dopadu použité v této strategii ke kategorizaci dopadů na životní prostředí byly (1) změna klimatu, (2) lidské zdraví, (3) kvalita ekosystému a (4) zdroje. Do skupiny modelových plodin byla zařazena také rýže, rajče, pšenice a cukrová řepa a byly hodnoceny vlivy na životní prostředí v průběhu jejich celého pěstebního cyklu. Výsledky ukázaly, že vermikompost a chlévský hnůj při produkci rýže účinněji snižují negativní dopady zemědělství na životní prostředí ve srovnání s konvenční produkcí rýže. Použití kompostu nebylo navrženo jako vhodná volba pro pěstování rajčat kvůli jeho negativnímu environmentálnímu dopadu na kategorie lidské zdraví, kvalitu ekosystému a zdroje. Použití kombinace hnojiv a kompostu v suchých oblastech by mohlo zajistit vyšší výnos pšenice a také zmírnit negativní environmentální ukazatele. Také použití biouhlu při pěstování cukrové řepy snížilo emise skleníkových plynů a zároveň zvýšilo produkci bílého cukru. Celkově má každý organický doplněk nebo hnojivo specifické výsledky pro určitou plodinu. Je zapotřebí dalšího výzkumu, aby bylo možné integrovat environmentální benefity organických hnojivových doplňků a hnojiv na různé plodiny, a aby se našel nejlepší systém nakládání s organickými živinami pro každou plodinu, a který může zmírnit negativní vlivy na životní prostředí a také zvýšit výnos plodin.

Klíčová slova: Posuzování životního cyklu, Globální oteplování, Sladkovodní eutrofizace, Mořská eutrofizace, Management živin, Udržitelnost

Abstract

Climate change and global warming have become a much-debated issue in recent years. Agriculture contributes a major share of the greenhouse gas (GHG) emissions that are causing 17% of climate change directly through agricultural activities and an additional 7-14% through changes in land use. Also, different farming practices have different effects on GHG emissions and other environmental effects. Conventional farming systems have a negative impact on the ecosystem because they are based on the use of synthetic and mineral fertilizers and pesticides, which leads to groundwater pollution and greenhouse gas emissions. Often, organic farming is suggested as a solution to reduce the negative impact of agriculture on the environment due to the lower risks of chemical inputs, which can reduce environmental effects such as global warming and ecosystem degradation. However, the lower yields of organic farming systems are considered to be their main disadvantage. It has been approved that the use of organic amendments and fertilizers can increase crop yields, but careful consideration is required. For example, the life cycle assessment (LCA) concept is a frequently used method to examine the environmental impacts of any activity across its entire life cycle. In this regard, the environmental assessment of some common soil amendments in different systems of framings were assessed, including zeolite, compost, vermicompost, manure, straw, and biochar. The whole life cycle assessment process during this study has followed the guidelines of ISO 14040 and ISO 14044. The openLCA software was used for the calculation, and as a characterization model, the ReCiPe Midpoint (H) methodology has been used. The four primary damage categories used in this strategy to categorize the environmental effects were (1) climate change, (2) human health, (3) ecosystem quality, and (4) resources. Also, rice, tomato, wheat, and sugar beet have been included in the group of model crops, and their environmental impacts during the entire life cycle have been assessed. The results showed that vermicompost and cattle manure as organic fertilizers in rice production are more effective in diminishing the negative environmental effects of farming compared to conventional rice production. The use of compost was not suggested to be a good option for tomato cultivation because of its negative environmental impact on human health, ecosystem quality, and resources. Utilizing a combination of fertilizer and compost in dryland areas could ensure a higher wheat yield, as well as alleviate the negative environmental indicators. Also, the application of biochar in sugar beet cultivation mitigated greenhouse gas emissions while boosting the output of white sugar. Overall, each organic amendment or fertilizer has specific results on a certain crop. Further research is needed to integrate the environmental effects of organic amendments and fertilizers on different crops to find the best organic nutrient management for each crop that can alleviate negative environmental effects and also increase the crop yield per area.

Keywords: Life cycle assessment, Global warming, Freshwater eutrophication, Marine eutrophication, Nutrient management, Sustainability

Content

Chapter 1: Background of Study

1.1. Introduction

Following the development of agricultural technology, farming output has become a significant source of greenhouse gas (GHG) emissions (Yue et al., 2023). According to the Food and Agriculture Organization of the United Nations' reports, worldwide GHG emissions from crop cultivation and food production have grown by 17% over the last thirty years (FAO, 2022). Furthermore, soil properties which are directly influenced by different farming systems have a significant impact on GHG emission due to effective microbial functions (El-Ramady et al., 2023; Gandhamanagenahalli A et al., 2024)

On the other side of increasing productivity, emphasis is placed on sustainable agricultural practices to make sure soil, water conservation, and strengthen climate change (Yadav et al., 2022). However, it is important to consider sustainable food production regarding global environmental issues. Organic farming compared to conventional farming, is encouraged due to the lower risks of removing chemical inputs and can reduce environmental effects such as global warming and ecosystem degradation (Man et al., 2024; Mwangi et al., 2024). Additionally, a variety of cropping strategies (for example sole cropping, intercropping, crop rotation) have the potential to influence nutrient concentrations and emissions in different fertilization practices such as fully chemical-based (conventional), organic-based, and semi organic based (application of both chemical and organic fertilizers together) (Li et al., 2021; Mwangi et al., 2024; Verdi et al., 2022). Although the utilization of chemical fertilizers and other agrochemicals has been shown to increase plant nutrition and crop productivity, however overuse of fertilizers under continuous cultivation systems such as sole cropping results in decreasing soil fertility (Gandhamanagenahalli A et al., 2024; Mi et al., 2023). Also intensive tillage as frequently used in conventional agriculture causes soil degradation, decrease soil nutrient availability, and increase GHG emissions (Yue et al., 2023). It has worth to note that the used inputs in conventional agriculture cause additional emissions, due to the manufacturing of chemical fertilizers, fossil fuel consumption, and agricultural machinery (Pesce et al., 2024). Conventional farming system has a negative impact on the ecosystem (Bernas et al., 2021; Shakoor et al., 2021), because this system is based on the use of synthetic and mineral fertilizers and pesticides leads to groundwater pollution and greenhouse gas emissions. Often organic farming is suggested as a solution to reduce the negative impact of agriculture on the environment (Li et al., 2020). However, some studies have reported lower performance of the organic farming system than conventional farming system in relation to the amount of yield, indeed, the lower yields of organic farming systems are considered as their main disadvantage (Sanchez Bogado et al., 2022; Tang, 2024; Tran et al., 2024). Therefore, more land is usually needed to produce the same amount of food in organic farming systems in compared with conventional farming. However, the low land use efficiency in organic agriculture is a serious challenge. It has been reported that organic agriculture requires around 84% more land than conventional farming (Jung et al., 2024). This is mostly due to reduced yields, which range between 20% and 34% lower than conventional farming (Tripodi et al., 2024). The use of organic modifiers in organic farming systems can increase crop yields but requires careful consideration (Prodhan et al., 2023).

Assessment of environmental characteristics of agricultural production needs a tool that can evaluate different aspects of agricultural systems (Hauschild et al., 2018). Life cycle assessment is a standard method that can evaluate the environmental impact of a product, a farming system or production process (Ghasemi-Mobtaker et al., 2022). Therefore, the purpose of this study is investigating the environmental impact assessment of different systems of farming within selected group of crops also investigated different organic amendments and fertilizers which are used in organic farming.

1.2. Literature review

1.2.1. Systems of farming

The farming system refers to the combination of various components such as crops, livestock, and other farming practices that are used by farmers to achieve their production goals. The scope of farming systems is quite broad, and it encompasses a wide range of factors that are essential for successful farming. Conventional agriculture requires a wide range of external inputs to sustain output and profit (Bang et al., 2024; Rosinger et al., 2025). Chemical fertilizers and insecticides, in particular, can boost food production while efficiently decreasing crop pests and illnesses to satisfy the rising food demand linked with population expansion (Eide et al., 2025). In addition, the overuse of chemical fertilizers and pesticides results in a number of environmental problems, such as greenhouse gas (GHG) emissions, nitrate leaching, water eutrophication, soil acidification, groundwater pollution, biological diversity loss, soil degradation, and toxicity across the food chain (Amirahmadi et al., 2020; Xie et al., 2024). Due to the high proportions of non-renewable resources used in agriculture (such as fuel for machinery), as well as the fact that the production of frequently toxic chemicals causes environmental dangers, it is essential to pay special attention to these issues. To summarize, the production of agriculture is currently facing the enormous challenge of feeding a rising population(Kopittke et al., 2019).

Organic farming, which prohibits the use of synthetic agrochemicals to ensure long-term sustainability in agricultural systems and biodiversity protection, is frequently touted as an essential alternative to conventional farming. The results of some research showed that organic farming methods cause a lower toxicity and eutrophication per unit of product (Verdi et al., 2022; Zhou et al., 2020). Due to its capacity to enhance soil fertility, the use of organic fertilizer may be a sustainable way to raise grain production (Man et al., 2024). For the development of sustainable cropping, it is essential to identify the factors that are affecting the crop's reaction to organic amendment (Khan et al., 2017)

1.2.2. Selected crops for the thesis

Rice (*Oryza sativa* L.), with around 161 million ha grown globally, is one of the most significant agricultural crops in the world. Over half of the world's population bases its food security on rice. In 2018, around 782 million tons of paddy rice were produced globally (Delina et al., 2024; Tran et al., 2024).

Wheat (*Triticum aestivum* L) is a strategic agricultural crop that plays a significant role in maintaining national food security and sustainable economic development. Increasing technical performance considering lowering costs, energy, and environmental consequences are significant aims for wheat cultivation (Amirahmadi et al., 2024).

Tomato is one of the important crops that are most widely grown and consumed due to its outstanding flavor and great nutritional content. The geographical, environmental, and economic conditions are the main important factors for producers of agricultural products. Sufficient food production is required due to the rising population and worldwide food demand. Tomatoes are planted both in the greenhouse and open fields. Therefore, developing a sustainable production system is essential for improved crop growth and a consistently high tomato yield (He et al., 2016; Tripodi et al., 2024).

Sugar beet (*Beta vulgaris* L.), which contributes significantly to the global supply of sugar for family food baskets. After sugarcane, sugar beet is considered as the second most cultivated crop for white sugar production in the world. It has been reported that sugar beet has 30% more sugar and needs less fertilizer compared to sugarcane (Li et al., 2020). In addition, sugar beet produces a variety of by-products, such as molasses which is widely usable in agricultural issues such as livestock purposes, and poultry feeding (Chen et al., 2022). Also, raw sugar from sugar beets has intrinsic potential to produce biofuels, particularly ethanol, which can be considered to substitute fossil fuels (Garcia Gonzalez and Björnsson, 2022).

1.2.3. Selected amendments and fertilizers for the study's purpose

Biochar is a type of organic amendment formed by oxygen-limited pyrolysis of biomass materials at low to moderate temperatures (300-700 °C), which has been widely used for agricultural purposes (Ghorbani et al., 2024). In recent years, biochar is rapidly evolving for application in agriculture and environmental modification due to its ecological compatibility (Chen et al., 2022). A porous structure, a high carbon content, and an alkaline pH are common characteristics of biochar (Liu et al., 2024). Because of these characteristics, biochar can be used for soil and plant modification purposes, including boosting carbon storage, improving soil water retention, increasing soil porosity, immobilizing soil contaminants, improving soil fertility, as well as increasing nutrient uptake and crop productivity (Chi et al., 2024; De Lima Veloso et al., 2022; El-Naggar et al., 2024). Recent findings have demonstrated that maintaining soil mineral nitrogen levels with biochar enhances root nitrogen uptake (Chen et al., 2022). Additionally, using biochar strongly encourages the development of dry matter since it can effectively increase photosynthesis rate and raises agricultural yields (Zhang et al., 2020). Biochar, as opposed to natural organic waste, which decomposes quickly, provides a more stable type of carbon. As a result, it has been proposed as an effective solution for increasing soil carbon stocks (Hou et al., 2024), and it has the potential to significantly add to the mitigation of global climate change.

Compost and *Vermicomposting* are types of biofertilizers which are able to provide a variety of crucial nutrients to the soil. In simple terms, manure contains a lot of organic matter and provides the soil with a few nutrients. Manure is created when animal excrement and plant waste decompose. Manure adds nutrients and organic elements to the soil, improving its fertility. The majority of the organic matter in manure helps to improve soil structure. This requires increasing the water-holding capacity of sandy soils. Compost and vermicompost have been implemented for decades to maintain and enhance agricultural soil functioning (Amirahmadi et al., 2024; Głąb et al., 2018; Velasco-Velasco et al., 2011)

Manures are another type of organic fertilizer that has been used in agriculture due to their features such as high concentration of available nutrients and enhanced soil porosity, increased soil accessible water content, increased organic matter content, and increased agricultural production (Hou et al., 2015; Lee et al., 2024)

Zeolites are classified as crystalline aluminosilicates and play a significant role in soil amendments by enhancing soil aeration, nutrient availability, and plant production. Other possible usages which were already investigated are zeolite application as a carrier of slow-release fertilizers, insecticides, fungicides, and herbicides, and as a trap for heavy metals in soils (Ferretti et al., 2024).

1.3. Life Cycle Assessment (LCA)

LCA is a technique for environmental systems analysis aimed to assess the potential environmental impacts for a product over its life cycle. The system analytical character of the LCA technique is important to understand and manage since this is probably one reason behind the perceived complexity of the LCA tool. Systems analysis has been applied in many different types of sciences and disciplines.

The LCA method used in this study is based on ISO 14040 (2006) and ISO 14044 (2006) and contains four phases, including goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and data interpretation (ISO 14040, 2006; ISO 14044, 2006). The following sections provide a summary of the major decisions taken during these four phases.

1.3.1. Goal and scope definition

”The goal and scope of a LCA study shall be clearly defined and consistent with the intended application”. ”The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal. LCA is an iterative technique. Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected” (ISO 14040, 1997). To define goal and scope is an important groundwork in the start phase of a LCA study. LCA studies can be conducted with many different types of goal and scope definitions. It is of importance how e.g. the technical system is identified, how the system boundary is defined and how the environmental burdens are allocated. Considerations related to inventory data, like level of detail and data quality are critical since they strongly influence the cost for the study. The system boundary has to be considered from different points of view, e.g. in relation to the time perspective and the geographical location. The function of the technical system should be as clearly specified as possible since this influences the choice of the functional unit to be used as an allocation basis for calculation of the environmental impacts. A proper definition of the functional unit is of special importance when comparing different types of technical systems. Furthermore, allocation principles have to be considered, e.g. if more than one product is produced in the same production process.

1.3.2. Life cycle inventory (LCI)

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. Inventory analysis is often referred to the most time consuming phase of a LCA and is thus critical in relation to the objectives of this thesis. Access to inventory databases containing data for various unit processes is one potential way to facilitate inventory work. Input data to inventory analysis has to be collected for many different unit processes like:

- Manufacturing e.g. amounts and types of materials and energy used.
- Transport, e.g. distances and modes of transport.
- Use of the product, e.g. energy use and amounts of maintenance materials.
- End of life, e.g. dismantling-, scrapping- and waste treatment processes.

1.3.3. Life cycle impact assessment (LCIA)

In the first step of impact assessment, classification, the environmental impacts are assigned to different environmental impact categories, e.g. global warming or acidification. There is no universally accepted set of impact categories to be used in the classification step. In the next step, characterization, the total impact is calculated within each category by using characterization factors. In the final weighting step, the values for all impact categories are aggregated into one single value, using weighting factors. Several different weighting methods have been developed. Some of them are based on national political goals for pollution reduction or on the willingness to pay for either impact on human health and ecological status or to restore/protect certain safeguard objects. To compare the impact of emissions with those of resource depletion (or activities like deforestation) adds to the methodological complexity as do the existence of synergies between emission categories and the fact that the localization of impact activities in space and time may be important. It could therefore be argued that the weighting step in impact assessment is moved to the interpretation phase. The impact assessment phase will then become a procedure based on natural sciences and weighting becomes a natural part of an already value based interpretation process.

1.3.4. Interpretation

The interpretation phase is a systematic procedure to identify, qualify, check, evaluate and present the information from a LCA study in order to meet the requirements defined in the goal and scope of the study. Interpretation includes communication of the result and serves as an important link between the LCA technique and its' applications. An issue to deal with in the interpretation phase is the comparability aspect, e.g. what system and system level with which to compare.

1.4. Research objectives and hypothesis

The main objective of this study was determining the parameters leading to differences in environmental impacts among different organic and conventional nutrient management through comparative LCAs. In addition, to explore the efficiency of soil amendments and fertilizers in organic practices approach, a variety of different soil organic amendments were practically evaluated and their efficiency in crop production were investigated in some single research, simultaneously.

Also, the hypothesis of the study was as follows:
GHGs (CO_2, CH_4, and N_2O) emissions and other environmental parameters are different among organic and conventional systems of farming.

Organic amendments and fertilizers can effectively justify the insufficiency of nutrients in crop products, alleviate the environmental side effect in field, and cause the increase in crop yield.

Chapter 2: Methodology

2.1. Life Cycle Assessment

The LCA method used in this study is based on the standards ISO 14040 (2006) and ISO 14044 (2006). This LCA used the ReCiPe 2016 midpoint (H) impact assessment methodology, data from the AGRIBALYSE v1.2/v1.3 and Ecoinvent V.3.5 databases, and openLCA software V.11.0.

Eighteen indicators of environmental impacts are included in the ReCiPe midpoint method, which are further specified into four main damage categories: (1) human health, (2) ecosystem quality, (3) resources, and (4) climate change. Figure 1 and Table 1 represent the detail information regarding the indicators of environmental impacts.

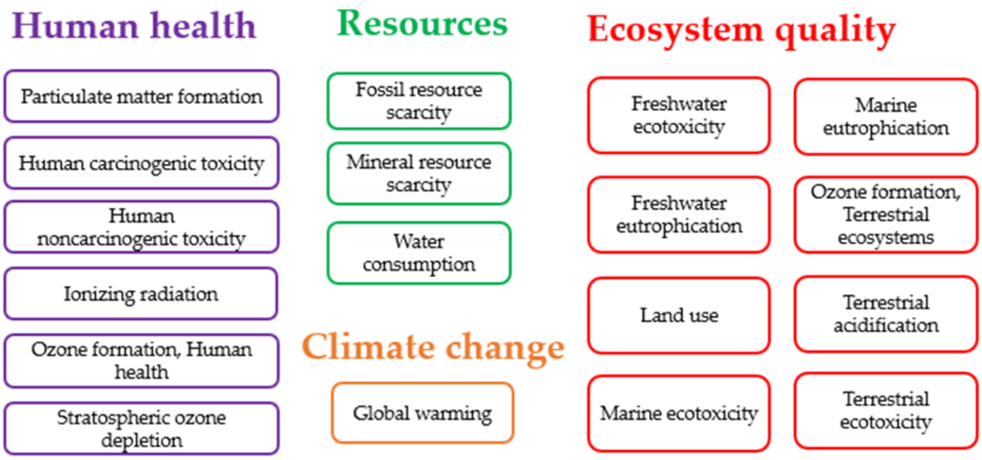

Figure 1. Overview of the midpoint impact categories in four different damage categories (human health, ecosystem quality, resources, and climate change).

Table 1. Overview of the midpoint impact categories and related indicators

Impact Category	Midpoint Characterization Factors	Indicator	Abbreviation	Unit	Damage Category
Particulate matter formation	Particulate matter formation potential	PM2.5 population intake	PMFP	kg PM2.5 eq	Human health
Human carcinogenic toxicity	Human toxicity potential	Risk increase of cancer disease incidence	HTPc	kg 1.4-DCB	Human health
Human non-carcinogenic toxicity	Human toxicity potential	Risk increase of non-cancer disease incidence	HTPnc	kg 1.4-DCB	Human health
Ionizing radiation	Ionizing radiation potential	Absorbed dose increase	IRP	kBq Co-60 eq	Human health
Ozone formation, Human health	Ozone formation potential—ecosystems	Increase tropospheric ozone increase	EOFP	kg NO_x eq	Human health
Stratospheric ozone depletion	Ozone depletion potential	Stratospheric ozone decrease	ODP	kg CFC11 eq	Human health
Fossil resource scarcity	Fossil fuel potential	Upper heating value	FFP	kg oil eq	Resources
Mineral resource scarcity	Surplus ore potential	Increase of ore extracted	SOP	kg Cu eq	Resources
Water consumption	Water consumption potential	Increases of water consumed	WCP	m^3	Resources
Freshwater ecotoxicity	Freshwater ecotoxicity potential	Hazard-weighted increase in freshwaters	FETP	kg 1.4-DCB	Ecosystem quality
Freshwater eutrophication	Freshwater eutrophication potential	Phosphorus increases in freshwater	FEP	kg P eq	Ecosystem quality
Land use	Agricultural land occupation potential	Occupation and time-integrated land transformation	LOP	m^2a crop eq	Ecosystem quality
Marine ecotoxicity	Marine ecotoxicity potential	Hazard-weighted increase in marine water	METP	kg 1,4-DCB	Ecosystem quality
Marine eutrophication	Marine eutrophication potential	Phosphorus increases in marine water	MEP	kg N eq	Ecosystem quality
Ozone formation, Terrestrial ecosystems	Ozone formation potential: humans	Tropospheric ozone population intake increase	HOFP	kg NO_x eq	Ecosystem quality
Terrestrial acidification	Terrestrial acidification potential	Proton increase in natural soils	TAP	kg SO_2 eq	Ecosystem quality
Terrestrial ecotoxicity	Terrestrial ecotoxicity potential	Hazard-weighted increase in natural soils	TETP	kg 1.4-DCB	Ecosystem quality
Global warming	Global warming potential	Infrared radiative forcing increase	GWP	kg CO_2 eq	Climate change

2.2. Meta-Analysis approach

2.2.1. Literature survey and eligibility criteria

To follow up a structured literature survey, we set our data collection based on Web of Science, Scopus, and Crossref databases. To ensure meaningful comparisons during the process of meta-analysis, the following criteria were applied to select appropriate studies: (1) studies which reported the results of both control and treatment were considered; (2) studies without replicated control and treatments had been ignored; (3) all studies were published in peer reviewed journal; (4) all studies were published in English; (5) all studies had available data for at least 2 target affected variables.

Most of the used data were extracted directly from the tables in the studies. Also, those data which were presented in figures, were extracted using GetData Graph Digitizer 2.24 software.

To store the maximum available data from studies in our dataset, all studies had been checked to see if they had any supplementary files.

2.2.2. Meta-analyses

Meta-analysis determines the extent of a variable's change and its relevance in response to a variable. The magnitude of the change is referred to as the effect size. The natural logarithm of the response ratio (RR) was used to compute the effect size (Hedges et al., 1999):

$$\ln(RR) = \ln\left(\frac{X_T}{X_C}\right)$$

X_C and X_T are the means of the variable in the control and treatment, respectively. The RR can be thought of as $(e^{\ln(RR)} - 1) \times 100$, which is the percentage change following effective factors (Nave et al., 2010). We recorded the standard deviation (SD) and number of replicates (n) for the control and treatment groups to generate confidence intervals (CIs) around effect sizes. If a study provided standard error (SE) or coefficient of variation (CV), the SD was determined using the formulas $SD = SE \times \sqrt{n}$ and $SD = CV \times mean$. For each effect size, the statistical significance was determined using the 95% CIs. If the 95% CIs ($p \leq 0.05$) did not intersect the zero line, the group means were significantly different.

2.2.3. Data analyses

The SPSS software v.28 (IBM Statistics, New York, USA) was used to calculate the effect size and the 95% CIs of each categorical group, and the random effects model was selected according to the results of the heterogeneity test (Rosenberg et al., 2000). The groups with less than three pairwise comparisons were excluded from each analysis. Resampling tests were generated from 999 iterations. The funnel plot statistics and Fail-safe N technique (Rosenthal's method) were conducted to assess the effects of publication bias and the robustness of the meta-analysis (Rosenberg et al., 2000). The calculated Fail-safe N was used only to compare with the $5n + 1$ (n is the number of cases) when the funnel plot statistics (Kendall's Tau and Spearman Rank-Order correlation) was significant ($p < 0.05$) (Nguyen et al., 2017). The data for any of the parameters did not contain any evidence of publishing bias. The between-group variability (Q_b) among observations (n) and p-value were used to assess the heterogeneity between groups using random-effect models. To analyze existing correlation between affected parameters, Pearson regression test was performed. The presence of autocorrelation between regression variables was evaluated by Durbin-Watson test. The residuals of all models passed heteroscedasticity for existence of potential outliers by Cook-Weisberg test. The normality of unstandardized residues values ($p < 0.05$) was assessed by Shapiro-Wilk test. The significance of regression model passed by Fisher–Snedecor test significance as the mean of the residuals was close to zero, and the residual distribution was near to the normal distribution.

Chapter 3: Results and conclusions

One of the most essential tools for evaluating environmental impacts in production is the life cycle assessment (LCA). The findings of the rice study indicated that GHG emissions in organic rice farming were higher than in conventional rice. This is related to the application of a large amount of organic manure in the first year of conversion to organic farming, as the transition of the systems takes some time to reach a new stable state. Therefore, it is important to examine the organic and conventional system of farming over a period of several years. Overall, organic rice production was more effective in diminishing negative environmental effects of farming compared to the conventional system. The LCA results of wheat crop showed that in both dryland and irrigated farming, compost application increased the amount of yield due to providing a sustain source of essential nutrients for plant growth. Also, application of compost notably reduced the environmental indicators in both farming systems. The lowest environmental impacts of compost application in dryland and irrigated farming showed the outstanding potential of compost as an organic soil fertilizer, in terms of securing human health, resources, and ecosystem quality. Therefore, it would be suggested that utilizing a combination of fertilizer and compost, especially in dryland areas, could ensure a higher yield while also alleviating the negative environmental indicators. The LCA result of tomato study, indicated that the use of compost in an organic open-field scenario was not suggested to be a good option for tomato cultivation, because of its negative environmental impact on human health, ecosystem quality, and resources. The finding of sugar beet assessment showed that in both autumn and spring sugar beets, the highest root yield obtained from field treated with cattle manure. However, biochar application showed its superior benefits in terms of sugar yield quality, and white sugar yield due to its inherent characteristics. As a total conclusion, it is important to examine different organic and conventional nutrient management on different crops over several years.

To achieve the maximum yield and minimizing greenhouse gas emissions, semi-organic fertilization produces higher crop yields than conventional fertilization while having an equal greenhouse gas intensity, it is expected that using a semi-organic approach has the potential to lower costs associated with both the production and use of chemical fertilizers. By restoring the proper balance of nutrients in the soil, it can also eventually lower greenhouse gas emissions in the long term. This indicates that using organic fertilizers in part place of chemical fertilizer inputs is a more effective approach to management with the intention to lower greenhouse gas intensity and increase nutrient usage efficiency. On the other hand, crop rotation and intercropping, which supply nutrients from plant wastes, may assist to increase crop yields while lowering greenhouse gas emissions and fertilizer expenditures. While the results of this study can provide an improved comprehension of the importance of selecting an appropriate strategy for cereal cultivation, the analysis of changes in vegetable cultivation also highlights the great potential of these plants to lower the intensity of greenhouse gases per product.

Organic amendments are shown to improve soil fertility in terms of the physical and chemical properties of the soil. Physical improvements include better aeration, porosity, and bulk density of the soil. Chemical properties such as electrical conductivity and organic carbon content are also enhanced for better plant growth. Biochar provides several agricultural and environmental benefits, such as soil health improvement, better crop growth and yield, carbon sequestration, decreased greenhouse gas (GHG) emissions, and regulation of nutrient dynamics. The availability of macronutrients and micronutrients is higher in vermicompost than in traditional compost and inorganic fertilizer, indicating that vermicompost is a better supplement to improve and stimulate plant growth. Zeolite has a tremendous capacity to transfer water throughout soil, making it an exceptional capillary distributor. It is very porous atomic structure and negative charge enable it to attract and retain water-soluble cations such as ammonium, potassium, magnesium, and calcium, as well as water. In conclusion, as organic agriculture continues to grow on a global scale, organic fertilizer and amendments are needed to sustain the yield and growth of organic crops as a whole. The future of organic farming involves improving and developing current technologies to improve fertilizer efficiency in terms of nutrient supply and utilization of locally available organic fertilizer resources. The current use of organic fertilizer by farmers is still low due to its higher retail price as compared to synthetic fertilizer. More research therefore needs to be conducted to address farmers' concerns.

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32 **Amirahmadi, E***., Ghorbani, M., Hörtenhuber, S.J., Bernas, J., Moudry, J. Neugschwandtner R.W., Krexner, T., Konvalina, P (2024). Life cycle assessment of biochar and cattle manure application in sugar beet cultivation – Insights into root yields, white sugar quality, environmental aspects in field and factory phases. *Journal of Cleaner Production, 00*(0):0000. UNDER REVIEW| **Q1, IF:9.7**

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10. Ghorbani, M*., Konvalina, P., Neugschwandtner, R.W., Kopecký, M., **Amirahmadi, E.,** Walkiewicz, A., Bucur, D. (2022). Interaction of biochar with chemical, green and biological nitrogen fertilizers on nitrogen use efficiency indices. Agronomy, 12(9):2106. http://dx.doi.org/10.3390/agronomy12092106 | **Q1, IF:3.7**

9. Ghorbani, M*., Konvalina, P., Neugschwandtner, R.W., Kopecký, M., **Amirahmadi, E.,** Moudrý, J.J., Menšík, L. (2022). Preliminary findings on cadmium bioaccumulation and photosynthesis in rice (Oryza sativa L.) and maize (Zea mays L.) using biochar made from C3- and C4-originated straw. Plants, 11(2):43. https://doi.org/10.3390/plants11111424 | **Q1, IF:4.5**

8. Asadi, H*., Ghorbani, M., Rezaei-Rashti, M., Abrishamkesh, S., **Amirahmadi, E.,** Chengrong, C.H.E.N., Gorji, M. (2021). Application of rice husk biochar for achieving sustainable agriculture and environment. Rice Science, 28(4), 325-343. https://doi.org/10.1016/j.rsci.2021.05.004 | **Q1, IF:4.8**

7. Ghorbani, M*., **Amirahmadi, E.,** Zamanian, K. (2021). In-situ biochar production in paddies: direct involvement of farmers in greenhouse gases reduction policies besides increasing nutrients availability and rice production. Land Degradation & Development, 32(14), 3893-3904. https://doi.org/10.1002/ldr.4006 | **Q1, IF:4.377**

6. **Amirahmadi, E.,** Mohammad Hojjati, S., Kammann, C*., Ghorbani, M., Biparva, P. (2020). The potential effectiveness of biochar application to reduce soil Cd bioavailability and encourage oak seedling growth. Applied Sciences, 10(10), 3410. https://doi.org/10.3390/app10103410 | **Q2, IF:2.7**

5. **Amirahmadi, E.,** Mohammad Hojjati, S., Biparva, P., Kammann, C (2019). Effect of zeolite on nitrate leaching, aggregate stability and growth of Chestnut-leaved oak (*Quercus castaneifolia C. A. Mey*.) seedlings. *Iranian Journal of Forest and Poplar Research*, *27*(3), 258-271. https://dx.doi.org/10.22092/ijfpr.2019.120632 | **Q2, IF:0.211**

4. Ghorbani, M*., & **Amirahmadi, E.** (2018). Effect of rice husk Biochar (RHB) on some of chemical properties of an acidic soil and the absorption of some nutrients. Journal of Applied Sciences and Environmental Management, 22(3), 313-317. https://doi.org/10.4314/jasem.v22i3.4 | ISSN: 2659-1502

3. Ghorbani, M*., & **Amirahmadi, E.** (2018). Effect of rice husk biochar on some physical characteristics of soil and corn growth in a loamy soil. Iranian Journal of Soil Research, 32(3), 305-318. https://dx.doi.org/10.22092/ijsr.2018.117821 | **IF:0.078**

2. **Amirahmadi, E.,** Hojjati, S. M., Poormajidian, M. R., & Najjari, A. (2016). Evaluation of Carbon sequestration in pure and mixed Plantations of Cupressus arizonica. *Journal of Applied Sciences and Environmental Management*, *20*(4), 979-984. https://doi.org/10.4314/jasem.v20i4.10 | ISSN: 1119-8362

1. **Amirahmadi, E.,** Poormajidian, M. R., Hojjati, S. M., & Najjari, A. (2015). Evaluation of plant diversity in pure and mixed plantations of *Cupressus arizonica*-Iran. *Journal of Biodiversity and Environmental Sciences (JBES)*, *6*(6), 76-82.| ISSN: 2220-6663

Curriculum vitae

Elnaz Amirahmadi
Researcher in Plant and Soil Science
Scopus-based H-index: 12

Education

- **Doctor of Philosophy (Ph.D. 2)** in Plant Science,
  University of South Bohemia, Czechia, 2024.
- **Doctor of Philosophy (Ph.D. 1)** in Forest Ecology,
  Sari Agricultural and Natural Resources University, Sari, Iran, 2019.
- **Master of Science (M.Sc.)** in Forest Ecology and management,
  Sari Agricultural and Natural Resources University, Sari, Iran, 2015.
- **Bachelor of Science (B.Sc.)** in Forest Engineering,
  University of Guilan, Iran, 2012.

Positions, Trainings, Internships

- **Visiting Scholar** at Ghent University,

  Belgium, September-October 2024.

1) Understanding of state-of-the-art techniques for soil-physical and soil-hydraulic characterization of soil (KSAT, HYPROP, EMI, ERT, GPR, …) and telemetric sensor-based monitoring of soil variables.
2) Discussion and demonstration on the use of soil amendments, especially biochar to build resilience against drought: from lab to greenhouse to field.

- **Research Assistant** at Geisenheim University,

  Germany, June-July 2024.

Attended the DAAD-funded summer school on agricultural greenhouse gas (GHG) flux measurement techniques, novel analytical methods, potential methodical, drawbacks and pitfalls, flux calculation and upscaling/sum calculation protocols. Experienced in:

3) Encompasses CO_2 footprint calculations according to the latest IPCC global warming potential considerations as a preparation for agricultural life cycle analysis.
4) Novel experimental approaches on agricultural tests of biochar and rock powder (enhanced weathering) as CDR techniques, alone and in combination (co-pyrolysis). Within the current BMBF-funded Network project “PyMiCCS” (pyrolysis and enhanced mineral weathering for carbon capture and storage) within the CDRterra Consortium.
5) Methodical use of a Picarro analyser employing the novel measurement technique CRDS 8cavity ring-down spectroscopy) for gaseous stable Carbon isotope measurements and their application in agricultural ecology.
6) Soil acoustic measurement techniques for monitoring soundscapes below-ground as a tool to investigate belowground macrofauna biodiversity in soils.
7) State of the art knowledge on GHG flux measurement calculation methods (closed and dynamic chambers; different analytical methods and platforms and their operation modes), all of which also demand digital skills, due to different types of analysers, software and R protocols that have to be modified and used.
8) Use of R protocols for experimental block design statistics and graphics.

9) Use of the respective R protocols and R programming skills to put the newly acquired theory into research practice.

- **Visiting Scholar** at University of Milan,

  Italy, May 2024.

Experienced in the field of biosystems and bioresources management in agriculture at the Department of Agriculture and Environmental Science.

- **Visiting Researcher** at Aarhus University,

  Denmark, April 2024.

Experienced in novel methods to measure soil water retention in the dry region using pressure plate, Vapor Sorption Analyzer (VSA), CT scan imagery, ...

- **Fellow Researcher** at the University of Natural Resources and Life Sciences in Vienna,

  Austria, March 2024.

Leading a project aiming at the assessment of absorption capacity of pristine and modified biochar in immobilization of heavy metals through ICP analysis.

- **Research Assistant** at the University of Helsinki,

  Finland, May-June 2023.

Experienced in:

1) GHG sampling from field with chamber method
2) Gas Chromatography measurements
3) X-ray diffractometry (XRD) analysis of biochar - PANalytical X Pert Pro.
4) TDR methods for soil moisture measurements
5) Drone running, setting plan with Pix4D and analyzing the data for photosynthesis measurements.

- **Visiting Scholar** at Charles University,

  Czechia, February 2023.

Experienced in:

1) Elemental analyzer (Agilent /ICP-OES-5900)
2) FTIR spectrometer (Thermo Scientific /Nicolete)
3) Combined liquid and ion chromatography (Dionex ICS 5000+)
4) Gas chromatograph (Hewlett Packard 5890 Series II)
5) Atomic absorption spectrophotometer (Perkin Elmer 306)
6) Gas chromatography analysis (Thermo Scientific TRACE 1310 GC IsoLink II Interface-IRMS)
7) Isotopic composition of elements (Neptune Plus High-Resolution Multicollector ICP-MS).

- **Researcher** at the University of Natural Resources and Life Sciences in Vienna,

  Austria, June-August 2022.

Experienced in:

1) CHNS Elemental Analyzer (Leco 630.100.500)
2) FTIR-Fourier (Perkin Elmer Spotlight 400N)
3) Scanning electron microscope (SEM) imaging (Hitachi TM3030)
4) Vacuum Coater (Leica EM ACE200)
5) Electrical Muffle Furnace (Nabertherm N41/13)
6) Phenotyping with a high-resolution RGB camera mounted on a drone
7) Diversity in oats: winter versus spring sowing
8) Resistance research: resistance to stone blight in winter wheat

9) Smart assessment of wheat growth and photosynthesis (experienced in FieldSpec Handheld, Greenseeker, SPAD, *PolyPen, AccuPAR, …).*

- **Internship** at Geisenheim University,

  Germany, June-September 2018.

joined to a research group which worked on biochar as a tool for sustainable environmental management.

- **Firm Owner in Rasht, Iran,**

  Iran, June-August 2019.

A consulting company with aims of biochar production and integrating farmers to use their local agricultural wastes in a beneficial approach.

- **Project Manager at Rice Research Institute of Iran and Guilan Science and Technology Park,**

  Iran, 2018.

During my career, I conducted some field research projects focusing on the effects of biochar on rice productivity, heavy metal immobilization, and GHG emissions from paddy fields.

| Scholarships

- **Winner of faculty scholarship for abroad scientific mobility (June 2022)**
  For mobility to the University of Natural Resources and Life Sciences in Vienna, Austria.
- **Winner of faculty scholarship for internal scientific mobility (February 2023)**
  For mobility to Charles University, Czechia.
- **Winner of faculty scholarship for abroad scientific mobility (May 2023)**
  For mobility to the University of Helsinki.
- **Winner of ERASMUS+ higher education scholarship for scientific mobility (March 2024)**
  For mobility to the University of Natural Resources and Life Sciences in Vienna, Austria.
- **Winner of ERASMUS+ higher education scholarship for scientific mobility (April 2024)**
  For mobility to Aarhus University, Denmark.
- **Winner of ERASMUS+ higher education scholarship for scientific mobility (May 2024)**
  For mobility to the University of Milan, Italy.
- **Winner of ERASMUS+ higher education scholarship for scientific mobility (June 2024)**
  For mobility to Geisenheim University, Germany.
- **Winner of ERASMUS+ higher education scholarship for scientific mobility (September 2024)**
  For mobility to Ghent University, Belgium.
- **GAJU-Project scholarship from the doctoral university (2021- 2024)**
  For progress in the Ph.D thesis and achievements in scientific publication.

Conferences

- **5th Global Food Security Conference in KU Leuven, Leuven, Belgium. 9th - 12th April 2024**
  Biochar for food security and GHG emissions mitigation. Insights into involving farmers in sustainable biochar production- challenges and opportunities.
- **3rd Conference of Doctoral Students in University of South Bohemia, České Budějovice, Czechia. 21st - 22nd November 2023**
  Comparison of organic and conventional cropping systems: A review of life cycle assessment as a solution for sustainability.
- **2nd Conference of Doctoral Students in University of South Bohemia, České Budějovice, Czechia. 7th - 8th December 2022**
  Environmental life cycle assessment in organic and conventional rice farming systems: using a cradle to farm gate approach.
- **8th International Conference on Trends in Agricultural Engineering, Czech University of Life Sciences, Prague, Czech Republic 20th - 23rd September 2022**
  A review on organic farming in a sustainable environment.
- **3rd National conference on sustainable development, Tehran, Iran. 3rd February 2016**
  Development of urban space in sustainable urban management.
- **1st National conference on soil protection and watershed management, National Soil Conservation and Watershed Research Institute, Tehran, Iran 25th March 2015**
  Evaluation of quantitative and qualitative characteristics of pure and mixed stand of *Cupressus arizonica* and *pinus eldarica*.
- **1st National conference on soil protection and watershed management, National Soil Conservation and Watershed Research Institute, Tehran, Iran 25th March 2015**
  Evaluate the influence of mixture on qualitative and quantitative characteristics of *Cupressus arizonica* and *pinus eldarica*.
- **3rd *National Congress of Student Scientific Associations on Agriculture and Natural Resources*, Tehran, Iran. 6th - 7th May 2015**
  A review of mixed plantation and some aspects of it compared to pure plantation.
- **3rd *National Congress of Student Scientific Associations on Agriculture and Natural Resources*, Tehran, Iran. 6th - 7th May 2015**
  Introduction and importance of biodiversity as the foundation of life on Earth and the reasons for its destruction.
- **1st *Congress on Biology and Natural Science*, Tehran, Iran 18th December 2014**
  Light role in the growth of woody plants.
- **1st *Congress on Biology and Natural Science*, Tehran, Iran 18th December 2014**
  Review of the importance and ways to protect *taxus bacata* and important ways to prevent the extinction of this species.

Teaching, Talks

- **At: Department of Agroecology - Soil Physics & Hydropedology, Aarhus University, Foulum, Denmark.**
  On: The capability of biochar as an organic soil amendment for sustainable agriculture. 2024.
- **At: Department of Agroecosystems, Faculty of Agriculture & Technology, University of South Bohemia, Ceske Budejuvice, Czechia**
  On: Advantages and disadvantages of organic farming. 2024.
- **At: Institute for Environmental Studies, Faculty of Science, Charles University, Prague, Czechia.**
  On: Environmental impact assessment of organic and conventional farming. 2023.
- **At: Institute of Agronomy, Department of Crop Sciences, University of Natural Resources & Life Sciences in Vienna, Austria.**
  Investigation of the occurrence of soil humus forms concerning environmental factors describing climates and plants. 2022.
- **At: Department of Forestry, Faculty of Natural Resources, Sari Agricultural and Natural Resources University, Sari, Iran.**
  On introducing soil humus forms in relation to environmental factors describing climates and plants. 2016.
- **At: Department of Forestry, Faculty of Natural resources, Sari Agricultural and Natural Resources University, Sari, Iran.**
  On: review of mixed and pure plantation. 2015.

Practical Research Experiences

- **Field & Greenhouse**
  Crop processing (Wheat, Rice, Canola, Maize, …) / Intercropping systems / Organic and conventional farming / GHGs emission monitoring in crop fields / Soil and plant sampling / Nutrient leaching experiments / Heavy metal immobilization / Soil water content using TDR / nutrient cycling / Smart assessment of wheat growth and photosynthesis using FieldSpec Handheld, Greenseeker, SPAD, PolyPen, AccuPAR, ...
- **Laboratory**
  Spectrophotometry / Gas chromatography / Soil moisture analysis using pressure plate, Vapor Sorption Analyzer (VSA) and CT scan imagery / Batch experiments for heavy metal sorption / / FTIR, ...
- **Biochar**
  Biochar production in muffle furnace using a variety of temperatures and feedstocks/biochar characterization in basic analysis such as FTIR
- **Software**
  SPSS / OriginPro / open-LCA/ Microsoft office.

Professional Services

- **Journal Reviewer**
  Springer: Water, air and soil pollution / Journal of Soil Science and Plant Nutrition.
  MDPI: Plants / Agriculture / Agronomy / Applied sciences / Environments / Forests / Horticulture / Sustainability/ Water.
- **Journal Editor**
  Special issue on Application of Biochar in Sustainable Soil Management: Challenges and Perspectives. Agriculture Journal – MDPI. 2024
  Special issue on Sustainable and Ecological Agriculture in Crop Production. Agriculture Journal – MDPI. 2023

- **Book Translator**
  A book named Biocharculture by Dr. Sai Bhaskar Reddy translated from English to Persian.