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Master thesis

Long term development of soil organic carbon influenced by different agricultural practices

Master in Applied Ecology

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Abstract

The study analyses the long-term trends in the soil carbon breakdowns and builds up in agricultural land. Various farming practices are examined here, focusing on cover crops, tillage systems, and organic amendments. The study provides a direct evaluation of the effectiveness of these practices on soil organic carbon (SOC) as affected by the number of years and soil depth. Data were taken from a published research paper that includes best management practices that have continued for more than five years and provide values in gram SOC per kg of soil or equivalent transferable units. The initial and final SOC were taken from the various articles with soil sampling depths from 0-15 and 0-30cm. A mixed model meta-regression was done to analyse the data, using the package "lme4" version 1.1-29 in R, where the number of managed years was set as a fixed variable and the three management practices as random variables, and with a 95% confidence interval for the prediction.

Continuous farming with zero tillage increases SOC at a significantly higher rate than that of organic manures and cover crops. The increase in SOC is maintained year after year, with slight variations. Organic manure also increases SOC, but the rate of the increase is lower. Cover crops increase SOC over time, but the pace of the increase is lower as the years pass. Analysis revealed that the increase in SOC was mainly observed in the top layer of the soil profile (0-15cm) but not in the bottom layer. All three practices show significant positive relation with SOC. Implementing a focal agriculture management practice had a positive effect on the soil's organic carbon concentration. To achieve a sustainable agriculture system, farmers need to adopt practices geared toward conserving organic carbon. This can be done by using cover crops, organic manures and reduced soil tillages, which can help increase the soil carbon. This can also help cut down on greenhouse gas emissions and mitigate climate change. A sustainable and eco-friendly climate-smart agriculture production system is necessary for protecting soil and meeting future food security.

Keywords: *Soil organic carbon, soil depth, cover crops, tillage, organic amendments*

Norwegian abstract

Studien analyserer de langsiktige trendene i nedbrytning og oppbygging av karbon i jordbruksland. Her utforskes hvordan ulike dyrkningspraksiser påvirker resultatet med fokus på bruk av fangvekster, ulike jordbearbeidingssystem og bruk av organisk gjødsling. Studien gir en direkte evaluering av effektiviteten til disse praksisene uttrykt over antall år og jorddybde. Data ble hentet fra publiserte forskningsartikler som inkluderer god jordbrukspraksis som har vart i minst 5 år og som oppgir tall for jordkarbon i form av gram per kg jord eller tilsvarende omregnbare enheter. Fra de ulike artiklene ble den initielle og avsluttende verdien for jordkarbon anvendt og med jordprøvedybder fra 0-15 og 0-30 cm. En meta-regresjonsanalyse, og med hjelp av en blandet modell, ble kjørt på datamateriale, dette ved hjelp av R pakken "lme4", versjon 1.1-29, hvor antall år ble brukt som en fast variabel og tre dyrkningspraksisene som tilfeldige variabler, og med et 95 % konfidensintervall for prediksjonen. Kontinuerlig dyrking uten jordarbeiding øker oppbyggingen av jordkarbon og med en rate som er betydelig høyere enn organisk gjødsel og dekkvekster. Økningen i jordkarbon opprettholdes år etter år og med små variasjoner. Ser vi på bruk av organisk gjødsel, viser den en konstant økning av jordkarbon ettersom årene går. Fangvekster gir også til økt jordkarbon med årene, men raten i oppbyggingen avtar med årene. For alle tre praksiser viste analyse at økningen i jordkarbon hovedsakelig ble observert i det øverste laget av jordprofilen (0-15 cm), men det tilsvarende ikke ble observert samme effekt i det nederste laget. Men alle tre praksisene gir en positiv effekt på mengden karbon i jorda. Å implemente en landbruksforvaltnings med fokus på disse praksises vil ha en positiv effekt på jordens organiske karbonreserver, og i gjennomsnitt. For å oppnå et bærekraftig landbrukssystem, må bøndene ta i bruk praksiser som er rettet mot å bevare jordkarbon. Dette kan gjøres gjennom bruk av dekkvekster, organisk gjødsel og redusert jordarbeiding. Dette kan bidra til å kutte ned på klimagassutslipp og dempe klimaendringer. Bærekraftig og klimasmart landbruksproduksjon er nødvendig for å beskytte jordsmonnet og møte fremtidig matsikkerhet.

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List of abbreviations

BMP	Best Management Practice
C	Carbon
C:N	Carbon ,Nitrogen
CT	Control Tillage
OF	Organic Farming
SOC	Soil Organic Carbon
UN	United Nation
ZT	Zero Tillage

Long term development of soil organic carbon influenced by different agricultural practices

1. Introduction

The terrestrial carbon pool stores more carbon than the vegetation and atmosphere pools combined (Davidson & Janssens, 2006). Around 75% of the carbon in the terrestrial pool is stored as soil organic carbon (SOC) (Batjes, 1996). Agricultural land occupies 38% of the earth's land surface, and its SOC stock is strongly influenced by human activities (Bank, 2010). Changes in SOC in agricultural land over time are characterised by dynamic exchange processes which are controlled by environmental conditions such as soil texture, temperature, and rainfall and management practices such as cropping systems, fertilisation, residue removal, and tillage regimes (Alston, Beddow, & Pardey, 2009; Dolan, Clapp, Allmaras, Baker, & Molina, 2006; Rattan Lal, 2004). Agricultural activities such as removing land from agricultural production and altering its biogeochemical pathways can lead to significant changes in the balance of carbon in the oilfield(Compton & Boone, 2000). Carbon is a vital component of life, which provides insulation and maintains the equilibrium of various elements.

Carbon is a vital component of life, which provides insulation and maintains the equilibrium of various elements. During the carbon cycle process, there is a carbon exchange in the atmosphere and with the different terrestrial and marine organisms, mainly absorbed by the soil (Hayduk, Satoyama, & Vafadari, 2015). Healthy soils are the largest reservoir of carbon which play a vital role in mitigating climate change by reducing greenhouse gas and storing carbon emissions. If soils are not appropriately managed, carbon dioxide is released into the atmosphere, contributing to climate change and global warming. Due to the conversion of green forests, grassland and high unmanaged urbanisation, there is a considerable loss of soil carbon worldwide.

Climate change is linked to the storage of soil carbon, which can help mitigate greenhouse gas emissions. Improved agricultural techniques can help restore the lost SOC pool from cultivated land. The effects of cropland management on SOC storage can be studied to identify appropriate strategies to reduce greenhouse gas emissions (Rattan Lal, 2004). Soil carbon is essential because of its effects on soil quality functions and sustaining different biological activities, diversity, and productivity. Soil carbon plays an essential role in regulating and partitioning water and solute transport, filtering, buffering, degrading, immobilising, and detoxifying organic and inorganic, materials as well as storage and cycling of nutrients and other essential elements within the earth's biosphere—field (Fenton, Brown, & Mausbach, 2018).

Conventional tillage increases the rate of loss of soil organic carbon by accelerating the amount of oxygen concentration on the surface of the soil as well as destroying soil aggregation. Zero tillage practices slow down the disturbance of soil and also increase soil aggregation and SOC accumulation. Carbon storage was higher in the top 20 cm in zero tillage compared to the conventional tillage system but the soil surface deeper than 30 cm shows no significant differences in SOC between zero tilled and conventionally tilled soils(H. V. Cooper et al., 2021). Conventional tillage followed by zero tillage alters the soil's physical and biological properties and the arrangement of solid particles where different types of microbial decomposers are situated (Mangalassery et al., 2014). No-till and permanent vegetation are capable of storing carbon in the soil. Minimising physical and mechanical disturbance to the soil helps increase soil porosity, which helps for stable macro-aggregates and degradation of soils is lesser. It contains more organic carbon compared to conventional tillage practice. Soil erosion causes carbon to accumulate with soil sediments and be removed from the soil carbon pool. The removal of carbon from the soil will lead to a decline in soil fertility and aggregate stability (Wilts, Reicosky, Allmaras, & Clapp, 2004). Heavy tillage activities significantly decrease SOC loss from the soil with high organic matter content. No-tillage eliminates the mixing and turning of the soil by using herbicides to control weeds. It also allows the plant to enter the soil directly at the desired depth. It is widely believed that intensive soil tillage accelerates the organic matter decomposition process by warming the soil and breaking up the residue (Wilts et al., 2004).

Cover cropping is a technique that can help increase the productivity of a farm system by taking advantage of the high-quality plant residue. Generally, cover crops improve the soil carbon content. Fallow in spring should not be used in soils with low carbon stocks. Grasses can help increase the carbon content of the soil. A cover crop can be used to enhance the diversity of a farm system, or it can be planted in conjunction with the main cash crop (Wiesmeier et al., 2019). The nutrients and organic matter that come from a cover crop are important factors that affect the soil organic matter dynamics. The quality and quantity of cover crop residue can affect the soil's organic matter dynamics and its nitrogen supply; aside from soil quality, a cover crop's composition can also affect the greenhouse gas emissions and the performance of the cash crop. Cover crops increase the soil carbon, but it is unclear what kinds of cover crop management and environmental conditions will respond to soil carbon in different cropping systems (Rosenzweig, Fonte, & Schipanski, 2018). The diversity of cover crop species helps increase the biomass, and the presence of bicultural supports a higher accumulation of N and C(McClelland, Paustian, & Schipanski, 2021). Residue management techniques can help improve soil C stocks by diverting soil C away from previously protected areas which can help improve the soil's health and provide additional nutrients(Six, Elliott, & Paustian, 2000). The beneficial effects of species diversity on soil stocks have been attributed to the increased organic matter produced by the diverse communities of plants. Intercropping, which occurs when a field has multiple crop species, increases aboveground productivity, and this benefit would increase the soil carbon due to the increased input of root litter (Cong et al., 2015).

Cover cropping is a practice that can help conserve organic matter in the soil. It can also improve soil quality and increase farm yield (Bedoussac et al., 2018). Soil quality is a crucial factor in determining the productivity of farmland. Soil C and N levels are also linked to the availability of nutrients and their resistance to erosion and surface crusting. Improvement of soil Carbon can help mitigate atmospheric CO2 increment, and the presence of root residue in intercropping systems can increase the C content of the soil (Cong et al., 2015).

There is growing interest in the use of soil carbon sequestration and biological activities related to organic farming, which is helpful for sustainable agriculture farming system as well as mitigation of climate change (Han, Xu, Wei, Shi, & Ma, 2013). Synthetic chemicals pesticides and any kind of inorganic fertilisers are not used in organic farming. However, different principles of organic farming, crop rotation with legumes and compost are used for farming. Different types of biological, physical, and mechanical processes are used for pest control and management so that soil health can be improved. It also stores a high amount of soil carbon and plant nutrients, and soil microbial biomass concentration is higher in organic farming compared to conventional farming Fields (Han et al., 2013). Soil organic matter is composed of various components, such as crop residue, roots, and microbes. It is considered a vital component of the soil system and has been used as an indicator of soil quality. Soil organic matter can be turned into atmospheric carbon by sequestering it in the ground. A study revealed that organic farming systems produce higher soil organic carbon levels than non-organic farming systems and contribute to higher atmospheric carbon (Gattinger et al., 2012). Despite the potential environmental benefits of carbon sequestration, the researchers caution that efforts to reduce greenhouse gas emissions are only part of the solution to global climate change.

Further research is needed to analyse the effects of varying farming systems on carbon capture and storage (Gattinger et al., 2012). The accumulation of carbon dioxide causes climate change in the atmosphere. In order to minimise its effects, organic agriculture can help by sequestering atmospheric carbon. Soils play a significant role in mitigating climate change which is known to sequester SOC. A large amount of sequestration of soil organic carbon can enhance the cycling of the organic matter very fast, which is a vital component of crop production (García-Palacios et al., 2018).

Climate change is growing as a global issue and a serious problem to the world's food security, which can harm the biological properties of soil. Carbon loss is recognised as a problem to the soils directly related to the production of crops. Soil carbon sequestration helps retain soil moisture and strengthen the ecosystem. The UN's Food and Agriculture Organization has launched a Climate-Smart Agriculture initiative to promote a coordinated approach to address the challenges of climate change. (Hayduk et al., 2015).

Climate-smart agriculture is being widely embraced by the agriculture industry as it can safeguard the productivity of the crop. Climate-smart agriculture is a strategy that addresses the challenges of food security and greenhouse gas emissions. Its goals include increasing food production and reducing greenhouse gas emissions (Chandra, McNamara, & Dargusch, 2018). Sustainable agriculture techniques such as conservation agriculture and agroecology have been around for decades. Although climate-smart agriculture is commonly used in the environment, its relationship with climate change is not well understood. Agriculture is a major contributor to global greenhouse gas emissions. Climate change and variability are likely to have significant impacts on the agriculture (Chandra et al., 2018). In 2007, the IPCC stated that interactions between agriculture and climate change could result in both mitigation and adaptation.

This study focuses on long term trends in soil carbon breakdowns and builds up in agricultural land. Different farming practices influence the soil carbon capturing process and cycling system. The study investigates how different agriculture practices like conservation tillage, cover crop, and organic amendments influence soil carbon as well as how soil carbon storage helps in climate change mitigation and its management practices on soil in different climatic conditions and highlights best practices for climate-smart agriculture.

1.1. Study objectives

The objective of the study was to identify the optimal management practices that will allow the conservation of SOC under different agriculture practices. The following specific questions were addressed in the meta-analysis:

1. What are the impacts of different agriculture practices on SOC and soil health?

2. How do the number of years under different management practices affect SOC storage?

3. How does the availability of SOC depend on the different depths of soil?

4. What are the management practices of SOC and its role in climate change as well as food security?

2. Materials and Method

2.1. Systematic article search

Through a systematic search, different articles discussed the various aspects of soil organic carbon influenced by different agriculture practices and its impact on soil health.

For more availability of articles, online access to the university library was used, and articles accessed through Oria were selected for advanced search. Four thousand three hundred thirty-one articles were found under the topic and made them specific and more precise for systematic search under the research topics. Before starting the search, the terms that would be most useful for searching related articles under three main topics, organic amendments, cover crop and no-tillage practice, were identified. The search was carried out in September 2021 and was able to find over 1300 potential articles, which are then filtered based on their subject matter. The remaining articles were excluded from the search. These words selected for the systematic search were

"organic farm*" OR "organic ag*" OR "organic system*" OR "organic amendment* "cover crops" and "tillage practices", "soil organic carbon" OR "microbial biomass".

https://bibsys-almaprimo.hosted.exlibrisgroup.com/primo-explore/search?vid=HH

2.2. Inclusion criteria and article screening

The inclusion criteria for the article screening process were developed using the Population, Treatment, and Control Outcome framework. For the meta-analysis, articles had to meet all four inclusion criteria.

1. Published research paper on the topic of organic farming, tillage and cover crops systems

Articles that reported soil health metrics such as SOC and total carbon storage in organic farming, cover crops and different tillage system were included. Articles could be published in any location, and only those were included where organic management systems had been practised and observed for at least five years or more.

2. Farming with best management practices:

Research articles had to contain at least one article describing at least one treatment to investigate one type of BMP. If different agriculture practices were used, data were extracted for each one separately.

3. Farming systems without BMP (Control):

The managed control group is a system that follows the same management practices (e.g. no organic amendments, no zero tillage, no cover crops).

4. **Measured soil carbon**

Articles had to include the measurements for at least one of the following soil carbon metrics

a. Soil organic carbon (SOC) concentration(g kg^{-1} soil)

b**.** At least five years of the experiment period

Table 1 Synopsis of the studies included in meta-analysis

References	Latitude	Longitude	Research period	Focal_Agriculture_Practice	Initial/Control soil carbon g/kg of soil	Final soil_organic_carbon_g/kg	Soil texture	Cropping_intensity	Depth_measured	Location
Jiang, Hu, Bedell, Xie, and Wright (2011)	30.00°N	105.00°E	17	no-tillage	21.7	35.7	clayey	double	0-20	China
(Hontoria et al., 2016)	39°22'N	5°23'W	6	no tillage	19.61	22.7	sandy	single	0-20	Spain
(Grandy & Robertson, 2007)	42°24'N	85°24'W	12	no tillage	31.8	45.4	sandy	single	0-20	USA
(Mandiola, Studdert, Domínguez, & Videla, 2011)	37°45'S	58°18'E	15	no tillage	19.2	24.9	loamy	single	0-20	Argentina
(Nandan et al., 2019)	25°37'N	85°13'E	6	no tillage	4.9	7.24	clayey	single	0-20	India
(Wang et al., 2019)	28°07'N	112°15'E	11	no tillage	7.25	20.49	loamy	double	0-20	China
(Modak et al., 2020)	28°38'N	77°10'E	9	no tillage	5.5	7.59	sandy	double	0-20	India
(Ngwira, Sleutel, & De Neve, 2012)	6.369°S	34.8888°E	5	No-tillage	5.93	10.4	sandy	double	0-15	Tanzania
(Metay et al., 2007)	15° 47' S	47° 52' W	5	no tillage	12	16.5	clayey/oxisol	double	0-10	Brazil

(Plaza-Bonilla, Cantero-Martínez, Viñas, & Álvaro-Fuentes, 2013)	41°48' N	1°07'E	20	no tillage	11.9	24	silt/clay	single	0-10	Spain
(E. Liu, Yan, Mei, Zhang, & Fan, 2013)	35°169'N	107°309'E	8	organic farming	6.38	7.6	calcarid	double	0-20	China
(Zheng, Fan, Xu, & Zhou, 2017)	28°120' N	116°550' E	5	manure ,organic	7.06	20.75	ultisol	double	0-15	China
(Lv, Li, Che, Han, & Liu, 2011)	35°169'N	107°309'E	18	organic manure	9.56	11.92	redsoil	double	0-15	China
(Ghimire, Lamichhane, Acharya, Bista, & Sainju, 2017)	25°N	78.96°E	20	organic manure	4.9	14.9	alluvial	double	0-15	India/Nepal
(Benbi et al., 2018)	30° 47' N	76° 54' E	8	organic manure	6.39	8.1	Sandy	double	0-7.5	India
(Benbi et al., 2018)	30° 47' N	76° 54' E	8	organic manure	5.74	7.62	Sandy	double	7.5-15	India
(Das et al., 2017)	25°65'N	91°88'E	9	organic farming	24.6	31.2	typic pleudalf	double	0-15	India
(Das et al., 2017)	25°65'N	91°88'E	9	organic farming	20.1	26.4	typic pleudalf	double	0-15	India
(X. Liu et al., 2005)	47°26'N	126°38'E	16	organic manure	30.35	32.33	clayey,loam	double	0-15	China
(X. Liu et al., 2005)	47°26'N	126°38'E	16	organic manure	28.29	28.51	clayey loam	double	15-30	China
(Das et al., 2017)	25°65'N	91°88'E	9	cover crop	24.6	28	typic pleudalf	double	0-15	India

(Das et al., 2017)	25°65'N	91°88'E	9	cover crop	20.1	25.2	typic pleudalf	double	0-15	India
(Mazzoncini, Sapkota, Barberi, Antichi, & Risaliti, 2011)	43°40' N	10°19'E	15	cover crop	12.4	13.1	sandy		double	0-10
(Mazzoncini et al., 2011)	43°40' N	10°19'E	15	cover crop	9.9	10.2	Sandy	double	0:30	Italy
(Sainju, Singh, & Whitehead, 2002)	37° 5' N	(-)113°57'E	6	cover crop	16.5	24.9	sandy/loam	double	0-20	Italy
(Frasier, Quiroga, & Noellemeyer, 2016)	34°070' N	88°590' W	5	cover crop	9.7	17.1	loamy	single	0-12	USA
(Frasier et al., 2016)	34°070' N	88°590' W	5	cover crop	9.1	16	loamy	single	0-12	USA
(Rosolem, Li, & Garcia, 2016)	22°49'S	48°25'W	5	cover crop	18	20.42	clayey	double	0-5	Argentina
(Garcia, Li, & Rosolem, 2013)	22°49'S	48°25' W	7	cover crop	15.3	20.1	clay	double	0-5	Brazil

2.3. Data extraction

The articles containing both the SOC and BMP measurements were considered one of the main factors in assessing the potential of an article to contribute to the meta-analyses. After the screening process, selected articles were included in the study. Each article could contain multiple measurements, such as the organic amendment treatment, cover crop and tillage treatment. After identifying the candidate articles, the necessary data were extracted from the articles to create a more detailed analysis. From each article, initial and final SOC were obtained and measured soil sampling depth from 0-15cm and 0-30cm. Standard deviation was not available for all individual data. So Cohens-d was used for the calculation of effect size.

Where it is calculated as Final SOC-Initial SOC

Cohen’s -d was calculated using package “effsize” version 0.8.1 in R programming.

2.4 Study Area

2.4.1 Map showing different areas from where data were obtained

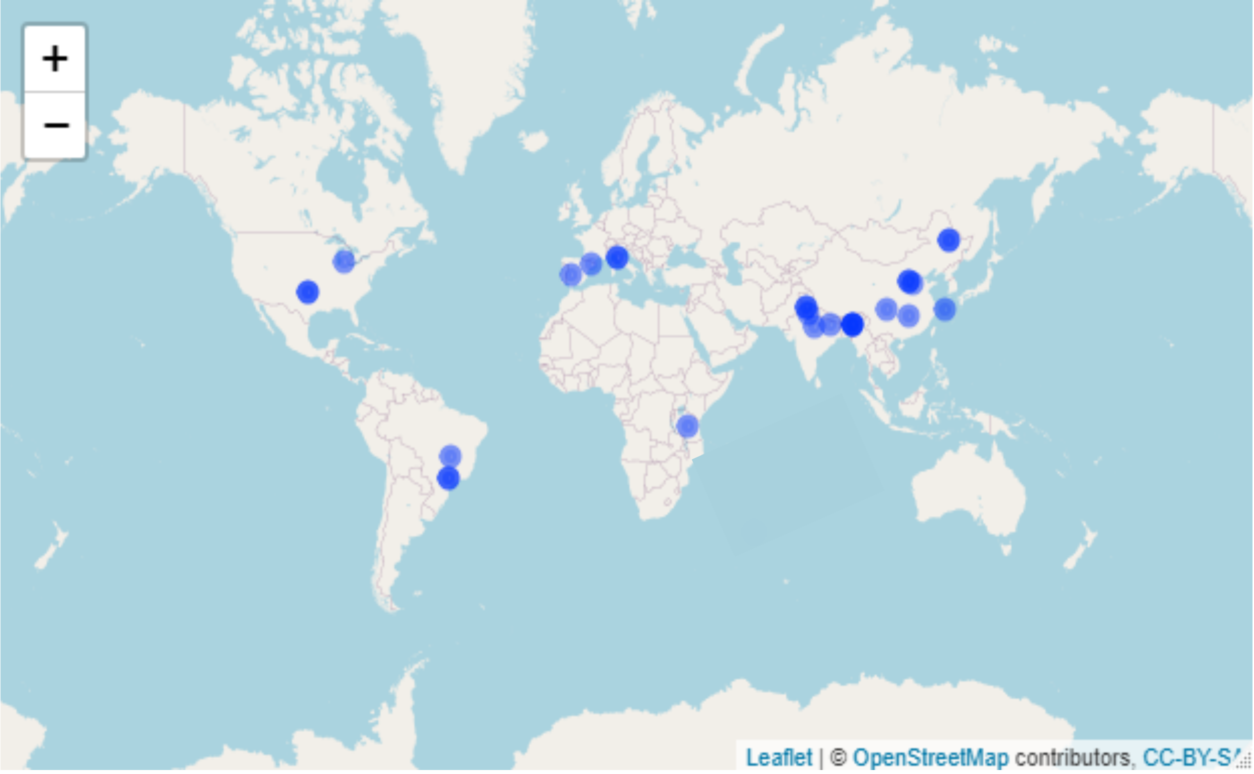


Figure 1Geographical distribution of all articles that are included in analysis

2.5. Meta-analysis model

Natural log of the response ratios was selected in the meta-analysis, which is mainly used in the agroecological analysis (J. Cooper et al., 2016).

Mathematically it is expressed as,

$Ln(RR) = Ln(Xt/Xi)$.

where,

ln is the log response ratio, Xt and Xi represent the mean value of SOC with best management practice groups of treatment, and Xi represents initial soil organic carbon, respectively.

Mixed-effects meta-regression was conducted on SOC within the topsoil dataset, with the number of managed years used as a fixed effect and three management practices as a random effect. This model used a 95% of the confidence interval for prediction. Soil depth was categorised as from 0-15 and 0-30 cm as there was no more information about the soil depth deeper than 30 cm. The research question was also related to how the depth of soil sample affects the availability of soil organic carbon.

Mixed model meta-regression was done using package “lme4” version 1.1-29 in R programming. Where the model is fitted as:

```
`ln(RR)`~`Managed years`+(1|focal_agriculture_practice)
```

3. Results

3.1.Management practice and number of years effects on SOC

No-tillage has the highest positive relation with SOC among three agriculture practices, no-tillage, cover crop and organic manure. In the beginning, the carbon content in soil is slowly increasing. However, as the number of organically managed years increases, soil carbon content also increases significantly, and there was a year to year variation. The study suggested that continuous farming with zero tillage results in a significant increase of SOC relative to organic manures and cover crops.

Looking at organic manure and its relation to SOC in terms of the organically managed year, there is a constant increase in SOC as the number of years passes. It means there are not much more impacts on SOC after adding organic manures and amendments for a long time. From fig... it can be seen that SOC is increasing simultaneously throughout the organically managed years with mere year to year variation. The addition of organic manures does not show any relation with the number of years, whether it is one month or ten years of using organic manures.

In the case of cover crops, SOC increases but at a decreasing rate as the number of managed years passes. It implies that there are no more impacts on years, whether it is one month or ten years of inclusion of cover crops to enhance soil carbon contents. Also, the year to year variation seems to be increasing at decreasing rate.

Mixed effect model

The result of the mixed-effects model is associated with the SOC of topsoil subgroup analysis. The model took into account the effect sizes of different farming techniques on SOC concentrations. The response variable was effect size for all treatments, where the number of years was considered as fixed effects and focal agriculture practice (cover crops, no-till and organic amendments) as random effects.

Table 2 Result of the mixed-effects model is associated with the SOC of topsoil subgroup analysis

Fixed effects	β	SE	Lower-95	Upper-95	Random effect	Random effects σ2
Organically managed Years	0.00103	0.01164	-0.0218	0.02383	Focal agriculture practice	0.09289

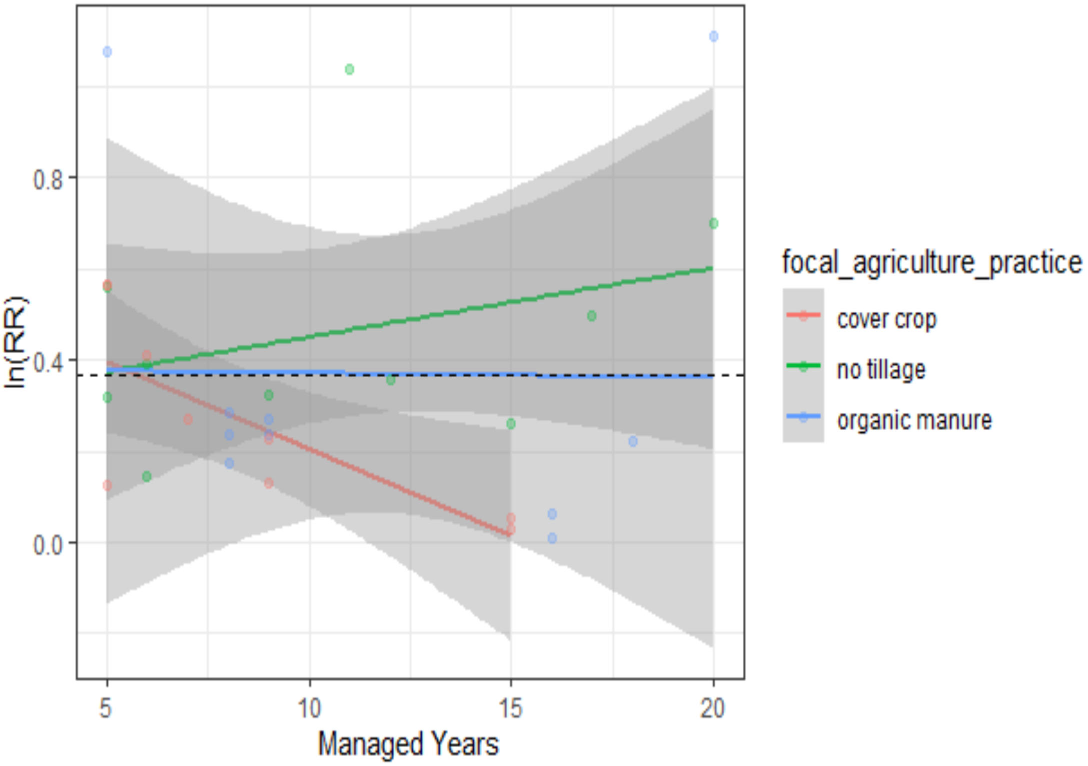


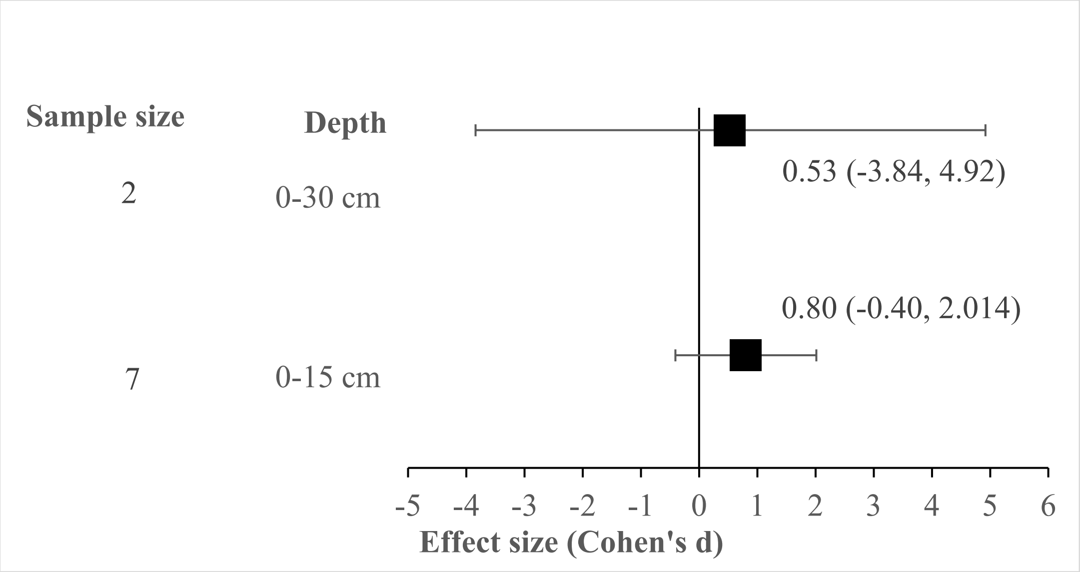
Figure 2 Mixed Effect Regression Model

Mixed-effects regression model with effect sizes (ln[RR]) listed along the y-axis. In the mixed-effects model, the fixed effect was set as organically managed years and the random effect as the focal agriculture practice. Focal agriculture practice explained approximately 22 % of the variation not accounted for by the organically managed years (REML criterion at convergence= 22.36).

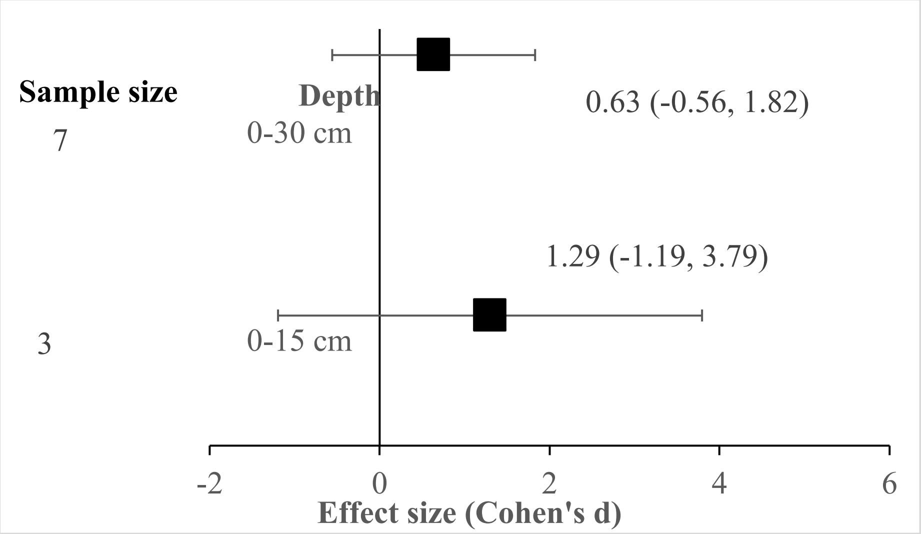
3.2. Management practice and soil sampling depth effects on SOC

When SOC was analysed in terms of soil depth, it suggested that no-till practice increases SOC in both soil depth from 0-15cm and 0-30cm, but a highly significant increase of SOC was observed on the top layer of soil profile from 0-15cm as shown in fig.3 (B). Compared to the other two practices, no-tillage has the highest SOC storage and soil carbon was more pronounced to increase in 0-15cm depth of soil. Cover crops also show a significant increase in SOC. The effects are more observed in 0-15cm of soil than in 0-30 cm. A slight increment was observed in SOC with the addition of organic manures and amendments. On the topmost soil layer from 0-15cm, it showed a significant increase in soil carbon compared to a soil depth of 0-30cm. From the fig.3(C), it is observed that when the depth of soil increases, it will bring about a substantial decrement in SOC regardless of the agricultural practice adopted.

A) Cover crop



B) No Tillage



C) Organic Manure

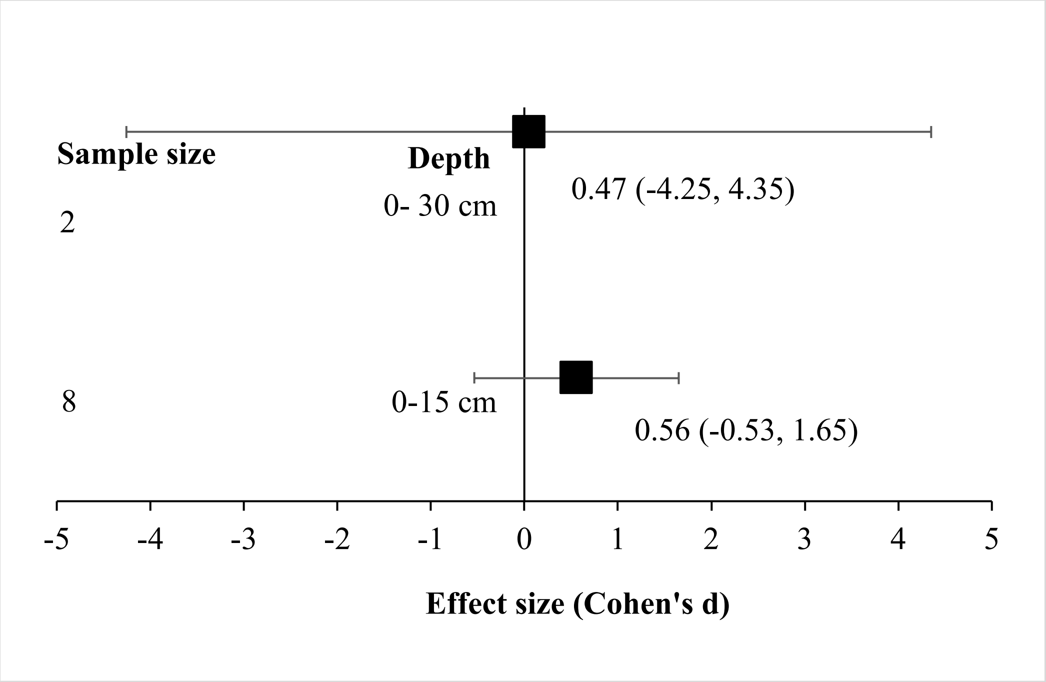


Figure 3 Mixed effect meta regression study of SOC under different soil sampling depth

The results of a mixed-effects meta-regression study shown in fig.3 indicate the effects of different focal agriculture practices on SOC concentrations in different sampling depths. (A)cover crop, (B)no-tillage, (C)organic amendment.

3.3. Focal Management Practices and Numbers of Years Changes in SOC

Focal agriculture management practices had a positive effect on SOC concentrations as there was a 22% increase in SOC compared to initial carbon storage. All practices show significant positive relation to SOC. When the combined effect of soil depth and a number of managed years were studied, cover crops showed a more significant relation with SOC.

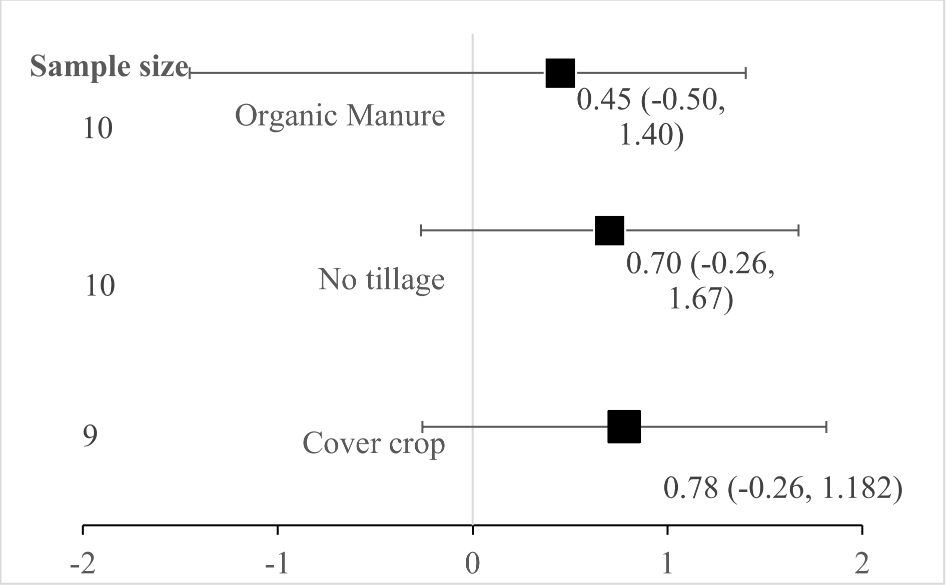


Figure 4 Mixed -effects meta regression combined study for best management practice of SOC

The results of the mixed-effects meta-regression study revealed that focal agriculture practice had a positive effect on SOC concentrations. The mean effect sizes were significantly different when the confidence intervals did not coincide with zero. Dots in the forest plot revealed more precise measurements.

4. Discussion:

This analysis gives information about the long term development of soil carbon influenced by different agriculture practices in different soil depths and years. The positive effects of various factors such as no-tillage, crop residue addition, and manure or compost application have been studied on the accumulation of SOC in cropping systems.

4.1. No-tillage drive changes in SOC

The results of our study support the idea that no-tillage helps conserve the organic carbon and is the most effective way to improve soil biological and chemical health and build resilient agricultural systems. The reduction in tillage intensity was compared with the reduction in deep inversion tillage. The data indicated that soil C stocks increased as a result of both the reduction in tillage intensity. No-tillage could lose the total yield by which the carbon sequestration process would slow down, and weeds occurrence would be increased. Conservation tillage is typically not used in organic farming systems. This practice could limit crop yields(J. Cooper et al., 2016). Mechanical tillage practices can increase greenhouse gas emissions and energy consumption. It also saves both time and labour. According to (Modak et al., 2020), Plots under ZT had ~38% higher SOC content than CT plots.

An analysis of the annual change in SOC in response to no-tillage shows that most change occurs in the first 10 to 15 years (West & Post, 2002). The increasing popularity of no-tillage (NT) is helping farmers reduce their soil erosion and production costs. It also helps them retain their productive land. About 23% of soil carbon increase was recorded in topsoil in(0-5cm) Zero tillage practice compared to conventional tillage, but there was no significant increase of SOC at 30-60 cm. (Modak et al., 2020). Soil organic carbon (SOC) under ZT has increased in many cases compared to the control condition (CT). The reduction in soil disturbance could cause this phenomenon.

Complete and depth tillage can cause soil compaction below the depth of the soil, which can also contribute to the development of wind and water erosion. It can also generate energy costs to increase. Due to the lack of mechanical soil disturbance, agricultural management has been able to mitigate some of the negative impacts on soil's physical and biological properties and conserve SOC.

4.2. Cover crops practice and change in SOC

Cover crops can help slow down climate change by increasing soil organic carbon. This environmental benefit can be achieved through no-tillage systems and the use of cover crops. Cover crops are beneficial for increasing soil organic carbon because they do not cause a decline in yields or emissions. They also do not contribute to the carbon losses experienced by other systems.

Instead of allowing a period of dormancy, cover crops should be included to increase the soil organic carbon stock, which can help compensate for the emissions caused by greenhouse gases. By replacing the bare period of dormancy with a period of carbon assimilation, cover cropping can improve the ecosystem's carbon balance (R Lal, 2001). The effect of the cover crops on the surface horizons was positively correlated with the annual change in the SOC stock. However, the effect of the cover crops decreased with depth. In the analysis, as the number of years increased, the effects were less, and the SOC contained in soil was increasing at decreasing rate.

(Poeplau & Don, 2015) also revealed that 13 plots reduced the carbon stock out of 139. The depletion of SOC might be caused by the addition of decomposable plant material, which can help break down the old compounds in the soil. Also, the energy needed to break down the old SOC can be used by the microbes. For the benefit of soil, the high input of crop debris into the soil, combined with the use of cover crop treatments, resulted in increased soil organic matter and carbon (Omay, Rice, Maddux, & Gordon, 1997)

Soil management can affect the development and functioning of soil microorganisms. It can also alter the spatial distribution and quantity of plant residue in the soil. Organic matter is more distributed in conventional systems than in non-conventional systems. In addition, mulching can increase the activity of enzymes in the soil. (Balota, Colozzi Filho, Andrade, & Dick, 2004). All cover crop species exhibited positive effects on the soil moisture and the C/N ratio in the uppermost layer of the soil. The highest increase in C stocks was seen in millet compared to other grasses and sunn hump plants at 0-10cm. From this, it can be said that the different grasses and crops have different impacts and effects on soil carbon conservation. Grasses increase the total carbon than leguminous crops in the short term, but the leguminous crops help increase the C:N ratio that enhances the higher carbon store for the long term (Rosolem et al., 2016).

4.3. Organic amendments addition and changes in SOC

The SOC concentration in surface soil and the storage of the SOC was not significantly changed by the 30 years of fertiliser treatments. The large-scale implementation of the combined organic matter and fertiliser treatments helps enhance the soil's carbon sequestration capacity. The use of NP+FYM was the most efficient method for sequestering SOC. Soil microbes were also more abundant under organic manure and fertilisers than in the control group, (E. Liu et al., 2013). The study also revealed that there was a constant increment of SOC from the first year of added manures. The organic C contents decreased due to the increasing soil depth. These changes were also correlated with the changes in SOC. Crop residue or adding farmyard manure with inorganic fertilisers to the soil surface can help improve the SOC level. Large-scale implementation of these practices can help improve the soil's condition and sustainable food production. After seven years of study, the results of the studies revealed that the combination of organic and inorganic fertilisers resulted in a higher amount of carbon accumulation on soil than those under control. Other studies also indicated that the use of organic manure could improve the physical properties of soil Fields(Bhatia & Shukla, 1982). Several long-term experiments have shown that the increase in soil organic carbon (SOC) under organic management is due to the addition of nutrients through the plant roots and the resulting increase in organic matter (OM). Another factor contributing to the increase in SOC is the slow decomposition of native and applied OM due to the high inherent SOC (Ladha, Khind, Khera, & Bueno, 2004; Lotter, 2003).

Another study revealed that the combination of chemical fertilisers and biogas slurry affects the SOC significantly, can increase the soil microorganisms content and improve crop productivity. It can also promote the growth and development of roots and microbes (Zheng et al., 2017). The organic agriculture practice significantly improved the activity of the C-cycle and microbial enzymes in soil. This resulted in the stabilisation and decomposition of organic matter.

(Benbi et al., 2018) observed that 11 % of the added C in soil that is organically managed for production has higher organic matter stocks than the conventional ones because the organic amendments, which FYM mainly generates, contribute to the increase in organic matter in the soil.

4.4. SOC, climate change and food security

Human activities are the main reason for the rise in CO2 emissions. Volcanic eruptions and permanently frozen soil contribute to the emissions of CO2. These activities are considered natural resources that help keep the Earth in balance. However, as CO2 emissions from non-natural sources continue to increase, this imbalance is becoming more apparent. Soils with higher SOC stocks are more productive and resilient to extreme weather conditions because higher levels of SOC can stimulate the development of higher biological activity and improve the soil's resilience. Despite the various factors that can improve the efficiency of cropping systems, the lack of comprehensive data on SOC in the region is the biggest challenge to increasing its sequestration. Soil organic carbon is a vital component of the ecosystem. As the climate changes, more carbon will be absorbed by the atmosphere instead of the soil. This feedback loop could contribute to climate change. High organic carbon soil types are more productive and can filter and purify water. Soils that have a high carbon content are also beneficial for the environment. The water that comes from the soil is the primary water source for around 90% of the world's agricultural production. It is also vital to preserve and restore it for future generations (Moshiri, Samavat, & Balali).

4.5. SOC management strategy

One of the essential strategies to reduce greenhouse gas emissions is the use of soil organic carbon.|Identification of the potential opportunities and challenges that can be utilised in the study of this strategy. The steps taken toward implementing the global-scale soil-climate-mitigation strategy are complex, diverse and take time. The SOC sequestration process involves managing different soil groups in different climate regions. Thus, it is crucial to establish a well-defined framework for implementing it. The complexity of the process requires that a wide range of stakeholder groups supports the various actions needed to implement it, which can be done through the development of effective multidisciplinary programs. The future storage of carbon in agricultural fields depends on the actions taken by farmers to increase their organic matter input relative to the current CO2 release and maintain their C stocks by implementing good agricultural practices (Amelung et al., 2020).

To achieve a sustainable agricultural system and eco-friendly environment, farmers need to adopt sustainable practices, and deep rooting crops and forages can conserve organic carbon well.

Using cover crops as green manure could help increase soil carbon sequestration. It could reduce global greenhouse gas emissions. Agroforestry systems can help sequester carbon by storing it in trees and reducing greenhouse gas emissions from the soil, and they can save around seven tones of carbon per year (Kim, Kirschbaum, & Beedy, 2016).

The most crucial factor that can be considered when it comes to improving soil organic matter is the management of perennial crops, such as legumes and grasses, which can help increase the organic matter in the soil and prevent water shortages through the development of effective multidisciplinary programs. Soil organic C storage can help improve fertility and crop yields through targeted interventions in regions. These include small-scale joint actions and the establishment of a sustainable soil management strategy among farmers.

5. Conclusion

This study revealed that no-tillage was the best option for managing soil organic carbon and provided a comprehensive analysis of the various effects of crop residue, tillage, and nutrient management on SOC sequestration. It also identifies the potential opportunities and challenges that can be utilised in the study of this strategy Cover crops can help reduce nutrient leaching and improve the efficiency of water and soil by acting as natural barriers to pests and diseases. They can also help prevent water erosion and improve the quality of life for all. Although cover crops are an essential management option for increasing SOC stocks in agricultural soils, their precise effects have been poorly studied. The use of cover crops has been shown to improve the fertility and biological activity of the soil. However, it is not clear how these activities affect the overall system. Various factors can affect the soil's health, such as its type, management practices, and weather conditions.

This study aimed to investigate the effects of long term fertilisation on SOC fractions. The importance of soil colonisation is also related to the accumulation of carbon in the soil. This issue is essential for further studies to determine the relationship between different agriculture practices and soil C resilience. Inorganic fertilisers with FYM and manures can also help improve the soil condition by adding nutrients to the surface. Large-scale implementation of this practice can help improve the soil' organic matter and long term food production. Local governments and agriculture research projects should encourage farmers to adopt integrated nutrient management practices to improve soil fertility and reduce greenhouse gas emissions, which can help boost crop productivity and reduce greenhouse gas emissions. Understanding the various effects of farming practices on soil organic carbon (SOC) is very important for reducing greenhouse gas emissions and improving soil productivity. Understanding the effects of different tillage systems, cover crops, and the addition of organic amendment on the soil organic matter dynamics is essential in developing effective strategies to improve the soil fertility and sequester carbon.

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