# Extended Essay

## The Impact of Sustainable Soil Management (SSM) Practises in Improving Soil Quality

Word count -3927

Topic: Soil Degradation and Sustainable Soil Management Practices

Research question:

To what extent do before and after sustainable soil management (SSM) practices (minimizing soil erosion, enhancing soil organic matter content, fostering soil nutrient balance and cycles, preventing and minimizing soil salinization and alkalinization, preventing and minimizing soil contamination, preventing and minimizing soil acidification, preserving and enhancing soil biodiversity, minimizing soil sealing, preventing and mitigating soil compaction, improving soil water management) affect the percentage of organic matter in soil in Yozgat Province?

Thesis:

Sustainable soil management (SSM) practices will significantly increase the percentage of organic matter in soil which plays a central role in maintaining soil functions and preventing soil degradation.

## Contents

# 1. Introduction

About 95% of our food is grown on the world's largest terrestrial carbon reserve which is soil. Sustainable Soil Management (SSM) is a very useful tool for adapting to climate change and preserving critical ecosystem services and biodiversity. Given the immeasurable value of the soil for the people and the societies it is quite important to take care of this valuable source. Sustainable soil management practices offer a high return on investment by boosting the effectiveness of the soil. The applications of sustainable soil management practices bring countless benefits to people, especially to the small-scale farmers and large-scale producers of agricultural products worldwide who directly on the use of soil.

The Status of the World's Soil Resources (SWSR) report[1], prepared by the FAO, indicates that approximately 33% of global soils are moderately or severely degraded due to unsustainable management practices. Globally, it's estimated that an annual loss of 75 billion tons of soil from arable land costs around USD 400 billion each year[2] in lost agricultural production. This loss also considerably diminishes the soil's ability to store and cycle carbon, nutrients, and water.

On the other hand, with the signing of the Paris Climate Agreement, the provisions that countries must comply with and the commitments they have made are increasing the importance of SSM practices for adaptation and mitigation of climate change, as well as protecting and increasing the quality of soils. Therefore, this essay has tried to compare the effects of SSM practices by evaluating the results of the applications made on the percentage of organic matter in the soil.

# 2. Sustainable Soil Management (SSM) Practices

## 2.1 Organic Matter and the Importance of Soil Organic Matter in a Healthy Soil

Organic material in soil refers to carbon-based compounds. These compounds can be found in nature quite abundantly. Living beings are labeled as organic because they consist of these carbon-based compounds. Nucleic acids, proteins, carbohydrates, and lipids are prime examples of these carbon-based compounds in nature. When living organisms die and decompose their components which contain carbon-based components break down into substances through decomposition. These organisms which contain carbon-based compounds also release materials through excretion or secretion which become a part of the environment. This results in organic matter being prevalent in the ecosystems such as the soil

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[1] Status of the World's Soil Resources - Technical Summary https://www.fao.org/documents/card/en?details=i5126e 21/08/2023

[2] Reaping economic and environmental benefits from sustainable land management, The Economics of Land Degradation (ELD) https://www.greenpolicyplatform.org/sites/default/files/downloads/resource/ELD_economic_environmental_benefits_land_management.pdf 23/08/2023

ecosystems. It transitions into the soil or water bodies where it becomes a source of nutrition for life forms.

Organic material can be transferred to water bodies, soil, and sediment. It also plays a role in the formation of coal and the formation of kerogen.

Soil organic material comes from plants such as leaves and woody materials, animals (including the remains of dead animals that are decomposing in the soil), and microorganisms. The presence of soil organic material is vital. It provides nutrients to crops and garden plants while also aiding in the retention of water and fostering the activity of soil microorganisms and earthworms. Also soil organic material helps the soil to maintain a healthy pH level, temperature, and air circulation.

Organic material in the soil provides benefits to forestry production. Soil that has a good amount of soil organic materials has a better ability to prevent and combat soil-borne diseases. Soil organic material can play a role in improving the fertility of the soil and quality of the soil in three ways;

Chemical; Soil organic material enhances the capability of the soil to store significantly. It also helps with the supply of nutrients like nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium and retaining harmful elements. It aids the soil when it adapts to changes in acidity. Acceleration of the decomposition of soil minerals is also increased.

Physical; Organic material in the soil enhances the structure of the soil, which in return helps in controlling erosion, improving water infiltration, and increasing water retention capacity. This creates ideal living habitat conditions for plant roots and the organisms in the soil.

Biological; Soil organic material can be a source of carbon © that provides necessary energy and nutrients for soil organisms. This increases the functionality of the soil by increasing the activity of microorganisms. This leads to biodiversity. By sequestering carbon in the soil emissions of $CO2$ into the atmosphere are reduced. This helps to mitigate climate change.[4]

## 2.2 Definition and Importance of SSM Practices

The definition of SSM has evolved since the 1980s to adapt to changing conditions. The most current and widely accepted definition was revised by the FAO at a conference in 2015, which was organized to celebrate the International Year of Soils.

The definition is;

"Soil management is sustainable when the supporting, provioning, regulating, and cultural services which is provided by soil are maintained or enhanced without drastically changing the functions of the soil that allows those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil

[4] *The importance of soil organic matter*. (n.d.). https://www.fao.org/3/a0100e/a0100e04.htm 13/09/2023

provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern”.[5]

SSM practices are important because they provide a 'One-Stop Solution' for soil, plant, carbon sequestration, greenhouse gas emission (GHG), climate change, and environmental problems.

## 2.3 Sustainable Soil Management (SSM) Practices

There are ten crucial factors to consider for effective Soil and Water Management (SSM), with different practices under each one. Given the broad scope of the topic, this article will focus solely on the enhancement of soil organic matter and its practices.

The 10 important factors are (i) minimizing soil erosion, (ii) enhancing soil organic matter content, (iii) fostering soil nutrient balance and cycles, (iv) preventing and minimizing soil salinization and alkalinization, (v) preventing and minimizing soil contamination, (vi) preventing and minimizing soil acidification, (vii) preserving and enhancing soil biodiversity, (vii) minimize soil sealing, (ix) preventing and mitigating soil compaction, (x) improving soil water management.

## 2.4 Enhancing Soil Organic Matter (SOM) Content

SOM is crucial for maintaining soil functions and preventing soil degradation. Soils are an indispensable source of carbon in the world and play a vital role in climate regulation and climate change mitigation through the balance between greenhouse gas emissions and carbon sequestration. Hence, SOM is vital for climate change adaptation and mitigation. Inappropriate land use, poor soil management, or ineffective cropping practices can result in Soil Organic Carbon (SOC) loss, leading to decreased soil quality and structure, increased soil erosion, and potentially causing carbon emissions into the atmosphere. Conversely, proper land use and soil management can enhance SOC and improve soil quality.

Multiple instances have shown the feasibility of restoring organic matter levels in soil. Techniques such as composting, implementing cover crops or green manure crops, crop rotation, planting perennial forage crops, practicing zero and reduced tillage, and adopting agroforestry can promote the accumulation and enhancement of soil's organic matter content.

**Composting:** Composting is the natural process of 'rotting' or decomposition of organic matter by microorganisms under controlled conditions. Raw organic materials such as crop residues, animal wastes, food garbage, some municipal wastes, and suitable industrial wastes, enhance their suitability for application to the soil as a fertilizing resource, after having undergone composting[6].

[5] Revised World Soil Charter, June 2015 https://www.fao.org/3/I4965E/i4965e.pdf 13/09/2023 13/09/2023
[6] https://www.fao.org/3/y5104e/y5104e05.htm 5/11/2023

Composting enhances the soil's physico-chemical and biological properties. This makes the soil more resistant to stresses like drought, diseases, and toxicity. It also aids in the improved uptake of plant nutrients and promotes active nutrient cycling.

**Implementing green manure cover crops (GMCCs):** Plants that are grown to provide soil cover and to improve physical, chemical, and biological characteristics of the soil are named green manure/cover crops (GMCCs). GMCCs may be sown independently or may be shown in association with crops. Generally, soil cover for No-tillage (reduces water evaporation and the temperature of the soil, and also increases infiltration of water), protects soil from erosion, reduces the infestation of the weed, adds biomass to the soil, improving soil structure, reduce pest and disease infestation are provided by green manure/cover crops[7].

**Crop rotation**: Crop rotation is a technique used by farmers to enhance the quality of soil maximize levels and tackle issues related to pests and weeds. The process involves planting crops in sequence, on the land.

To illustrate this, let's consider a scenario where a farmer grows corn in one field. After the corn harvest is complete, the farmer might decide to plant beans. This decision is due to the fact that while corn depletes nitrogen from the soil, beans replenish it. Crop rotation can be as simple as rotating between two or three crops or as intricate, as incorporating a dozen or more crops in a pattern. This agricultural practice also disrupts pest and disease cycles improves soil health by increasing biomass through crop root structures and promotes biodiversity on the farm. The diversity of plant life, above ground attracts insects and pollinators while enhancing the thriving ecosystem in the soil.[8]

**Planting perennial forage/grain crops;** The rise of grain crops offers a promising strategy to enhance the diversity and benefits of agricultural landscapes. By combining cropping methods, with perennial grains that have unique growth patterns and management techniques there is potential for increased soil organic matter (SOM) accumulation. Perennial cropping systems, which involve practices like no tillage management, growing seasons and deep root systems can contribute to carbon storage in the soil profile[9].

**Embracing agroforestry;** Agroforestry refers to integrated land use systems where trees, shrubs, palms, bamboo along, with crops or livestock are intentionally grown together in a manner.By combining the cultivation of crops and livestock, with tree planting this approach offers the opportunity to broaden and enhance farmers yields by offering food, wood, fiber and medicinal resources. Additionally it brings about advantages like improved soil quality, erosion prevention, water management, carbon capture, biodiversity preservation and resilience, against calamities.[10]

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[7] Green manure/cover crops and crop rotation in Management Agriculture on small farms https://www.fao.org/3/i2190e/i2190e00.pdf 12/01/2024

[8] Crop Rotations - Rodale Institute. (2020, December 15). Rodale Institute. https://rodaleinstitute.org/why-organic/organic-farming-practices/crop-rotations/ 17/01/2024

[9] Soil organic matter pools response to perennial grain cropping and nitrogen fertilizer, Soil and Tillage Research Volume 220, June 2022, https://www.sciencedirect.com/science/article/abs/pii/S0167198722000629 17/01/2024

[10] Agroforestry and tenure, FAO https://www.fao.org/3/CA4662en/CA4662en.pdf 17/01/2024

## 3. Methods of Investigation

During the preparation of the essay, the soil analysis samples taken within the scope of sustainable soil management practices carried out by the General Directorate of Forestry (OGM) Kayseri Regional Directorate in Yozgat province were used. Some of the soil analyses belong to 2015 and 2016 before the SSM practices and belong to 2023 after the application of SSM practices. Soil analyses were carried out both by the OGM Kayseri Regional Directorate in the laboratories of the research institute and in some private laboratories. All laboratories where analyses are performed are laboratories certified by the Turkish Accreditation Agency (TÜRKAK).

Ssecondary sources were consulted to understand the process of soil analysis and the parameters examined. A wide range of literature reviews were conducted by both local and foreign sources to understand the technical aspects of the soil analysis. This specific data set was used because of these soil management practices were carried out by the General Directorate of Forestry (OGM) Kayseri Regional Directorate. The General Directorate of Forestry (OGM) is a very trusted government source so it is an extremely reliable source to use.

The soil analyses included an examination of Nitrogen, Organic Matter, Lime (CaCo3), pH, EC, and Salinity values. However, this research focused on comparing the amount of soil organic matter and nitrogen, which showed the most significant impact from the SSM applications.

During the research, interviews were conducted with officials from both the General Directorate of Forestry and the General Directorate of Desertification and Erosion Control to gather information on SSM practices. Additionally, expert opinions were collected through interviews with soil experts at the Food and Agriculture Organization (FAO) based in Rome through online meetings, and these insights were used as reference sources.

In the comparative interpretation of soil analysis results, the Analysis of variance (ANOVA) test was applied. ANOVA is a statistical technique used to check if the means of two or more groups are significantly different from each other. ANOVA checks the impact of one or more factors by comparing the means of different samples.

The data set used was obtained from the General Directorate of Erosion and Desertification and is the data of official offices.

## 4. Data and Analysis

The organic matter content in the soils of Yozgat province is known to be low. According to the Yozgat fertilization guidelines prepared by the Ministry of Agriculture and Forestry, 39.2% of the province's soils contain very little organic matter, while 60.8% contain low levels of organic matter. For soils with an organic matter content below 2%, it is recommended to apply Soil Specific Management (SSM) to address this deficiency.

| Soil Analyses Trials | Organic Material Percentage Before Soil Management Practices (%) ±0.01 | Organic Material Percentage After Soil Management Practices (%) ±0.01 |
|---|---|---|
| 1 | 1.36 | 2.38 |
| 2 | 0.73 | 0.9 |
| 3 | 1.15 | 1.00 |
| 4 | 0.79 | 3.06 |
| 5 | 1.73 | 1.58 |
| 6 | 0.52 | 1.53 |
| 7 | 1.57 | 2.43 |
| 8 | 2.93 | 2.22 |
| 9 | 0.31 | 2.91 |
| 10 | 1.26 | 1.21 |
| 11 | 1.36 | 1.11 |
| 12 | 1.88 | 1.00 |
| 13 | 0.47 | 2.11 |
| 14 | 0.47 | 1.90 |
| 15 | 1.05 | 1.48 |
| 16 | 0.97 | 3.27 |
| 17 | 1.20 | 1.48 |
| 18 | 0.37 | 0.69 |

*Table 1 Comparison of the soil before and after soil management practices*

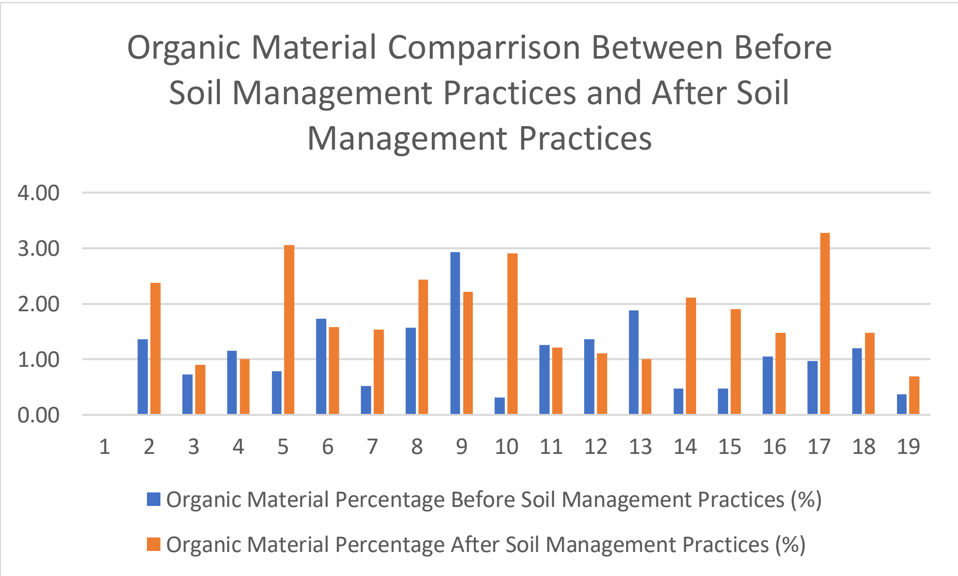


*Figure 1 Organic Material Comparison Between Before Soil Management Practices and After Soil Management Practices*

## Mean and Standard Deviation

Calculation of the mean provides a measure for the central tendency, showing the typical value in the data set in hand. The standard deviation measures the spread of the data around the mean. It shows how the data points deviate from the average. Both of these values help to understand the distribution and reliability of the available data. So both of these values are quite vital for the experiment.

$$\text{Mean} = \frac{\sum_{i=1}^{n} x_i}{n}$$

"xi" represents each individual data point.
"Mean" is the mean (average) of the data points.
"n" represents the total number of data points.
"Σ" denotes the sum of all squared differences between each data point and the mean.
"√" denotes the square root of the result obtained from the sum of squared differences divided by the number of data points.

The sum of central values:
1.36+0.73+1.15+0.79+1.73+0.52+1.57+2.93+0.31+1.26+1.36+1.88+0.47+0.47+1.05+0.97+1.2+0.37

The sum of central values = 22.99

Number of measurements = 18

Mean = Sum of central values / Number of measurements

Mean = 22.99/18≈1.2772

$$\text{Standard deviation} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \text{Mean})^2}{n}}$$

Where:

Xi represents each of the individual points of data
Mean is the average of the points of data
n is the number of data points available
The sum of all squared differences between the each data point and the mean is given by Σ

The graph and data table above shows the percentage of organic material percentage in soil before soil management practices and after soil management practices. The organic material percentage ranged from approximately 0.31% to 2.93%, before the use sustainable soil management practices. This shows that there is variability in in the soil organic material percentage across the different trials. An increase in the soil organic material percentage after the use of sustainable soil management practices is observable as the range of the data is approximately 0.69% to 3.27%.
This increase in the soil organic material percentage suggests that soil management practices had an positive impact on the soil organic material percentage. The mean of the organic

material percentage also increased from approximately 1.19% to 1.76% after the use of these practices.

The variability in organic material percentages before and after soil management practices can be because of several factor. Some of these factors are soil composition, environmental conditions, and the specific types of management practices implemented across different trials. Overall, the mean increase in organic material percentage suggests a positive response to soil management practices.

Despite the fluctuations in the column of “Organic material percentages before the use of soil management practices”, it is easy to observe that the percentages of organic matter in soil are pretty low. The differences in the percentage of organic matter in soil can be due to variability in soil heterogeneity, microclimatic and weather patterns, management practices, and biological activity. Also the average organic matter content, in the soil samples analyzed is 1.07% indicating a level of organic material present. Half of the trials have organic matter percentages than 1.05% as shown by the value. While the specific common percentage isn't given, examining the distribution could reveal any patterns or groupings. The range of matter content across the trials varies from 0.31% to 2.93% displaying a difference of 2.62% between the lowest values. This diversity is further explained by the deviation, which measures how each data point deviates from the mean and is around 0.69%. The coefficient of variation representing the deviation as a percentage of the mean is 64.49% indicating a moderate level of dispersion compared to the mean value.

Similarly to the soil before soil management practices the organic material percentages after the use of soil management practices fluctuate quite much. The differences in the percentage of organic matter in soil can again be due to variability in soil heterogeneity, microclimatic and weather patterns, management practices, and biological activity. The average percentage of matter, in all the trials gives an idea of how much organic material is present overall. Finding the median, which is the value when the data is arranged in order helps to understand the central tendency of the dataset and provides a typical organic matter percentage. Identifying the mode, which is the common organic matter percentage reveals common patterns in the dataset and shows typical levels of organic material content. Moreover calculating the range, which indicates how variation there is between the lowest organic matter percentages demonstrates how diverse the data is and reflects different levels of organic material content. Additionally working out the deviation and variance gives insights into how spread out organic matter percentages are around the average value showing whether there's consistency or variability in organic material content in soil samples. These statistical analyses together give an understanding of soil matter content helping guide decisions, on agricultural practices and environmental management effectively.

| | Mean | Standard Deviation |
|---|---|---|
| Organic Material Percentage Before Soil Management Practices (%) ±0.01 | 1.19% | 0.54802 |
| Organic Material Percentage After Soil Management Practices (%) ±0.01 | 1.76% | 0.77988 |

*Table 2 Comparison of the means and standard deviation of the soil before and after soil management practices*

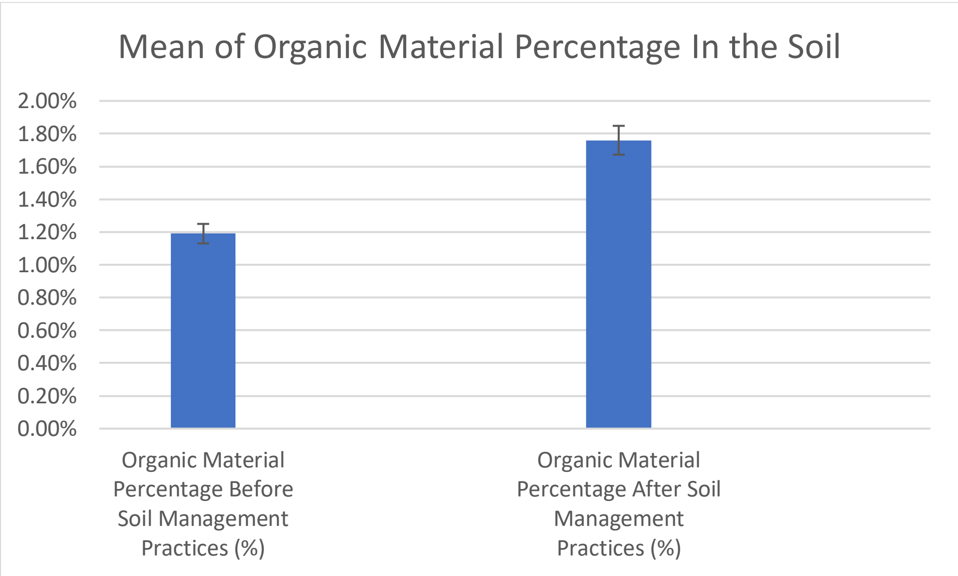


*Figure 2 Mean of Organic Material Percentage In the Soil*

An ANOVA test was also conducted to better analyze and interpret the results of these soil analyses.

| F Statistic | **P-value** |
|---|---|
| 7.8J18 | 0.0083£i9 |

| **Source** | DF | Sum of 5quare | Mean Square |
|---|---|---|---|
| Groups (between groups) | 4 | 4.0939 | 4.0935 |
| Ezcor (within groups) | 34 | 17.75 | **0.5221** |
| Total | 35 | 21.OM39 | **0.6241** |

*Table 3 ANOVA test results*

1. Based on the findings we reject the assumption (H0) since the p value is less, than α. This suggests that some groups have values indicating a statistically significant difference in sample averages among certain groups.

2. The p value is calculated to be 0.00835864, with a probability of $p(x \le F) = 0.991641$. This implies a chance of committing a type 1 error (incorrectly rejecting H0) at 0.84%. A smaller p value provides evidence in favor of the hypothesis (H1).

3. The test statistic F is determined to be 7.841771 falling outside the 95% confidence interval range; [0 ; 4.13].

4. With an effect size f of 0.48 it signifies a substantial difference in averages between groups.
The coefficient $\eta^2$ is calculated as 0.19 indicating that the group accounts for 18.7% of the variance from the value (similar to $R^2$ in linear regression).

5.The Tukey Honestly Significant Difference (HSD) or Tukey Kramer test reveals differences in means, between pairs x1 and x2.

The ANOVA test results show that there is a statistically significant between the means of the groups. This can be understood by the obtained p-value of 0.008359. This result will result in the rejection of the null hypothesis (H0). This suggests that at least one group's average is different from the other one. So the variation observed in the data is not due to random chance alone, but rather due to the effect of the independent variable (groups).

The effect size, as shown by Cohen's f and eta squared ($\eta^2$), which further shows the significance of the observed differences. The effect size f of 0.48 is a large effect size. This indicates the substantial magnitude of difference between the averages of the group. Similarly, the eta squared value of 0.19 suggests that approximately 18.7% of the variance in the dependent variable (outcome) can be explained by the grouping variable (independent variable).

Specific pairs of group mean that are very different from each other, can be identified by the Tukey Honestly Significant Difference (HSD) also known as the Tukey-Kramer test which is generally used for post hoc analysis in the test of ANOVA. In this experiment, the means of the pair x1-x2 are quite different. This difference suggests that there is a big contrast between these two groups in terms of the dependent variable.

To sum up, these values show that there are meaningful differences between the groups regarding the outcome variable under investigation. So it is fair to say that soil management practices have a considerable impact on the percentage of organic matter in the soil.

## 5. Conclusion

The general idea of soil management practices is to optimize soil health and productivity. While doing this soil management practices also minimize the effects on the environment. The practices aim to enhance soil fertility, structure, and moisture retention while reducing erosion and nutrient loss. Soil management practices can not completely fix the quality of of the soil. However, they can drastically assist in growing better crops. Ultimately, these management practices aim to support sustainable agriculture by ensuring long-term productivity and the health of the ecosystem. After learning about the soil management practices and their effect on the soil and environment, I came to the conclusion that soil management practices are a viable option when battling with the deficiency of organic material percentage in the soil at hand. Therefore, I hypothesized that sustainable soil management (SSM) practices will significantly increase the ratio of soil organic material. This thesis of mine is proven to be true through this investigation. The use of sustainable soil management (SSM) practices has increased the organic material available in the soil. Therefore, this increase in organic material facilitated plant growth by improving and enhancing nutrient validity. They release essential nutrients, ultimately leading to improved crop yields.

Moreover, the effect of soil management practices on the organic material percentage in this region serves as a successful example and guide as to how to increase the organic material percentage in other regions which is suffering from the same issue. The use of sustainable soil management practices not only increased the organic matter percentage, it also improved crop yields. The use of sustainable soil management practices is truly detrimental to the soil. Unfortunately, it took the minimal organic material percentage to realize how important sustainable soil management practices are. Therefore, this investigation can be used as a reminder of how important sustainable soil management practices are when battling with environmental issues.

In addition to the benefits of sustainable soil management practices in soil health and the increase in agricultural productivity, the use of soil management practices also aids in mitigating the impacts of climate change. By storing carbon in the soil and increasing the organic material content, these soil management practices contribute to carbon-storing efforts. This in return will help mitigate greenhouse gas emissions which in return will combat global warming greatly. To add to this, the positive outcomes shown by the investigation that I did underline the importance of the adaptation of soil management practices. Through concentrated efforts and investments more sustainable agricultural practices can be used and environmental challenges can be overcome.

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