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Climate Change Mitigation through Agroforestry: Assessing Soil Quality and Organic Carbon Sequestration in Alfalfa-Cherry Systems of Gilgit′s Mountain Valleys

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Abstract

Purpose: Agroforestry can increase soil carbon and improve soil quality, so this study aimed to quantify soil organic carbon (SOC) storage and related soil properties in alfalfa–cherry and maize–cherry systems in Gilgit's mountain valleys for climate change mitigation. **Research design, data and methodology:** We compared Danyore and Sultanabad by sampling soils at 0–20 cm and 20–40 cm and measuring pH, electrical conductivity, moisture, bulk density, soil organic matter, SOC, and SOC stocks; we then compared patterns by valley, system, and depth and examined Pearson correlations. **Results:** Results showed higher SOC stocks under alfalfa–cherry than maize–cherry in Danyore at 0–20 cm (37.74 vs 28.13 Mg ha^{-1}), stocks generally increased with depth except for maize–cherry in Sultanabad, SOC correlated positively with SOC stocks, bulk density was higher in Sultanabad and increased with depth, and pH, moisture, and texture differed by site and system. In discussion, the greater stocks under tree-based systems align with continuous litter inputs and management effects that favor SOC protection, and the higher topsoil SOC reflects typical depth gradients in agroforestry soils. **Conclusions:** We conclude that alfalfa–cherry agroforestry enhances soil quality and increases SOC storage in this high-altitude region, supporting its use as a local climate mitigation strategy and warranting continued monitoring of SOC stability.

Keywords : Agroforestry, Alpha-cherry, carbon sequestration, Maize-Cherry, soil organic carbon

JEL Classification Code : O13, O44, Q15, Q54, Q56

1. Introduction

Soil is the biosphere's largest pool of terrestrial organic carbon, storing more carbon than plants and the atmosphere combined. Soil organic carbon (SOC) is thought to be important for many soil functions and ecological processes (Schjonning et al., 2018). One of the most important resources for the health and sustainability of ecosystems, including agroecosystems, is healthy soil. Although the

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agroforestry community has long been convinced of agroforestry practices' soil health benefits, many of these practices are still not widely accepted by the agricultural community. Agroforestry has shown solid evidence of its role in improving soil quality and health as a sustainable land management practice based on at least four decades of data gathered from around the world (DollingerandJose,2018). The ability of agroforestry to improve soil quality has been usually used (Nair, 2011). The land use soil and vegetation absorb about 30% of the carbon (C) emitted to the atmosphere through the burning of fossil fuel and cement production (Cardinael et al 2014). Agroforestry systems may store more soil organic carbon (SOC), than annual cropping systems because permanent woody vegetation continuously provides plant litter to the soil and tree removal occurs less frequently (Paul et al., 2002; Montagnini and Nair, 2004, Oelbermann et al., 2004; Lenka et al., 2012; Abbas et al., 2017).

There has been a resurgence of interest in soil health and quality as indicators of agricultural sustainability in recent years. Agroforestry practices have been promoted for years in both the tropics and temperate parts of the world because potential benefits of not only delivering various ecosystem services but also increasing soil quality (Jose 2009) Agroforestry methods lessen the harvesting strain on natural forests, they indirectly benefit soil carbon sequestration. Food insecurity can be addressed, CO2 Sequestration is increased, and agricultural systems are less vulnerable when shrubs and trees are incorporated into crop systems. Additionally, agroecosystems reduce the effects of climate change and serve as a farmer's adaptation tool (Gautam,2002). Soil organic carbon (SOC) stocks are impacted by land use changes. An ecosystem can function as a carbon sink or source while undergoing natural or human-caused changes, depending on the direction of the conversion. This issue is significant and frequently debated in relation to soil degradation, CO2 emissions, and from a purely academic perspective (Batjes, 2014). Soil being the largest organic carbon (SOC) pool in terrestrial ecosystems (Donetal.,2011), land use change (LUC) becomes a major concern of soil organic carbon (SOC) changes (Qin et al., 2016). SOC dynamics and carbon flow from the soil can be considerably influenced by land use and soil resources management strategies (Post and Kwon, 2000). According to the land usage and soil depths, SOC concentration varies widely in region (Begum et al., 2020). Indicators of soil quality are significantly impacted by land use changes, especially at the surface horizon. Due to intensive agricultural practices and the usage of inorganic fertilizers for the last three decades in western, Ethiopia, the soil forms of replaceable bases and the amount of readily available micronutrients were impacted (Achalu et al., 2012).

Agroforestry is a long-standing practice of integrating trees with agronomic crops or pasture to gain multiple benefits from a single piece of land management. Kalinganire et al. (2007) defined Agroforestry is "The deliberate integration of woody components with agricultural and pastoral operations on the same piece of land, either in a spatial or temporal sequence, to allow for both ecological and economic interaction. "The trees grown on farmland improve the efficiency of soil microclimate conditions. Agroforestry trees no only improve soil fertility, but they also protect us, our animals, and our homes from the hot sun in the summer and the cold winds in the winter (Simons and Leakey, 2004). The limitations of production from specific soils are influenced by management and quality standards. Thus, land resource inventories, assessments of degradation hazard, production capacity evaluations, improvements to soil fertility, land regeneration against desertification, and integrated land use planning are among the fundamental activities that support the promotion of the best possible use of the land (Baig et al., 2008). One of the main benefits of agroforestry in general is the role that trees play in improving soil. (Sanchez et al.,1997).

In research comparison, the productivity of crops grown on soils created under tree canopies and on control soils in open areas, the improvement of soil fertility by trees is evident (Craig and Wilkinson, 2004). Differences in soil fertility, as indicated by in situ crop productivity, vary depending on the location of the tree (Botha, 2006). Generally, soil has higher nutrient status under tree cover is reflected in the mineral content of understorey herbaceous species (Tonye et al.,1997). The stress on the soil caused by an ever-ending cycle of crop growth without allowing it to rest results in soil infertility. It is thus important to recognize that, in order to ensure optimum land use, the applicability of a country's land resource base for various amounts of inputs for various land uses, such as agriculture, forestry and grazing, should be evaluated. When trees are grown alongside agricultural crops and large herds of cattle are raised on the land utilizing the agrosilvopastoral system, this integrated land use is known as agroforestry, agrosilvopastoral activity, etc. in many developed and developing countries (Gebrehiwot, 2004). Since soils store a considerable amount of the world's carbon, it has a big effect on atmospheric carbon (Smith et al,.2008). It is estimated that a global total of 1500 Pg (Pg = petagram = 1015 g = 1 billion ton) C is stored in soil as compared to 760 Pg C in the atmosphere. Approximately 30- 50% of soil organic C (SOC) is lost due to intensive tillage practices, which can be restored by agroforestry (DavidsonandAckerman, 1993).

The management system of soil performance significant role in sustainable agriculture and the quality of environment. The direction and intensity of changes in soil characteristics are significantly influenced by management strategies. Degradation of the soil and a drop in quality may be caused by the conversion of an area from a natural environment to farmed land (Kilic et al.,2012). Dunjo et al. (2003). Observed the variations in the soil quality and its possible effect in the ecosystem. The most important effect in soil is the loss of organic matter of soil (SOM) due to excessive cultivation. This tremendous loss can be managed by the cultivation of trees and shrubs along agriculture crops. Trees in the farm enhance the biological process which enhances the efficiency of seasonal and long-term nutritional delivery through litter fell, root decomposition and exudation, and their mineralization, as well as leaching of nutrients stored in canopies. Based on the size of the tree, the soil can have different textures. The causes of these variances in tree size are unclear (Sangha et al., 2005). Improvements in the microclimate and increases in organic matter. Trees improve the physical, chemical, and microbiological qualities of the soil (Tian et al., 2001). This has two to three times more biological activity than open places. Trees may be able to catch fine soil lost to wind erosion and deposit it through stem flow and fall. Additionally, because of nitrogen fixation, trees improve soil nitrogen availability (N'goran et al., 2002). Bird droppings and livestock dung deposition from animals that rest and eat beneath tree shade may both contribute to increased fertility under trees. Where livestock is not present, the tree effect might be more noticeable than in agro-silvopastoral systems that are naturally present (Anon, 2000). Small trees produce substantially less organic litter and root turnover inputs, as well as little to no change in the soil's fertility. Larger trees had deposited excrement beneath them, whereas smaller trees did not. With increased tree size comes greater nutrient enrichment. Young trees don't seem to have much of an effect on the size of a nutrient pool, and the concentration of nutrients in sub-canopy soils rises with tree size (Brown, 2001). More thorough information is needed on the dynamics of soil fertility with expanding tree size in connection to the productivity of related crops. As enhanced nutrient availability from these stands has the potential to increase agricultural yields, recommendations on the size, age, and other aspects of tree stands are also required (Sangha et al., 2005). By decreasing nutrient losses due to soil erosion and deep soil leaching, trees may potentially boost system productivity (Dove, 2003). By boosting nutrient availability through nitrogen fixation, deep roots, and their increased absorptive capacity due to mycorrhizae and fungal infection, trees may increase the productivity of the whole system. There are restrictions on these processes, even if they may be significant in specific locations with suitable soil conditions and water availability (Botha, 2006).

1.1. Influence of Agroforestry on Soil Properties

Botha (2006) stated that the improvement of fertility of the soil through trees is a useful procedure. He also proposed that the soil under agroforest region is more productive and fertile than the open soil. Craig and Wilkinson, (2004) conducted a study to evaluate the soil fertility of agroforest region. For this purpose, they collect samples of different soil and examine their nutritional value. The study revealed that the soil under the agroforest region is more fertile than the soil other than forest regions i.e., open land soil. Tonye et al. (1997) stated that infertility of the soil is the result of the continuous crop growing cycle which inserts a pressure on the soil nutrient content. So, to overcome the said problem the technique of agroforestry should use, this technique is far better than the usage of synthetic fertilizer because it provides fuel wood in addition to improve the soil fertility level. It is essential to use a country's land resources completely for the development of the country, therefore the land on which agricultural practices are not applying shod take under the mechanism of agroforestry. In this way, in addition to wood resources, the agroforest will also improve the productivity of the soil and it becomes able for agricultural practices. When trees are cultivated alongside agricultural crops and huge herds of cattle are raised under an agro-silvopastoral system of land use, this practice is known as agroforestry, agro-silvopastoral activity, etc. in a number of developed and developing countries. (Gebrehiwot, 2004).

1.2. Influences of Agroforestry on soil Carbon stock

Last couple of years, scientists have focused on mitigation i.e., reducing or enhancing the sink of greenhouse gases, particularly CO2 in their research. Mitigation of CO2 becomes a serious due to climate change. In addition of climate change the increase in rate of deforestation plays a great role in the emission of CO2 in the environment. Agroforestry systems appear to be a viable method for managing agricultural output and reducing CO2 by increasing carbon stocks (IPCC 2013) In semiarid, subhumid, humid, and temperate climates, agroforestry is thought to contain 9, 21, 50, and 63 Mg C ha1 of carbon, respectively. Agroforestry systems with a variety of tree species can adapt to climate change better and store more carbon. Trees grown alongside crops can significantly boost carbon stock when compared to monocrop systems; for instance, an agro-silvicultural system produces 34.61 t C ha1 versus 18.74 tC ha1 in a monocrop system. Reduced Emissions from Deforestation and Forest Degradation (REDD) projects use research on carbon sequestration in various land uses to provide information that will likely allow certain countries to sell carbon credits to interested buyers or receive financial assistance from funds (The World Bank 2011). This system is especially important for REDD because it reduces pressure for further forest conversion to agriculture by serving as a source of fuel-wood and construction material. Furthermore, community-based agroforestry carbon programs pose fewer risks to communities than large-scale industrial plants and strict forest preservation, and they have the greatest potential to improve local livelihoods. (Smith &Scherr, 2003). Soil is necessary for carbon sequestration. When compared to other forms of intensive land management, agroforestry systems can be conceived of as systems with high soil carbon storage efficiency and low vulnerability. These systems are among the many different types of land use centred on agricultural output (Nair. 2009). Despite continued agricultural exploitation, agroforestry production preserves the soil ecosystem by maintaining the less degraded soil body and enabling more effective nutrient and water cycling through the creation of litter and shading from the trees. However, depending on the planted shade species and commodities, several studies revealed that over 10 years, soil organic matter in the 0-45cm layer—or roughly 8–21 Mg C ha-1—had risen by 16– 42 Mg ha-1 (Beer et al. 1998). On the other hand, Climate, soil type, and land use management, in general, govern the physical, chemical, and biological controls of soil carbon sequestration and turnover. Soil organic matter dynamics are influenced by a number of these factors as well (Feller & Beare,1997). Agroforestry ecosystems that grow under various shade trees offer carbon stocks as an extra ecosystem service, and this needs to be evaluated. This research aimed to compare the capacity of agroforestry's ecosystem to store carbon in both above- and below-ground carbon pools when shaded by various trees and when not. The results of this study may contribute to the preservation and planting of shade trees for the benefit of carbon sequestration. Agroforestry ecosystems that grow under various shade trees offer carbon stocks as an extra ecosystem service, and this needs to be evaluated ecosystems can play in REDD programs because, as mentioned by (Schmitt-Harsh et al.2012).

1.3. Problem Statement

Variability in soil characteristics, rainfall variability (both in space and time), and vegetation variability all play a role in how much biomass may be produced. Drought conditions in the area have exacerbated the ecosystem's already precarious situation by causing temporary or seasonal plant cover removal that has left the soil surface bare in certain areas. This hinders the carbon sequestration potential, as well as creating a spatial distribution of SOCS, which makes it difficult to manage the land with the aim of combating the effects of climate change and improving soil quality, subsequently enhancing ecosystem services. With the impacts of projected climate change of decrease in effective rainfall this may further decrease in NPP (Net Primary Productivity) and worsen the situation, leading to further degradation of SOC. Most important problem of the farmers of Gilgit Baltistan is unawareness about the mechanismofagroforestryforthemaximumutilizationandrest oreofsoilfertility through this precious procedure. In addition to it the soil organic matter is leaching down day by day to restore the SOM (soil organic matter) is necessary to keep maintaining the soil fertility.

1.4. Objective of this study

Considering the above facts and figures, this study was conducted to achieve the following objectives.

- To evaluate the impact of agroforestry on soil properties.
- To estimate the soil organic carbon content under different agroforestry systems.

1.5. Significance of this Study

Agroforestry has been practiced in Gilgit-Baltistan for centuries. Two valleys were selected, Danyore and Sultanabad are vital for agricultural productivity. Agroforestry and intercropping both use similar principles to allow for the vicinity of two or more plant types (such as nitrogen-fixing plants). Compared to traditional agricultural and forestry production techniques, agroforestry systems can be favorable. They deliver higher production, financial gains, and a greater variety of ecological products and services. Agroforestry systems often have higher biodiversity than traditional agriculture systems. Studies in other parts of the world show that Agroforestry practices can increase carbon stock in soil and woody biomass (NAS,2019). Increased food security by restoring soil fertility for food crops. Thus, the study is important to know the potential of soil organic carbon stock under agroforestry system in a mountainous area. Studying soil is significant because it is a natural resource that is vital to the needs of the world's population, which is expanding quickly. (Pappendick & Parr, 1992). Gilgit-Baltistan is agrarian society, so the health of soil is very important for food production. The rapid increase in population and the demand for food and other products is also increasing, which directly or indirectly affects our natural resources.

2. Literature Review

Generally, it is believed that the trees should grow only in forest land, and agricultural land is only specified for the cultivation of agricultural crops. 25% forest land is mandatory for the development of the country. unfortunately, our country, Pakistan, has near about 5% forest land, which is much smaller than the mandatory forest land. Agroforestry system is only possible mechanism to increase the forest content of the country as well as to improve the fertility of the soil. Although soils are essential to life on Earth, human pressure on soil resources is beginning to reach critical levels. One crucial component of sustainable agriculture is careful soil management, which also offers a useful mechanism for climate regulation and a route for preserving ecosystem services and biodiversity (FAO, 2015). Soil provides a variety of ecosystem services associated with production systems, including fertility, structure, filter and reservoir, climate regulation, resources use and biodiversity conservation (Dominati et al.,2010). Due to its connection to crop yield, soil organic carbon (SOC) is a significant indicator of soil fertility (Pan et al., 2009). For instance, declining SOC levels often leads to decreased crop productivity (Dominy et al., 2002; Lal, 2006). Keeping SOC level constant is crucial for agricultural sustainability. The concept of sustainable agricultural production highlights the value of SOC management for protecting the environment and ensuring food security (Buyanovsky & Wagner, 1998; Pan et al., 2009). SOC depletion as a result of soil degradation in intensive agricultural systems can result in the loss of nutrients and soil structure, as well as the resilience, biodiversity, and disruption of critical biotic and abiotic production processes (Lal2015).The SOM serves as storage area for vital nutrients required for plant growth and development, such as nitrogen (N), sulfur(S) phosphorus (P),and Other micronutrients are one of the major binding agents of soil aggregation. It holds together and creates soil pores within and between aggregates to provide air and moisture to the roots and drain excess water (Kaisi et al. 2014). has been determined that the soil use, cultural management, fertiliser application, harvest characteristics, residues management, microclimate, and soil tillage all affect the soil organic carbon (SOC) content of agricultural ecosystems (IPCC, 1997). Agriculture, which largely contributes to CO2 emissions by either increasing the CO2 flow into the atmosphere or utilizing conventional tillage practices, is one of the primary anthropogenic-mediated changes on the surface of the world.(The majority of the flow is caused by the transition from a natural system toa conventional one), by the substantial fuel consumption of farming machinery, or by the production of commercial fertilizer and chemicals. 20–25% of the total CO2 flow into the atmosphere is caused by CO2 emissions from agricultural operations (Smith et al.,2008; Duxbury, 1994). The main method and cause of losing carbon in the soil is thought to be CO2 release from the soil (Parkin & Kaspar,2003).Some agricultural practices, including tillage, can increase the quantity of CO2 emitted into the atmosphere because they disturb the soil, extrude it, and oxidize plant and soil leftovers (Jastrow et al., 1996; Sainju et al., 2006).To increase soil carbon (C)sequestration, it is recommended that reduced tillage and the addition of organic residues be used. These techniques are also seen to be economical and environmentally benign (Victoria et al., 2012). Other chemical and physical soil characteristics, such as nutrient storage, water holding capacity, aggregation and sorption of organic and/or inorganic contaminants, are also enhanced by increasing soil C content (Kibblewhite & Swift,2008). In agriculture, the presence of soil organic matter indicates the soil's potential and health. Its significance can be emphasized in a variety of ways, including as a source of nutrients for plants and microbial ecosystems to grow and nourish (e.g. Nitrogen, Phosphates, and Sulfur), as a significant contributor to soil structure and a valuable source of micronutrients such as zinc, copper, and manganese. Echreshavi (2013) The presence of SOC has numerous beneficial effects on the physical, chemical, and biological properties of soil. For example, soil structure and infiltration capacity, its ability to hold water and provide it to plants when needed, and providing nutrients and micro elements to plants and microbes. Soil carbon sequestration could therefore be a sensible and harmless way to store carbon. It can also improve other biological systems management derived from soil, such as rural development, clean water supply, and biodiversity by expanding SOM content and in this manner improving soil quality (Lal, 2004). Soil carbon sequestration is a mind-boggling process that is influenced by numerous variables, for example, farming practice, and climatic and soil conditions. Various investigations demonstrate that SOC levels increment under acts of adjusted preparation, natural revisions, trimming pivots, preservationist culturing (e.g., no-till), and decreased neglect (Purakayastha et al., 2008; Gongetal,2009). Soil is among the natural resources that makes possible life on the planet Earth, by providing a medium for the growth of plants. It is the upper layer of earth's crust and is composed of grains of minerals that have been produced from the weathering of rocks and consist of sand, silt and clay. Soil is composed of organic matter, mineral particles, water, and air. Assessment of land suitability is required for the successful establishment of plantation, Biologists and land managers in this regard have sought to identify suitable habitat (Mahdavietal.,2017). Rashid (1994) stated that low soil natural issue, dry season and flighty precipitation, lack of supplements unequal utilization of manures. As per NFDC, (1997) and N misfortunes from manure are the main considerations adding to low wheat efficiency in the bone-dry and semiarid rain region of Pakistan. During the previous three decades, a concentrated utilization of synthetic composts has contributed significantly to improving harvest yields. The natural dangers, poor support of long-haul soil profitability, significant cost of parity treatment, and energy crises in Pakistan have produced an enthusiasm for alternative supplements and yield management frameworks.

3. Research Methods and Materials

3.1. Study Area

This study was carried out in two outskirts (Sultanabad and Danyore) of Gilgit-Baltistan (GB), which is located in the extreme north of Pakistan. The entire GB is predominantly mountainous, with the higher mountains containing the world's greatest mountain system, the Himalayas, the Karakoram, and the Hindukush. Both valleys, Sultanabad & Danyore, are located in the district Gilgit (35°55'15.0024" N and 74° 18' 30.0024" E). Sultan Abad is a town in Gilgit-Baltistan and has an elevation of 1495 meters, having a latitude and longitude 35°56'22"N74°22'50"E, and Danyore at the altitude of 1468 meters, with a Semi-arid climate. It rises above the Indus River's north bank, a short distance upstream of the Gilgit River's junction. Danyore and Sultanabad are populated towns and very nearest to capital of GB. Majority of their households are dependent on agriculture and make it one of tools of their economy. To meet the demands of Ari product, both valleys face immense pressure on the soil. To minimize the pressure, traditionally, Agroforestry systems are adopted in different parts of both towns.

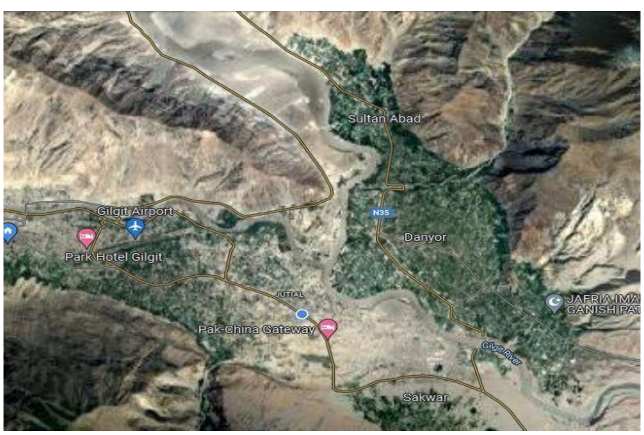

Figure 1: Map of Study Area

3.2. Research Design

3.2.1. Soil Sampling Procedure

Soil samples were collected from two different Agroforestry systems, i.e., a Combination of Alpha-cherry and Maize-cherry to identify the physical and chemical features of soil. At every land type fifteen replicate and two depths (2*15=30*2=60*2) were selected to ensure representative sampling for statistical analysis. A systematic random sampling method was used for soil sampling. Samples were collected from the 0-20cm and 20-40cm layer using a stainless-steel auger. Using a100 츠 3bulk density corerring, one undisturbed core sample was also taken from each location to determine the bulk density. The samples were tagged and put in different plastic bags. Then samples were brought to the laboratory for analysis of soil physical and chemical parameters. GPS was used to track the sampling spots' locations and altitude. Following physico-chemical parameters of the soil were measured from different Agroforestry systems to determine the variation of soil properties i.e Soil Moisture (SM), Bulk Density (BD), Soil pH, Soil Electric Conductivity (EC), Soil organic matter (SOM), SOC and SOCS.

3.2.2. Laboratory Analysis

Soil samples were air-dried and passed through 2-mm sieve proper to physico-chemical analysis. The core method was used to calculate bulk density (Black and Harte 1986). Using a gravimetric method, soil moisture was measured. EC was measured by (Electrical conductivity meter) the methodology which is given in US Handbook 60 (Richards1954). A pH probe with a glass-calomel electrode and a 1:1 soil-to-water ratio were used to measure the pH of the soil. (Mc lean 1982). Using dry combustion techniques, soil organic matter and soil organic carbon were measured (Nelson and Sommers 1982). Soil organic carbon stocks (SOCS) were calculated using the formula by Batjes (1996). SOC stock (Mg/ha) = soil depth(cm) xBD (g cm-3) xC cons (%)x (1-F).

3.3. Statistical analysis

Three-way analysis of Variance (ANOVA) were used to find the significant differences in soil physical and chemical parameters properties with respect to different valleys, agroforestry systems, and depth.

Table 1: ANOVA (three-factorial) of relevant parameters by Valley, Agroforestry

	Temp	pH	BD	Moisture	EC	SOM	SOC	SOCS	SAND	SILT	CLAY
Valley	3**	8.5**	2.9ns	10.8**	9.8**	2.7ns	2.7ns	2ns	31***	59.9***	95***
Agroforestry	3.3ns	7.4**	4.4*	46***	0.07ns	5.3*	5.3*	23.5***	190***	7.8**	810***
Depth	10.3***	8.2**	3.6ns	0.9ns	1.5ns	1.6ns	1.6ns	11.4**			

Note:*,**,***indicatesp<0.05,p<0.01,p<0.001andnsindicatesnon

Table 1: Pearson correlation

	TEM	pH	EC	BD	SOC	SOCS	MOIST	CLAY	SAND	SILT
TEM	1									
pH	-.2**	1								
EC	0.1	-0.1	1							
BD	-.1	0.3**	-0.2**	1						
SOC	0.09	-0.4**	0.1	-0.05	1					
SOCS	0.02	-.2*	-.03	.4**	.8**	1				
MOIS	0.07	-.1*	0.02	.04	.1	.14	1			
CLAY	-0.1	-0.3*	.05	.12	0.06	.11	.4**	1		
SAND	0.1	0.1	0.2	-.13	.02	-.05	-.4**	.7**	1	
SILT	-0.07	-0.02	-0.2*	0.1	-.07	.006	.3**	.4	-.9**	1

4. Results and Discussion

4.1. Influence of Agroforestry System on soil Physico-Chemical Properties

The results of ANOVA-F showed that Soil temperature (p<0.01), pH (p<0.01), electrical conductivity (EC) (p<0.01) and soil moisture (SOM) (p<0.01) significantly varied while bulk density, soil organic matter (SOM) and soil organic carbon (SOC) was not significant across the valleys. Similarly, in Agroforestry System Moisture (p<0.001), pH (p<0.01) and bulk density SOM and SOC (p<0.05) showed significant variation while Temperature and EC were not significant. The results of ANOVA showed that under different depth soil Temperature (p<0.001) and pH (p<0.01) were significantly different, while BD, moisture, EC, Soil organic matter (SOM), Soil organic carbon (SOCS) were not significant (Table 1).

The results of Pearson correlation amongst soil physicochemical properties showed (Table.2) that temperature has a highly negative and significant correlation (p<0.001) with pH. Bulk density has a highly significant positive correlation (p<0.001) with pH and a highly significant negative correlation with SOC and SOCS. EC has a highly significant negative correlation (p<0.01) with BD. pH has a negative correlation with SOC. SOCS, and clay. SOC has a highly significant correlation (P<0.01) with SOCS. Clay has a significant correlation (p<0.05) with sand. Sand has a highly significant negative correlation (p<0.01) with silt and no other relation with other parameters (Table.2).

4.2. Valley-wise variation of soil properties

According to our results the mean temperature under both maize-cherry and Alpha-cherry at Danyore (22.4℃,22.5℃) is higher than Sultanabad (21℃,22.2℃) (Figure 2). Similarly, the pH of maize-cherry in Danyore (8.8) was slightly more alkaline than Sultanabad (8.0), while the mean value of pH under alpha-cherry in Sultanabad (7.8) was higher than Danyore (7.5) (Figure 3). The Pearson correlation showed that pH has significantly negative correlation with moisture, clay, SOCS (p<0.05), temperature, and SOC(p<0.01), and has a positive relation with BD (p<0.01) (Table 2).

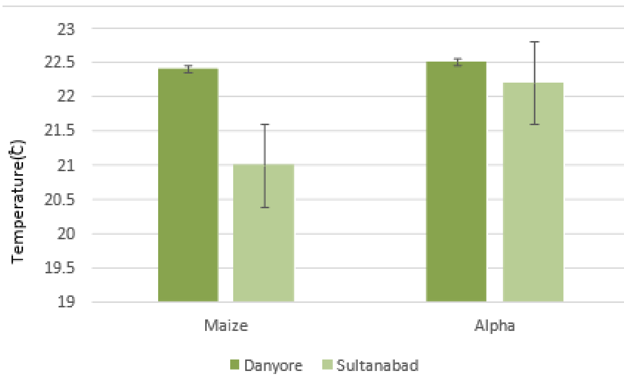

Figure 2: Mean value of temperature

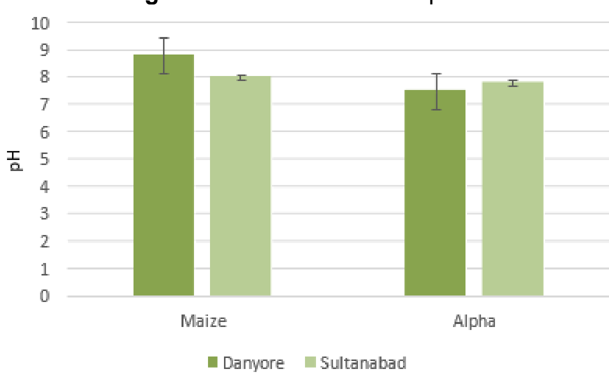

Figure 3: Mean value of pH

The results showed that EC significantly differed between the two valleys. The soil EC of both maize-cherry and alpha-cherry was found to be high at Danyore (358 µ/cm3and409µ/cm3) as compared to Sultanabad (328µ/cm3and293µ/cm3) (Figure 4). While the BD was found high in Sultanabad (1.2g/cm3and 1.1g/cm^3) under both agroforestry systems as compared to Danyore (1.04g/cm^{3}and 0.95g/m^3). The Pearson correlation showed that BD had a significant negative relation with EC ($p<0.001$) and silt ($p<0.01$) and had a positive relation with pH($p<0.001$) (Table 2).

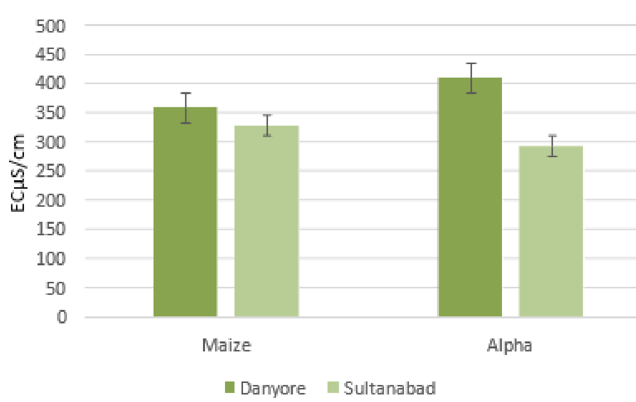

Figure 4: Mean value of EC µS/cm

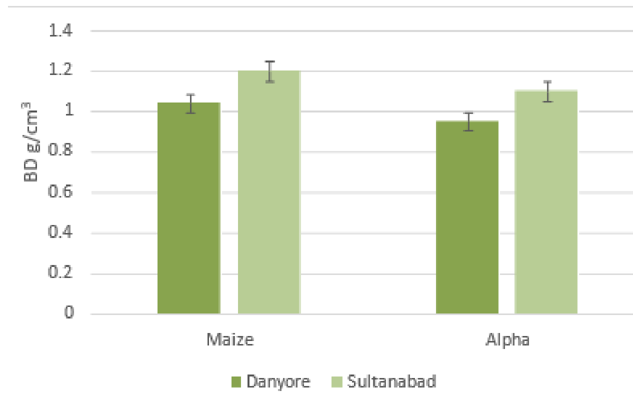

Figure 5: Mean value of BD g/cm^3

According to our findings, moisture content was found high in Sultanabad (19.9% and 23.8%) under both cropping patterns, Maiz-cherry and alpha-cherry agroforestry as compared to Danyore (23.5% and 13.5%) (Figure 8). Soil textures significantly varied under different agro-ecological forestry. The clay content in Sultanabad (46.4% and 50.2%) under Maiz-cherry and alpha-cherry agroforestry was higher than Danyore (36.4% and 49.2%). While sand was found high in Danyore (58.4% and 32.2%) under both agroforestry systems as compared to Sultanabad (27.8% and 24.6%) (Figure 8).

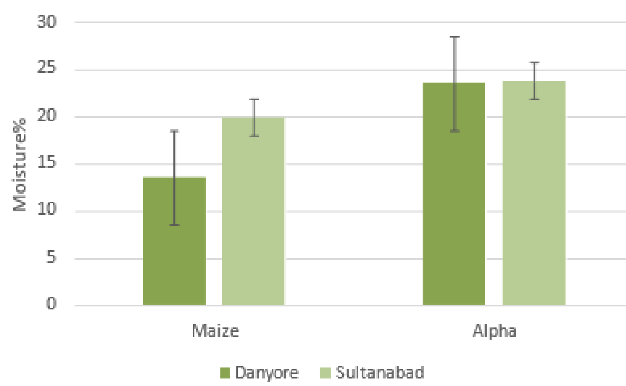

Figure 6: Soil moisture in two valleys

4.3. Soil Organic Carbon Stocks

The results revealed that the mean value of SOC under maize-cherry and alpha-cherry was high in Danyore (1.3%and1.7%) as compared to Sultanabad (1.2%and 1.2 %) (Figure 6). Similarly, the SOCS was found high under Maiz-cherry in Sultanabad (32.3) as compared to Danyore (27.4), while under alpha-cherry, SOCS was found slightly higher in Danyore (33.1) than Sultanabad (32.7) (Figure 7). The Pearson correlation showed that SOC had a positive correlation with SOCS and had a negative relation with pH and BD (Table 2).

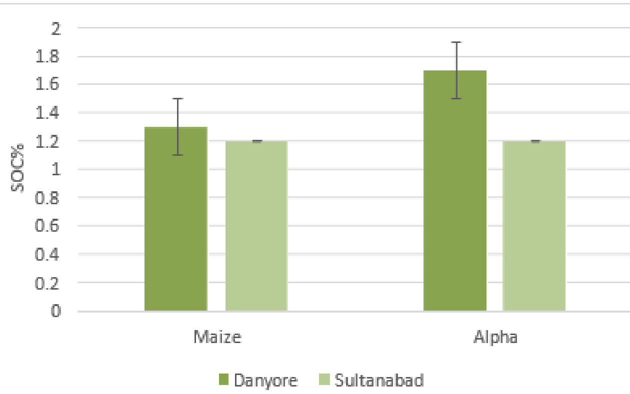

Figure 7: Mean value of SOC%

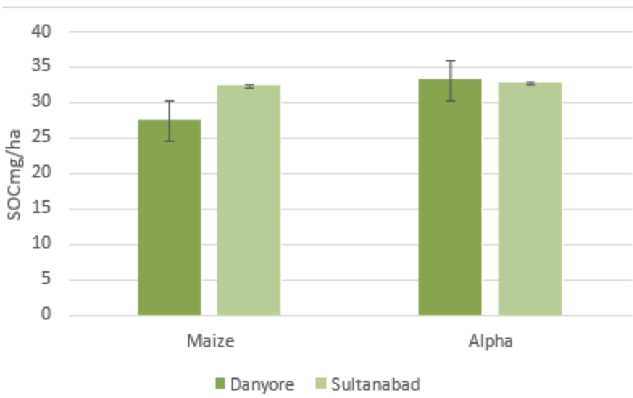

Figure 8: Mean value of SOCS Mg/ha

4.4. Influence of two agroecosystems and depth of soil properties

4.4. The results of the present study showed that the pH of soil significantly varied under different sites and also under different depths. The mean pH of soil under both depths (0-20 and 20-40) of Alfa-cherry (8.7 and 8.8) in Danyore was slightly higher than Maiz-cherry (8.2 and 8.6). similarly, pH was increasing with the increasing depth (0-20to20-40cm) at both cropping patterns (Figure 2).

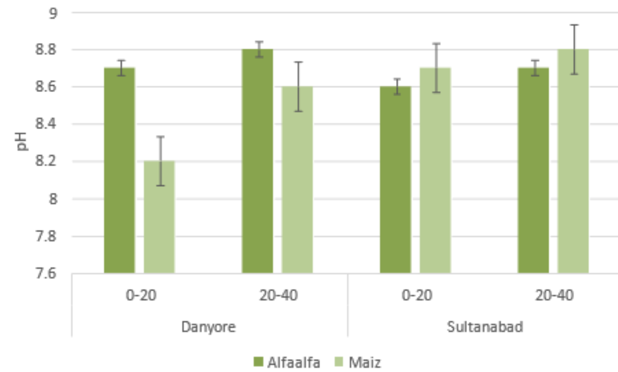

Figure 9: Soil pH in different Agroforestry Systems of the study area

The soil pH of Alpha Cherry agroforestry in Danyore has a high in both depth 0-20 and 20-40, and was highly significant at Danyore. While the pH of maize-cherry was lower than that of alpha-cherry, the agroforestry. While in Sultanabad pH of alpha-cherry agroforestry has the lowest in both depths.

4.5. Bulk Density

The current experimental study revealed that in Danyore valley, the bulk density in the field of Alfalfa-cherry agroforestry was recorded as 1.13 mg/cm^3, while in the field of maize-cherry was somewhat less than that of Alfalfa-Cherry (0.98 mg/cm^3) in the first depth (0-20 cm). It also revealed that the bulk density slightly decreases with increasing depth in Danyore Valley. While in the Sultanabad valley Maize-cherry agroforestry system had a higher BD than the Alpha-cherry agroforestry. Depth-wise, BD increased as the depth increased.

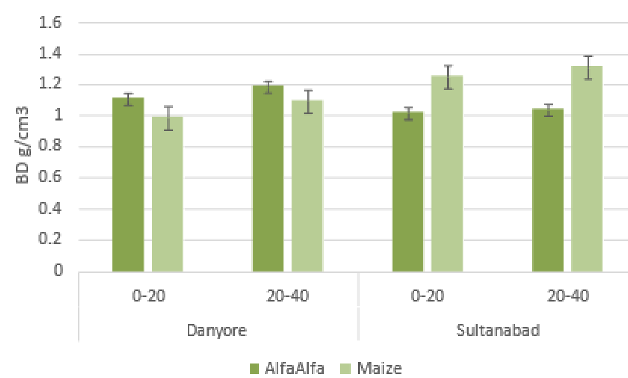

Figure 10: Soil BD in different Agroforestry systems of the study area

4.6. Electric Conductivity

The results of current study of Danyore Valley indicated that the electric conductivity for the alfalfa-cherry and maize-cherry agroforestry was 267.4 µS and 387.94µS, respectively, at first depth (0-20cm). Similarly, the EC for same crops was 2.80and 3.49 respectively in second depth 20-40cm. In case of Sultanabad valley, the EC of alfalfa-cherry and maize-cherry was recorded as 407µS and 336µS respectively in first depth 0- 20cm similarly when the depth was increased to 20-40 cm the EC was also changed to 384µS and 320µS for alfalfa and maize respectively.

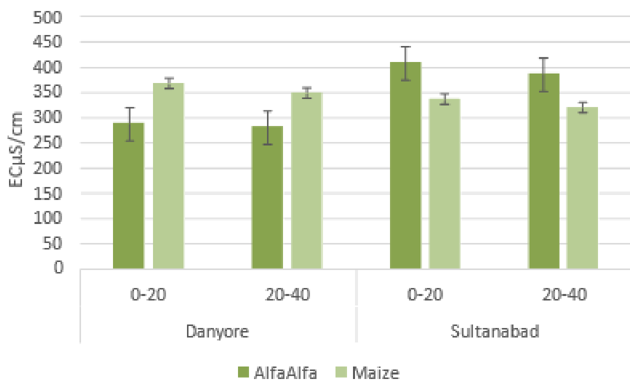

Figure 11: Soil EC in different Agroforestry system of study area

4.7. Moisture

The soil moisture content in the alpha-cherry agroforestry system in both villages were slightly higher than maize-cherry agroforestry system. While in-depth wise comparison, the soil moisture for Alpha-cherry agroforestry system showed any significant change in the top depth. But in the case of Maize agroforestry system it has shown a decreasing trend with increasing depth.

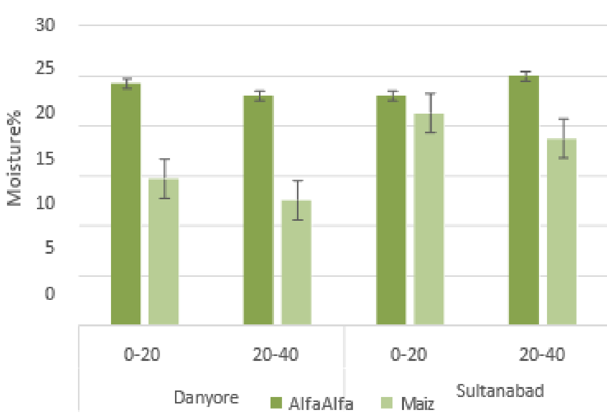

Figure 12: Soil Moisture in different Agroforestry system of study area

4.8. Soil Organic matter (SOM)and Soil organic carbon

In the current experimental study soil organic matter in relation to agroforestry was manipulated. The results of the study revealed that the soil organic matter of Danyore valley was 3.81% and 3.25% for the alfalfa and maize field in a depth 0- 20cm. Similarly with the increasing depth, the content of soil organic matter also increased that was 3.97 for alfalfa and 2.76 for maize when the depth was 20-40cm.

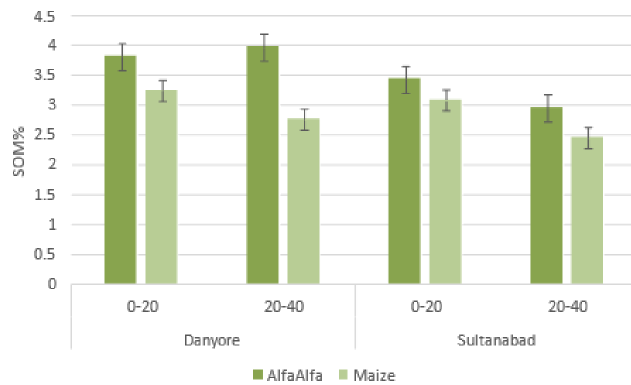

Figure 13: Soil SOM in different agroforestry systems of study area

Soil organic carbon (SOC). It plays a vital role in the agricultural productivity. The current study revealed that the soil organic carbon of alfalfa and maize field in the Danyore in the depth of 0-20cm was 1.68 and 1.43%. On the other hand, the SOCwasrecordedfromthedepthof20-40cmofsamesiteas1.75and1.21%. In case of Sultanabad valley, the soil organic carbon for alfalfa-cherry and maize-cherry for the depth 0-20cm was recorded as 1.51% and 1.36% respectively. While SOC was significantly decreasing with increasing depth(20-40cm) in both agroforestry systems (Maiz-cherry 1.30 and AlfaAlfa-cherry 1.08) (Figure13).

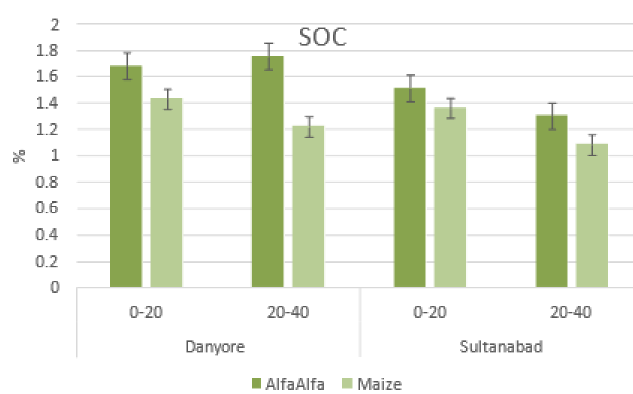

Figure 14: Soil SOC in different Agroforestry system of study area

4.9. SOCs determine the soil organic carbon stocks

The current investigation revealed that in Danyore valley, the carbon stock for alfalfa, cherry and maize-cherry was recorded as 37.74 Mg/ha and 28.13 Mg/ha in the first depth i.e 0-20cm. On the other hand, the soil organic carbon stock was increasing with the increasing depth (20-40cm) in both the valleys (Figure14). While comparing the agroforestry system the SOCS showed an increasing trend with increasing depth except in Sultan Abad Maize –cherry had slightly higher stocks in first depth.

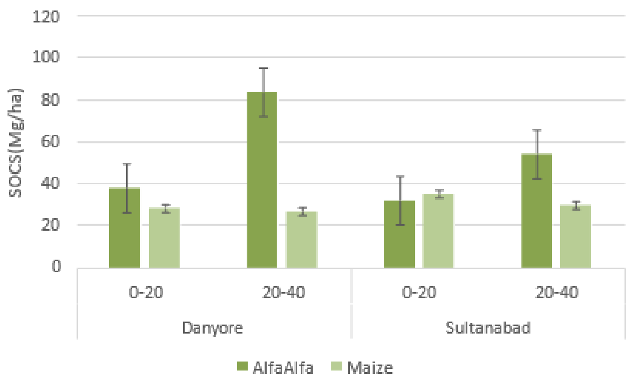

Figure 15: Soil SOCS in different Agroforestry systems of study area

4.10. Texture

4.10.1. Clay

In both the valleys the clay content was slightly higher in the Alpha –Cherry agroforestry system.

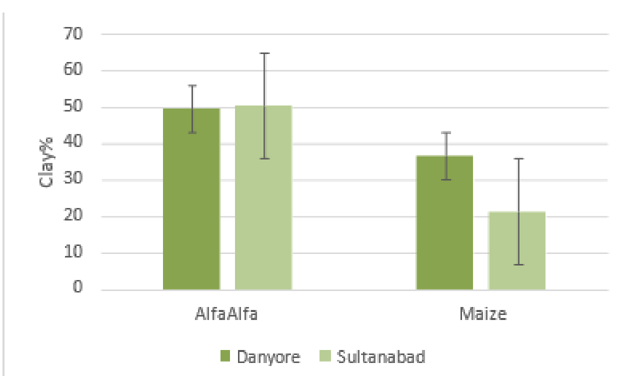

Figure 16: Soil Clay % in different Agroforestry system of study area

4.10.2. Sand content

The current study revealed that the sand content of Danyore valley was 32.2% for alfalfa-cherry agroforestry system and 24.70% for maize-cherry field. On the other hand, in Sultanabad valley the sand content of alfalfa-cherry field was recorded as 58.44% and for maize-cherry was 46.50% (Figure no 17).

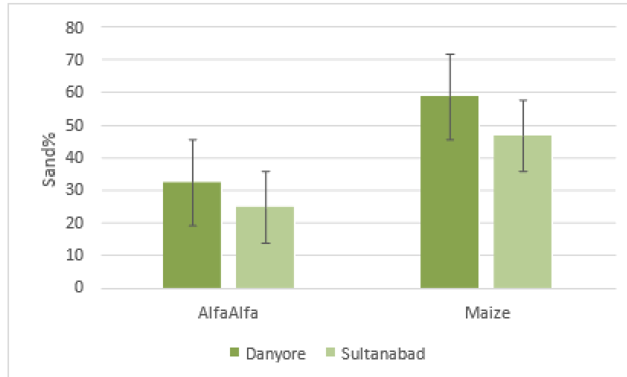

Figure 17: Soil Sand % in different Agroforestry system of study area

4.10.3. Silt content

The current study revealed that the silt content of alfalfa-cherry and maize-cherry was recorded as 18.5% and 5.4% respectively. On the other hand, the silt content in Sultanabad valley was measured for alfalfa-cherry and maize-cherry was recorded as 25.14% and 27.8% respectively.

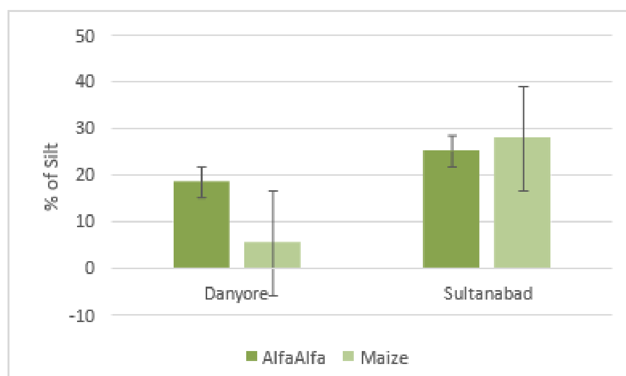

Figure 18: Soil Silt % in different Agroforestry system of study area

5. Discussion

The findings of this study shed light on the significant influence of agroforestry systems on soil quality and the dynamics of soil organic carbon (SOC). Agroforestry, as a sustainable land-use practice, has the potential to play a pivotal role in enhancing soil health and carbon sequestration. Agroforestry systems can enhance carbon stocks in the soil and tree biomass Under different pedo-climatic environments (Cardineal et al., 2017). Agroforestry has the potential to help reverse the negative effects in a variety of ways while also restoring and promoting soil health (Dollinger & Jose, 2018). Due to the continual return of plant litter to soil by perennial woody vegetation and the less frequent removal of trees compared to annual crop harvests, agroforestry systems may store more soil organic carbon (SOC) than annual crop systems (Abbas et al.,2017).It is crucial to comprehend how different land use patterns impact soil carbon dynamics and the quantitative shifts in carbon levels. This understanding is particularly significant due to the importance of carbon sequestration (Ghimire et al., 2023). The fertility of the soil is a direct determinant of crop productivity. Adequate levels of organic carbon in the soil are crucial as they result in enhanced soil quality, elevated productivity, and the formation of resilient soil aggregates (Shrestha et al., 2017). Converting natural vegetation cover to large-scale farmland resulted in a significant loss of soil organic carbon and total nitrogen in Western Ethiopia (Leul et al., 2023). The temperature of the soil is an important abiotic factor that influences its physical, chemical, and biological properties (Begum et al., 2009).

According to our results the mean temperature under both maize-cherry and Alpha-cherry at Danyore (22.4℃,22.5℃) is higher than Sultanabad (21℃,22.2℃) (Figure 2). Alam et al. (2022) and Kalu et al., (2015) found that soil temperature depends on seasonal variation and climatic conditions during sampling time. Soil pH is the sign of acidity and alkalinity in the soil, the availability of nutrients to plants depends upon it (Begum et al., 2009; Moges et al., 2013; Ishaq et al., 2015). The results of present study showed that pH of soil significantly varied under different depths. It was increasing with increasing depth. Similar studies were conducted by Rezaei et al. (2012) that soil pH increases with depth and its due to extensive leaching. Similarly, the pH of maize-cherry in Danyore (8.8) was slightly more alkaline than Sultanabad (8.0) while the mean value of pH under alpha-cherry in Sultanabad (7.8) was higher than Danyore (7.5) (Figure 3). According to Kinyili et al. (2020) that the lack of differences in pH could be attributed to the soil geology being over similar pH ranges, and most trees planted have little effect on soil pH. The planting of trees did not use lime or fertilizers, which could affect soil pH and could explain the observed similarity in soil pH between agroforestry adopters and non-agroforestry adopters.

Soil EC measures the dissolved material in an aqueous solution that relates to the material's ability to conduct electric current through it (Joshi et al., 2015). There was no any significant difference in EC values in different agroforestry systems and under different depth. This could be because all crops were grown in one field. According to Begum et al. (2020), the variation in EC among different depths may be due to the low availability of nutrients and dead organic matter. The water content of the soil's upper layers is an important parameter with various applications in hydrology, agriculture, and metrology (Sharma, 2006). The state and texture of the Top soil specifies soil moisture conditions (Miles et al., 2010). According to our findings moisture content was found to be high in Sultanabad (19.9% and 23.8%) under both cropping patterns, maiz-cherry and alpha-cherry agroforestry as compared to Danyore (23.5% and 13.5%) (Figure 8). While under depth wise the soil moisture content for the Alpha-cherry agroforestry system there was no any significant change in the top depth but in the case of maize agroforestry system, showed a decreasing trend with increasing depth (Figure15). As there is less stillage for alfalfathat's why there is no any significant variation in moisture content. Similar studies were conducted by Derpsch et al. (1991) and stated that zero tillage soil has a high amount of soil moisture and the duration of water availability to plants is also high. Bulk density revealed the compaction of soil of any specific geographical area. Soil compaction, which influences soil in filtration and runoff, is characterized by high bulk density and penetration resistance (Aksakal et al., 2014). The BD was found high in Sultanabad (1.2g/cm3and 1.1g/cm3) under both agroforestry system as compared to Danyore (1.04g/cm3and 0.95g/cm3). Bulk density in the soil was higher among adopters compared to non-adopters, and it increased with the duration of agroforestry adoption (Silva et al., 2011; Chaudhari et al., 2013). Results demonstrated that Bulk density was increasing with increasing soil depth at all cropping system. Similar results were found by Chaudhari et al. (2013) and Begum et al. (2020) also reported that bulk density of soil increased with increasing depth. A study by Singh et al. (2018) about soil physico-biochemical properties under different agroforestry systems in Terai region of the Garhwal Himalayas showed similar results to our study that bulk density was increased with increasing soil depth. Soil organic carbon is the organic component of the soil that improves the soil fertility and soil productivity.

Therefore, more sensitive indicators of the impact of management practices (Chan et al., 2000). The results revealed that mean value of SOC under maize- cherry and alpha-cherry was high in Danyore (1.3 % and 1.7 %) as compared to Sultanabad (1.2 % and 1.2 %) (Figure 6). Similarly, the SOCS was found high under maiz-cherry in Sultanabad as compared to Danyore (Figure 7). Soil organic carbon stock is the basic component that determines the soil fertility and soil productivity. Live biomass (intact plant and animal tissues and micro-organisms), dead roots, and other plant remains, and dead tissue and soil organic matter (SOM)are all organic components of soil (Brady et al.,2015). According to our findings SOC stock of alfalfa-cherry and maize-cherry was recorded as 37.74 Mg/ha and 28.13 Mg/ha in first depth (0-20cm) the decreasing depth (20-40cm) in both the valleys (Figure 14). While comparing the agroforestry system, the SOCS showed an increasing trend with increasing depth, except in Sultan Abad Maize –cherry had slightly higher stocks in the first depth. Oelbermann and Voroney (2007) studied that SOC stocks were not evenly distributed throughout the soil profiles, with the highest SOC stocks found at the 0-20 cm soil layer. Paul et al. (2002), higher SOC stock in treed areas compared to neighboring herb land areas is commonly attributed to higher plant residue input in treed areas as well as contrasting land management practices that also affect SOC input and protection. Mechanical harvesting and land-use practices such as tillage and traffic frequently remove plant residues, causing SOC loss through respiration and erosion (Lal, 2005). The Pearson correlation showed that SOC had a positive correlation with SOCS and had a negative relation with pH and BD (Table 2). Similar results were found by Begum et al. (2019, 2020) and Alam et al. (2022) that SOC had a positive relation with SOM and SOCS and had a negative relation with BD and pH. The proportion of clay, sand, and silt in the soil influences water retention and infiltration, ventilation, microbiological activity, and nutrient absorption (Gupta, 2004). In our study, the clay content was slightly higher in the Alpha-Cherry agroforestry system, while sand content at Danyore valley was 32.2% under the alfalfa-cherry agroforestry system and 24.70% under the maize-cherry field. On the other hand, in the Sultanabad valley, the sand content of the alfalfa-cherry field was recorded as 58.44% and for maize-cherry was 46.50%. According to Ali et al. (2017), low clay and high sand on agricultural land may be due to rapid water erosion removing clay. Plante et al. (2006) demonstrated that soil texture influences SOC content.

Agroforestry captures carbon and contributes to climate change mitigation. Perennial trees supply litter and roots each year. A portion of this input becomes stabilized in aggregates and on mineral surfaces, and another portion accumulates in woody biomass. Even moderate increases in SOC at the plot scale, such as the several megagrams of carbon per hectare observed between systems and depths, become meaningful when adopted across many farms. The size of the benefit depends on climate, soil, and management, as seen in differences between valleys, but the direction is consistent. To maximize mitigation, farmers should maintain continuous cover, limit soil disturbance, add organic residues, and measure both soil and tree biomass carbon over time. Overall, alfalfa–cherry improved soil quality and increased SOC more than maize–cherry, especially in the surface layer of Danyore. These gains, together with careful management to reduce compaction and conserve moisture, support agroforestry as a practical option for soil restoration and climate mitigation in mountain valleys. Future work should include multi-season sampling, direct measurement of tree biomass carbon, and long-term monitoring to test the persistence of stored carbon under farm conditions.

6. Conclusions

This study shows that the alfalfa–cherry agroforestry system sequesters more soil organic carbon than maize–cherry and improves key soil properties in Gilgit's mountain valleys. The largest SOC and SOC stocks were found in the surface layer, with decreasing values at greater depth, while bulk density increased with depth. Site effects were clear. Danyore had a higher mean SOC than Sultanabad, moisture was generally higher in Sultanabad, and pH increased with depth at both sites. Texture helped explain these patterns. Finer textures supported higher SOC protection, while sandier soils in Sultanabad limited carbon retention. SOC was positively related to SOC stocks and negatively related to bulk density and pH, which is consistent with aggregate protection and organo-mineral stabilization of organic matter. Taken together, these results indicate that alfalfa–cherry can raise SOC and improve soil quality while capturing carbon that contributes to climate change mitigation in a vulnerable mountain ecosystem. For Conclusions, the main conclusions of the study may be presented in a short Conclusions section, which may stand alone.

7. Recommendations

For the protection of ecosystem from overexploitation of land following practices are recommended.

- Promote alfalfa cherry on suitable land, especially on finer textured fields where aggregation can protect SOC.
- Maintain continuous cover, reduce tillage, keep residues on the soil, and avoid burning to increase inputs and protect stored carbon.
- Limit compaction by controlling traffic, using fixed lanes, and avoiding operations when soils are wet; monitor bulk density by depth.
- In sandier areas, apply organic amendments such as compost or manure and use mulches or cover crops to improve moisture retention and SOC buildup.
- Encourage adoption of agroforestry among farmers and land managers through extension support and local incentives, with a legislative framework that recognizes its climate benefits.

- Because arable land is scarce in the district, scale agroforestry to increase total output per unit area while maintaining soil health.
- Monitor both soil and tree biomass carbon to develop whole-farm carbon budgets and to document mitigation outcomes.
- Standardize sampling (season, depth, core method), record moisture at sampling, and report uncertainty and statistical results for comparisons across sites and systems.
- For tracking change, present layer values (for example 0–10, 10–20, 20–40 cm where possible) and cumulative stocks for 0–40 cm.
- Plan long term studies to test the stability and persistence of SOC in agroforestry, and link observed changes to soil health, crop productivity, and climate outcomes.
- Include a short site guide for farmers: favor alfalfa cherry where texture is finer and moisture is moderate, and add organic inputs and cover crops where sand content is high.
- Integrate climate policy goals with farm programs so that measured soil and biomass carbon can support access to incentives or carbon payment schemes.

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