Article

A Robust Carbon Sequestration Rate and Carbon Stock Assessment Method in Agroforest Systems

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Abstract: Climate change is deciding social-ecological system, threatening natural ecosystem. Nature human extreme participation interaction are changing climate conditions. This study was conducted to assess the role of different agroforestry systems to combat climate change through carbon sequestration; including i) the inventory data such as tree DBH (cm), height (m), biomass, carbon stock, soil carbon and total carbon stock of different agroforestry systems, and ii) regarding impact of different agroforestry systems on soil physicochemical properties are demonstrated. The study investigated the role of different agroforestry systems in biomass accumulation, carbon sequestration and also the soil physio-chemical properties at various depths under these systems. Among agroforestry systems, agri-silvihorticulture system and agri-silviculture system accumulate higher biomass and carbon as compared to agri-horticulture and agri-horti-silviculture system. This may be due to the higher variation in tree species, number and their size, management practices etc. Soil carbon also varies with the type of agroforestry system. Higher soil carbon at 0- 30 cm depth was found in agri-silvihorticulture system. Soil physiochemical properties such as soil EC, nitrogen, potassium, phosphorous and organic matter was higher in surface soil (0-15 cm depth) as compared to sub soil (15-30 cm). Thus, it was concluded that agroforestry systems, apart from providing livilihoods to local dwellers, play an important role in improving soil health, produce greater biomass and capture higher amount of vegetation and soil carbon.

Keywords: agri-horti-silviculture; agri-silviculture; agri-silvihorticulture; agri-horti-silviculture

1. Introduction

Climate change is statistical distribution of weather patterns for an extended period of time. Changes in climate are happening which are unparalleled such as life on Earth will be modified to such an extent that will be very difficult to fix. The last 100 years several activities including combustion of fossil fuels and removal of trees have extremely altered the chemical makeup of this flimsy layer of the atmosphere. As result, modifications in chemical composition has significant harmful results on the long-term weather conditions of the planet. The ecological systems supported and the welfare of human beings on earth. The maximum influence on the climate of the Earth is of rare trace gases. These gases include carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), chlorofluorocarbon (CFCs), nitrogen oxides (NOx), and ozone (O_3). Water vapors also have a very significant impact on the conditions of the climate of the Earth (Crutzen and Ramanathan 2000). Human beings are increasing the concentration of atmospheric CO_2 by the processes of burning of fossil fuels, changes in the use of land and activities which are related to forestry, as a result of these processes, global warming and change in climate are occurring in present times (Upadhyay et al. 2005). Global warming is among the greatest terrible horrors of the modern times. It is believed that carbon is among the most significant casual factors which cause global warming. So, enhanced carbon discharge in the atmosphere is one of today's major interests that is significantly referred in Kyoto Protocol. Globally, transportation and industrial sources are the cause of above than 80% CO_2 emissions caused by humans. The rest 20% comes mainly from removal of trees and combustion of biomass (CDIAC 2000). The mean concentration of CO_2 in the atmosphere was 280 μ mol mol−1 before the development of industries.

The year of 1994 industrial development has reached up to 364 μ mol mol−1. The rate at which concentration is in increasing is about 1.5 μ mol mol−1 year−1 (Kerr, 2007). Moreover, the ratio at which CO2 accumulates in the atmosphere is more by about 3.3 GtCyr-1 than the ratio at which it is lost from the atmosphere to its major natural sinks. Therefore, the concentration of CO2 in the atmosphere is increasing continuously and it has extended up to 367 ppmv. It is an expansion of 31% high than its preindustrial level (previous to the advent of industry) and it goes on increasing exponentially

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at about 0.5% per year (IPCC 2000). Plants capture atmospheric CO_2 via natural process of photosynthesis. Sequestration of carbon via plants is environment friendly process that removes CO_2 from atmosphere. This process has no side effect and does not need any technology. Each tree has little capacity to store CO_2 because after certain age the ability of trees storing CO_2 will remain constant when trees reach maturity. Plants store this CO_2 into their leaves, roots, bark, branches and stem. About 50% of tree's biomass is composed of carbon. Significant amount of carbon is stored into trees in the form of cellulose and lignin. It is anticipated that trees can store 6% of total CO_2 in next 10 year (De Villiers et al. 2014).

The growth of the forest is interrupted or the forest is demolished, CO_2 and other greenhouse gases (i.e. methane 'CH_4', nitrous oxide 'N_2O') are released backwards into the atmosphere through the processes of respiration, combustion or decomposition. This tells us that how much forest ecosystems are important in the global carbon cycle and the requirement of precise evaluation of the amount of C accumulated in forest ecosystems (Körner 2006). Forest ecosystems are in a state of being worthy of appreciation and can be viewed very respectfully in the overall situation of alteration of climate since they play their role as both sources as well as sinks of CO_2 which is the most profuse greenhouse gas (Haripriya 2002). Out of all the carbon sequestered in terrestrial ecosystem approximately two-thirds of that terrestrial carbon, other than that is captured in the solid aggregates of the Earth's crust and sediments, is captured in the forest under stormy plants, trees of standing forests, leaf and forest litter, and in soils of forest (Sedjo et al. 1998). There is only 4.7% area of the total surface area of Pakistan which comes under forest area. We are very unfortunate of having such a small area and it is not sufficient for environmental, social and economic requirements of Pakistan. Total forest area of Pakistan's different provinces and territories viz. Sind, Baluchistan, Punjab, Khyber Paktun-Khuwa (KPK), Azad Kashmir and Northern areas is 0.92, 0.33, 0.69, 1.21, 0.42 and 0.66 million hectares accordingly. When we compare this area with world it is too small to be compared (Mcketta 1990). Agroforestry plays a very significant role and it is a very vital part of daily life of population of Pakistan, particularly, population of rural areas. It has been reported in the Forestry Sector Master Plan that the annual yield production of the wood is 7.7 million m3 out of which the contribution of farmlands trees is about 4.4 million m3 (53%) (Qureshi 2005). Agroforestry, is a system in which trees and/or shrubs (perennial) are grown with agronomic crops (annual or perennial). This system has a great potential to capture both above and below-ground carbon. The practices of agroforestry have been approved as a scheme for capturing of soil carbon under reforestation and afforestation programs and Clean Development Mechanisms of the Kyoto Protocol. So, growing farm trees along with agricultural crops on the agricultural lands has a great potential of Carbon sequestration (Nair et al. 2009). Soil Carbon concentration is enhanced by magnitude and eminence of the residues of trees/ shrubs. Carbon can be stored in agroforestry systems for centuries if these systems are managed on sustained basis. Trees, pastures and agroforestry systems are very vital for the policies of carbon sequestration in arid environments (Dixon 1995).

Agroforestry practices can play a very vital in the sequestration of carbon. It has been estimated that up to 12-228 Mg ha-1 carbon can be stored through agroforestry systems (AFS), with an average of 95 Mg ha-1. Moreover, the quantity of carbon stored in any agroforestry system is determined by the type of connection between different components of system. AFS not only helps in the sequestration of carbon but also responsible for providing a great number of other services to the communities of rural areas (Schroeder 1994). Masera et al. (2001) studied the mitigation scenario of agroforestry practices for Mexico. He suggested that there is need to do research to find the amount of carbon stored in each component of agroforestry system. And the current practices of agroforestry practices will remain continue in the future also. It has been reported that quantity of carbon stored in any agroforestry system depends on number of different factors like age of the system, composition and purpose, management practices of silviculture, climatic conditions of soil like texture and other properties and history of the land-use (Albrecht and Kandji 2003).It has been predicted by using CO_2 FIX model that the capability of AFS to capture Carbon is nearly equal to 130-181 Mg C ha-1 in above ground biomass in the plantations of coffee, enhanced tropical fallows and taungya system (de Jong et al. 1995). It has also been reported that natural fallow systems have the ability to store 14 Mg C ha-1 in 2 years and upto 191 Mg C ha-1 in 25 years, on the other hand, approximately 60 Mg C ha-1 could be stored in enriched fallow systems in 5 years (Kotto-Same et al. 1997). Only that carbon which is newly sequestered through the practices of agroforestry can be considered as carbon credits according to the Kyoto protocol. These credits can be used in carbon marketing by selling them to industrialized countries to full fill their emission reduction targets. Soil carbon can also be included in carbon credits in the near future (Lal 2004). It is very necessary to know about the accurate information about the spatial distribution of carbon in both vegetation and soil, so that, we will be able to make better policies. There is no any significant study in Pakistan to calculate the carbon stocks of farm trees in arid conditions. So, there is an urgent need of assessment of carbon stocks and potential of carbon sequestration by farm trees. Tehsil Dunia Pur, Lodhran has selected due to prescience of diversified nature of agroforestry systems there. The research aimed to evaluate the current status of carbon stocks in various agroforestry systems, and capability of trees become under agroforestry systems for sequestering CO_2.

2. Materials and Methods

The present study was conducted in arid condition in tehsil Dunia Pur, District Lodhran. A total 12 rural union councils of selected tehsil were randomly considered for measuring inventory and soil sampling. Overall, 60 plots of 4 different agroforestry systems; 20 for each selected agroforestry system were selected for inventory and soil sampling. Tehsil Dunia Pur is the famous town in district Lodhran, Southern Punjab, Pakistan. The area is famous for its fertile lands and the major crops and fruits are wheat, cotton, maize, mango, guava and citrus. Large number of vegetables are also cultivated in the study area. The area experiences four distinct season such as summer, winter, spring and autumn. Summer season is the largest one and it lasts from April to August. The area experiences the average precipitation around 346 mm while the average temperature is around 24.1 °C as depicted below.

2.1 Biomass Estimation

Biomass was estimated by using the inventory data, tree diameter at breast height and tree height. The above and belowground biomass was calculated by using the allometric equations from literature. Belowground biomass was considered 26% of aboveground biomass for the species without already present allometric models. At the end total biomass was computed by adding the above and belowground biomass of trees and crops.

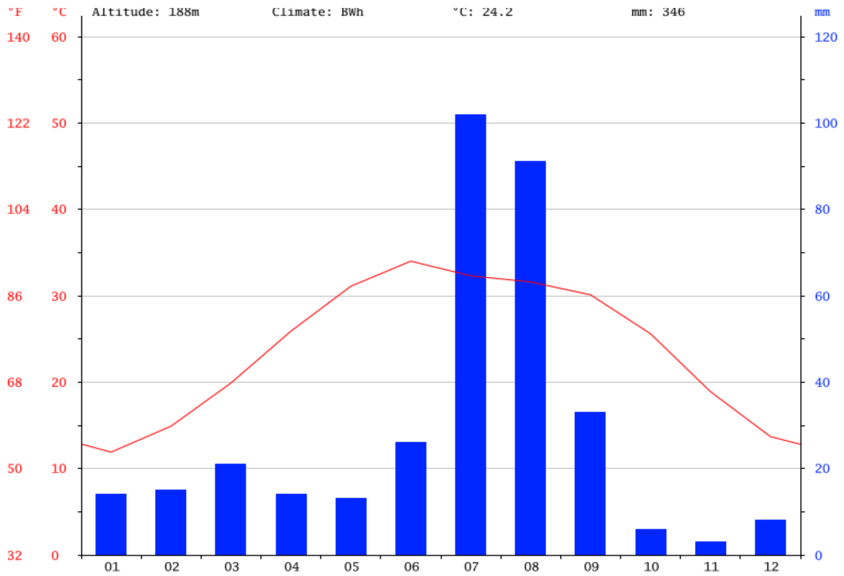

Figure 1. Climate data of the study area (Tehsil Dunia Pur, District Lodhran), Pakistan.

2.2 Trees Biomass Estimation

For measuring and estimating the tree biomass, field visits were carried out during March 2020 to July 2020. Tree inventory was carried out in four commonly observed agroforestry systems: Agrisilviculture, Agrihorticulture, Agrisilvihorticulture and Agri-hortisilviculture, in the study area. For each agroforestry system, 20 plots (0.405 ha) were randomly selected across the whole study area. All the trees present in an area of 0.405 ha were counted and measured for DBH and height. Tree height was measured with the help of Haga altimeter, initially in feet and then converted to meters while tree girth at breast height was calculated by using tailor inchi tap, which was then converted to diameter at breast height. For fruit trees, basal girth was measured above 30 cm from ground and then converted to basal diameter. The measurements were recorded on pre-designed performas and then transferred on Microsoft Excel sheet. By using the values of height and dbh, tree biomass was estimated into Kg/tree which was then converted to Mg/ ha.

2.3 Total Tree biomass

The total biomass of tree for agroforestry systems were calculated by adding the above and below ground biomass:

Total tree biomass= Aboveground biomass + Belowground biomass

2.4 Crop Biomass

For measuring the crop biomass, a quadrat of 2m × 2m were marked in all agroforestry systems to measure and estimate the crop biomass as follows:

For all types of vegetables, number of all vegetables were counted in a quadrate, uprooted and harvested to determined their aboveground biomass and dry weight. For cereals and pulses and other oil seed crops, the plants parts are harvested, dried and their aboveground biomass and yield is determined by using the procedure as adopted by (Yadav et al. 2019).

Belowground biomass for these crops is estimated by the following formula:

Belowground biomass= Aboveground biomass × root shoot ratio of vegetables and crops

The total crop biomass was determined by adding the above and belowground biomass of crops while the total ecosystem biomass was determined by adding the vegetation above and belowground biomass across all the agroforestry systems.

2.5 Estimation of Carbon Stock

For measuring the accumulation of carbon in agroforests and other terrestrial vegetation, the exact amount of carbon in the live tissue of vegetation. Mostly 50% of vegetation dry weight is taken as carbon in all the assessments done at regional as well as global scale. However, we followed the instructions explained by (Thomas and Martin 2012), who described the actual amount of carbon is 48.1% in vegetation acrosss subtropical climate. As the overall climate of the country is subtropical type, so for calculating the carbon stock across all selected agroforestry systems, following formula was used:

Carbon stock/ storage = Biomass 48.1*

The total carbon stock for all the agroforestry system was measured by adding the values of aboveground carbon and below-ground carbon:

Total Carbon stock = Aboveground carbon + belowground carbon

2.6 Soil Carbon

Soil sampling was done at two depths from all the selected agroforestry systems on the basis of assumption that the amount of soil carbon in all agroforestry system is different depending upon the management practices, soil bulk density and tillage. Soil sampling was done near the base of trees in cardinal directions from all the plots selected for inventory, mixed properly and a composite sample was made. After drying the soil, the amount of carbon in soil of each agroforestry system was computed by the procedure demonstrated by Walkly and Black (Savoy 2013).

2.7 Soil Filtrate Preparation by Mechanical Shaker

20 g of grinded soil was taken in a stoppered flask; half of it filled with double distilled water, allowed to shake for 30 minutes at mechanical shaker and kept it overnight. Next day it was filtered and volume was made up to 100 ml with double distilled water. The filtrate was used for the determination of pH, electrical conductivity, carbonate, bicarbonate, calcium, magnesium, chloride, sodium, potassium, and phosphorus and Sulphur contents.

2.8 Digestion of Soil Sample

For the estimation of nitrogen digestion of soil samples was carried out. 3 g of finely grinded soil sample was taken in digestion flask, one g catalyst mixture and 25 ml of conc. H_2SO_4 were added and heated for 5-6 hours. Finally, light green colored solution was remained in flask. Volume was made up to 100 ml by double distilled water. Positive and negative controls were also prepared to find out error. In case of positive control 3 g urea was taken instead of sample and whole process was repeated, and in case of negative control whole process was carried out in presence 1 g catalyst and 25 ml of H_2SO_4.

2.9 Determination of Moisture Contents

Three g soil sample was taken in a pre-weighed China dish and placed in an oven at 110° C for half an hour. After cooling, the dried sample was again weighed and the difference in weights of samples before and after heating was the moisture contents of the sample. The observed moisture contents were measured in percentage (Hesse 1971).

Weight loss in sample after heating
Moisture contents (%) =……………× 100
Weight of sample before heating

2.10 Determination of Nitrogen Contents

Five ml digested sample was alkalified with 40% NaOH solution and distilled in Markham's distillation apparatus. The distillate was collected in Boric acid indicator solution for about 10 minutes. The red color of boric acid indicator was turned green. Then boric acid indicator solution having distillate was titrated against 0.1 N HC1. End point was color change from green to red and volume of acid consumed during neutralization was noted. This procedure was repeated until three concordant readings were obtained. Same procedure was repeated for positive and negative controls (Bremner and Mulvaney 1982). The observed value of Nitrogen was measured in percentage.

% N = (V - B) × N × R × 14.01 × 100
Wt × 1000
Where
V = Volume of 0.01 N H2SO4 titrated for the sample (mL)
B = Digested blank titration volume (mL)
N = Normality of H2SO4 solution.
14.01= Atomic weight of N.
R = Ratio between total volume of the digest and the digest volume used for distillation.
Wt = Weight of air-dry soil (g)

2.11 Determination of Organic Matter

One g finely grinded soil sample was taken in 500 ml conical flask, 10 ml H_3PO_4, 20 ml $K_2Cr_2O_7$ was added in it. Shake for 1 minute and allowed to stand for 30 minutes. Then 200 ml water, 10 ml H_2SO_4 and 1 ml indicator solution was added. It was titrated against ferrous sulphate solution. End point was appearance of green color (FAO 1974).

Organic carbon (%)=10(A-T)×0.003 x100
B = wt.of sample
Where
A = Volume of ferrous ammonium sulphate solution required for sample
B =Volume of ferrous ammonium sulphate solution required for blank
Actual carbon (%) = Estimated organic carbon × 1.3

There is incomplete oxidation of organic matter in this procedure. So organic carbon multiplied by a factor of 1.3 on assumption that there is 77% recovery.

Organic matter (%) = Actual carbon (%) × 1.724
1.724 is Van Bemmelen factor and is used because organic matter contains 58%carbon.

2.12 Determination of Carbon

1) Weigh out 0.10 to 2.00 g dried soil (ground to <60 mesh) and transfer to a 500-mL Erlenmeyer flask. The sample should contain 10 to 25 mg of organic C (17 to 43 mg organic matter). For a 1 g soil sample, this would be 1.2 to 4.3% organic matter. Use up to 2.0 g of sample for light colored soils and 0.1 g for organic soils.
2) Add 10 mL of 0.167 M $K_2Cr_2O_7$ by mean of a pipette.
3) Add 20 mL of concentrated H_2SO_4 by means of dispenser and swirl gently to mix. Avoid excessive swirling that would result in organic particles adhering to the sides of the flask out of the solution.
4) Allow to stand 30 minutes. The flasks should be placed on an insulation pad during this time to avoid rapid heat loss.
5) Dilute the suspension with about 200 mL of water to provide a clearer suspension for viewing the endpoint.
6) Add 10 mL of 85% H_3PO_4, using a suitable dispenser, and 0.2 g of NaF. The H_3PO_4 and NaF are added to complex Fe3+ which would interfere with the titration endpoint.
7) Add 10 drops of ferroin indicator. The indicator should be added just prior to titration to avoid deactivation by adsorption onto clay surfaces.
8) Titrate with 0.5 M Fe^{2+} to a burgundy endpoint. The color of the solution at the beginning is yellow-orange to dark green, depending on the amount of unreacted $Cr_2O_7^{2-}$ remaining, which shifts to a turbid gray before the endpoint and then

changes sharply to a wine red at the endpoint. Use of a magnetic stirrer with an incandescent light makes the endpoint easier to see in the turbid system (fluorescent lighting gives a different endpoint color).

Alternatively use a Pt electrode to determine the endpoint after step 5 above. This will eliminate uncertainty in determining the endpoint by color change. If less than 5 mL of Fe^{2+} solution was required to back titrate the excess $Cr_2O_7^{2-}$ there was insufficient $Cr_2O_7^{2-}$ present, and the analysis should be repeated either by using a smaller sample size or doubling the amount of $K_2Cr_2O_7$ and H_2SO_4.

1) Run a reagent blank using the above procedure without soil. The blank is used to standardize the Fe2+ solution daily.
2) Calculate %C and % organic matter:

a. % Easily Oxidizable Organic C %C = (B-S) x M of Fe2+ x 12 x 100 g of soil x 4000

Where:
B = mL of Fe2+ solution used to titrate blank
S = mL of Fe2+ solution used to titrate sample
12/4000 = milliequivalent weight of C in g.

To convert easily oxidizable organic C to total C, divide by 0.77 (or multiply by 1.30) or other experimentally determined correction factor. To convert total organic C to organic matter use the following equation:

% Organic Matter = % total C x 1.72/0.58

2.13 Determination of Potassium

In volumetric flasks of 100 ml each, 5, 10, 15, 20, 25 ml of working solution was taken and made up the volume of each flask up to the mark. These are 5, 10, 15, 20, 25 mg L-1 solutions respectively. Then emission intensity of each concentration was noted directly by flame photometer. The calibration curve graph was plotted between concentration of potassium and emission intensity.

The emission intensity of soil samples was measured; concentration of potassium was calculated by using calibration curve. Necessary dilutions were made in order to adjust the emission intensity of samples in calibration curve (Richards 1954). The observed value of Potassium was measured in mg kg-1.

2.14 Determination of Phosphorus

Using six flasks of 50 ml each, 1, 2, 3, 4, 5 and 6 ml of solution A were added and labeled them as 1, 2, 3, 4, 5 and 6 respectively. Ten ml of solution B was added in each flask. Volume of each flask was made up to the mark. Yellow colored complex was formed. Absorbance of each was noted spectrophotometrically at 420 nm. Calibration curve was drawn by plotting the graph between concentration and absorbance. Same process was repeated for soil samples also and the concentration of phosphate (mg kg-1) was measured by the help of calibration curve. From phosphate value the phosphorus value was calculated (Olsen and Sommers 1982).

3. Results and discussion

3.1 Inventory Data

The inventory of trees is considered an important tree management tool for centuries (Tate 1985). These methods are utilized by researchers to gather the basic information about the group of trees or individual trees such as tree density in a forest, tree height and its diameter at height. Table 1. depicted the basic information regarding the inventory data across different agroforestry systems such agrisilviculture, agri hoticulture, agrisilvihorticulture and agrihortisilviculture. The results depicted that the DBH (cm) across all selected agroforestry systems ranged from 12.98 cm to 18.34 cm while tree height (m) ranged from 9.87 m to 12.32 m. The maximum DBH (18.34 cm) and height (12.32 m) was measured in agricilviculture system, followed by agri silvi horticulture systems (16.44 cm & 11.65 m). The minimum tree height (9.87 m) and diameter at breast height (13.24 cm) is computed for agri horticulture system.

3.2 Biomass Production

The results regarding biomass production and accumulation in trees and crops as well as in the completely different agroforestry systems is described in table 2. The above ground biomass in crops across all four selected agroforestry systems ranged from 11.10 Mg ha^{-1} to 14.55 Mg ha^{-1} while the belowground biomass in crops ranged from 2.67 Mg ha^{-1} to 4.07 Mg ha^{-1}. The total above and below ground biomass contributed by crops of selected agroforestry systems in this study ranged from 12.22 Mg ha^{-1} to 18.62 Mg ha^{-1}. The maximum total biomass in crops is computed for agri silvihorticulture system (18.62 Mg ha^{-1}), followed by agri silviculture system (15.79 Mg ha^{-1}) whereas, the minimum total biomass in crops is calculated for agrihorticulture system (12.22 Mg ha^{-1}). On average basis, the amount of above and belowground biomass was 11.88 Mg ha^{-1} and 3.32 Mg ha^{-1} as shown in table 1.

The above ground biomass in trees across all four selected agroforestry systems ranged from 20.81 Mg ha^{-1} to 42.87 Mg ha^{-1} while the belowground biomass in trees ranged from 5.83 Mg ha^{-1} to 9.36 Mg ha^{-1}. The total above and below ground biomass contributed by trees of selected agroforestry systems in this study ranged from 26.64 Mg ha^{-1} to 54.87 Mg ha^{-1}. The maximum total biomass in trees is computed for agri silvihorticulture system (54.87 Mg ha^{-1}), followed by agri silviculture system (42.78 Mg ha^{-1}) whereas, the minimum total biomass in trees is calculated for agrihorticulture system (26.64 Mg ha^{-1}). On average basis, the amount of above and belowground biomass across all the selected agroforestry systems was 31.16 Mg ha^{-1} and 8.72 Mg ha^{-1} as shown in table 1.

Table 1. Above, Belowground and Total biomass accumulation in different components across different agroforestry systems tehsil Dunia Pur.

		Biomass (Mg ha^{-1})		
Agroforestry Systems	Components	Crops (Mg ha^{-1})	Trees (Mg ha^{-1})	Crops + Trees (Mg ha^{-1})
Agri Silviculture	AG	12.34 ± 1.22	33.42 ± 3.44	45.76 ± 3.31

	BG	3.45 ± 0.45	9.36 ± 1.34	12.81 ± 1.59
	AG+BG (Total)	15.79 ± 1.67	42.78 ± 4.78	58.57 ± 4.90
Agri Hroticulture	AG	9.55 ± 2.39	20.81 ± 4.32	30.36 ± 4.02
	BG	2.67 ± 1.01	5.83 ± 1.09	8.50 ± 2.34
	AG+BG (Total)	12.22 ± 3.40	26.64 ± 5.41	33.66 ± 6.36
Agri-Silvi-horticulture	AG	14.55 ± 3.91	42.87 ± 2.34	57.42 ± 2.98
	BG	4.07 ± 1.11	12.00 ± 1.76	16.07 ± 1.22
	AG+BG (Total)	18.62 ± 5.02	54.87 ± 4.10	73.49 ± 4.20
Agri-horti-silviculture	AG	11.10 ± 2.31	27.54 ± 3.44	38.64 ± 2.76
	BG	3.10 ± 0.98	7.71 ±1.91	10.81 ± 2.02
	AG+BG (Total)	14.20± 3.29	35.25 ± 5.35	49.45 ± 4.78

Agroforestry systems	Tree diameter (cm)		Tree height
Agri Silviculture	18.34 ± 3.22		12.32 ± 1.39
Agri Hroticulture	13.24 ± 2.78		9.87 ± 2.22
Agri-Silvi-horticulture	16.44 ± 4.22		11.65 ± 1.67
Agri-horti-silviculture	12.98 ± 1.21		10.31 ± 2.87
Means of Agroforestry systems	AG	11.88 ± 1.44	31.16 ± 3.29
	BG	3.32 ± 1.12	8.72 ± 1.87
	AG+BG (Total)	15.20 ± 2.56	38.58 ± 5.16

The above ground biomass in crop + trees across all four selected agroforestry systems ranged from 30.36 Mg ha^{-1} to 57.42 Mg ha^{-1} while the belowground biomass in crop + trees ranged from 8.50 Mg ha^{-1} to 16.07 Mg ha^{-1}. The total above and below ground biomass contributed by crop + trees of selected agroforestry systems in this study ranged from 33.66 Mg ha^{-1} to 73.49 Mg ha^{-1}. The maximum total biomass in crop + trees is computed for agri silvihorticulture system (73.49 Mg ha^{-1}), followed by agri silviculture system (58.57 Mg ha^{-1}) whereas, the minimum total biomass in crop + trees is calculated for agrihorticulture system (33.66 Mg ha^{-1}). On average basis, the amount of above and belowground biomass across all the selected agroforestry systems was 43.04 Mg ha^{-1} and 12.05 Mg ha^{-1} as shown in table 1.

Figure 2 depicted the overall biomass accumulation in four different agroforestry systems in tehsil Dunia pur, District Lodhran. The order of biomass accumulation was: agrisilvihorticulture> agrisilviculture> agrihortisilviculture> agrihorticulture. The maximum above and below ground biomass was accumulated in agrisilvihorticulture, followed by agrisilviculture, agrihortisilviculture while the minimum above and belowground biomass was computed in agrihorticulture as given in fig.4.1. In agrisilviculture system, the above ground biomass was 45.76 Mg ha^{-1} while the below ground biomass was 12.81 Mg ha^{-1}. In agri horticulture system, the above ground biomass was 30.36 Mg ha^{-1}, whereas, the belowground biomass was 8.50 Mg ha^{-1}. The aboveground measured biomass in agrisilvihorticulture system was 57.42 Mg ha^{-1} and the belowground biomass was 16.07 Mg ha^{-1}, while in agrihortisilviculture system, the above and belowground biomass was 38.64 Mg ha^{-1} and 10.81 Mg ha^{-1}, respectively.

3.3 Total Carbon stock (Vegetation + Soil)

Table 2. described the aboveground biomass carbon, belowground biomass carbon, total biomass carbon, soil carbon at the depth of 0-30cm and total ecosystem carbon stock in different agroforrstry systems. The aboveground biomass ranged from 14.57 Mg ha^{-1} to 27.56 Mg ha^{-1} with maximum amount in agrisilvihorticulture system and minimum amount in agrihorticulture system. Similar trend was observed for belowground and total biomass carbon across the study area. The maximum total biomass carbon was 34.73 Mg ha^{-1} and minimum was 18.65 Mg ha^{-1}. Soil carbon as a depth of 0-30 cm was in order of: Agrisilvihorticulture system> agrihortisilviculture> agrisilviculture> agrihorticulture. The maximum soil carbon was 55.67 Mg ha^{-1} and it was observed in Agrisilvihorticulture system, followed by agrihortisilviculture 52.38 Mg ha^{-1}, whereas the minimum amount of soil carbon 48.78 Mg ha^{-1} was measured in agrihorticulture system as shown in table 2.

Overall, the maximum total ecosystem carbon (soil + vegetation) was 90.40 Mg has Agrisilvihorticulture system, followed by 79.13 Mg ha^{-1} agrihortisilviculture, while the minimum ecosystem carbon was computed in agrihorticulture system and it was 67.43 Mg ha^{-1} (table 2).

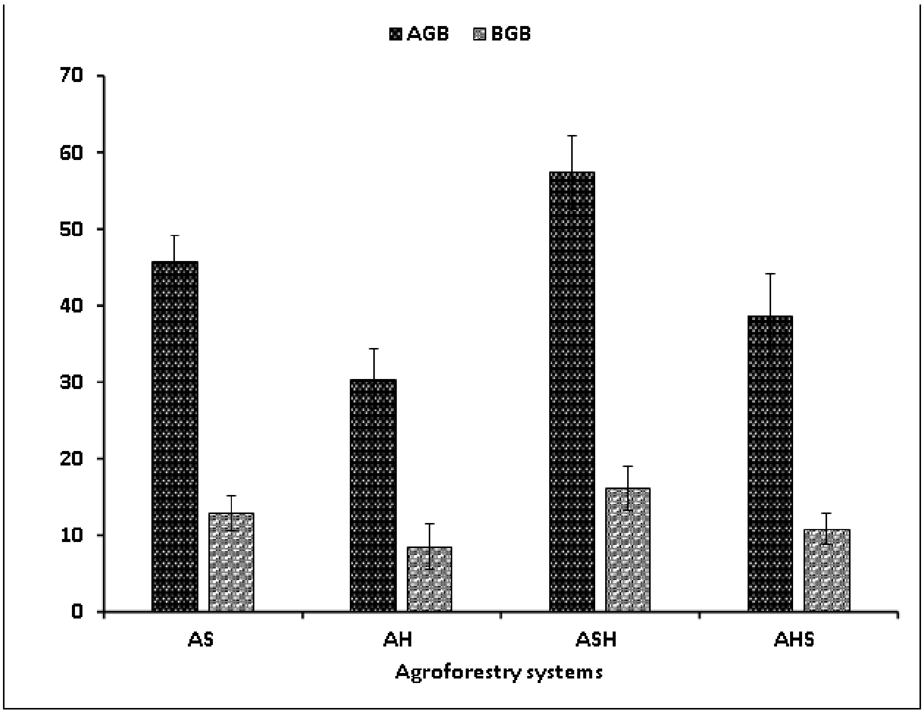

Figure 2. Tree Phenotypic Trait Measurements.

Table 2. Total ecosystem carbon stock (soil + vegetation) in different components across different agroforestry systems in tehsil Dunia Pur.

	Total Ecosystem carbon (Mg ha-1)				
Agroforestry Systems	Aboveground biomass carbon	Belowgound biomass carbon	Total Biomass carbon	Soil carbon (0-30 cm)	Total Ecosystem carbon
Agri Silviculture	21.96 ± 2.22	6.15 ± 1.8	28.11 ± 4.02	51.02 ± 6.55	79.13 ± 10.57
Agri Hroticulture	14.57 ± 1.89	4.08 ± 0.98	18.65 ± 2.87	48.78 ± 4.76	67.43 ± 7.63
Agri-Silvi-horticul-ture	27.56 ± 3.02	7.17 ± 1.09	34.73 ± 4.11	55.67 ± 5.98	90.4 ± 10.09
Agri-horti-silvicul-ture	18.54 ± 1.35	5.19 ± 0.80	23.74 ± 2.15	52.38 ± 7.22	76.11 ± 9.37

3.4 Chemical Properties

In this section, the impact of different agroforestry systems on soil physioco chemical properties was observed. This section explains the role of different agroforestry systems in soil fertility and its improvement.

3.5 Soil EC

Figure 3, explains the effect of different agroforestry systems on soil EC in the study area. The results depicted that maximum soil EC was estimated at 0-15 cm soil and it decreased with the increase of soil depth. At 0-15 cm depth, soil EC was greater (3.01 dSm^{-1}) in agrihortisilviculture system, followed by agrisilvihorticulture system (2.87 dSm^{-1}) whereas the minimum soil EC was measured under agrisilviculture system: 2.34 dSm^{-1}. However, the soil EC was remarkably decreased at 15-30 cm depth. The order of soil EC for 15-30 cm depth for all agroforestry system was in the order of: by agrihortisilviculture system > agrihorticulture system> agrisilviculture system > agrisilvihorticulture system. The higher EC (2.22 dSm^{-1}) was computed at 15 -30 cm depth for agri-hortisilviculture system while minimum soil EC at the same depth was measured for agrisilviculture system as depicted in figure 4.3.

3.6 Organic Matter

Figure 4, explains the effect of different agroforestry systems on soil organic matter in the study area. The results depicted that maximum soil organic matter was estimated at 0-15 cm soil and it decreased with the increase of soil depth. At 0-15 cm depth, soil organic matter was greater (1.67 %) in agrisilviculture system, followed by agrisilvihorticulture system (1.6 %) whereas the minimum soil organic matter was measured under agrihortisilviculture system: 1.52 %. However, the soil organic matter was remarkably decreased at 15-30 cm depth. The order of soil organic matter for 15-30 cm depth for all agroforestry system was in the order of: by agrisilviculture system > agrisilvihorticulture system > agrihorticulture system > agrihortisilviculture system. The higher organic matter (1.47 %) was computed at 15 -30 cm depth for agrisilviculture system while minimum soil organic matter (1.35 %) at the same depth was measured for agrisilviculture system as depicted in figure 4.

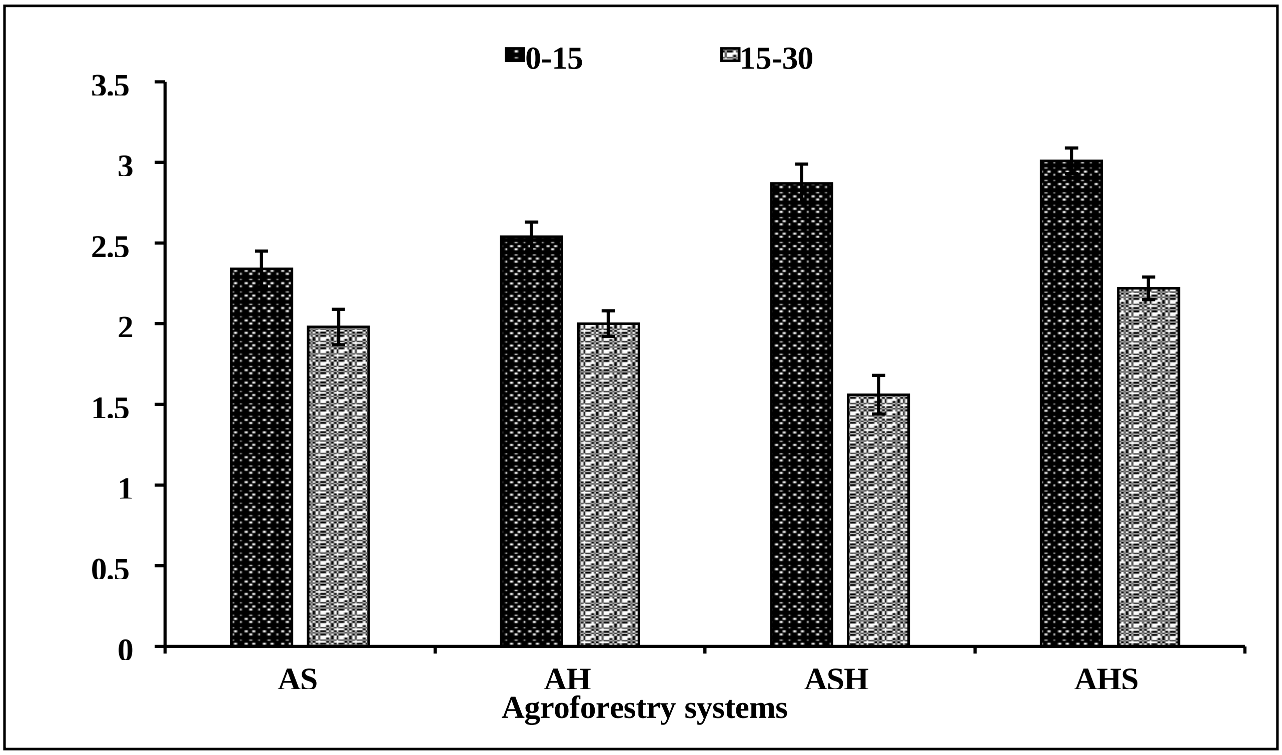

Figure 3. Effect of different agroforestry systems on soil EC at two depths in tehsil Dunia Pur.

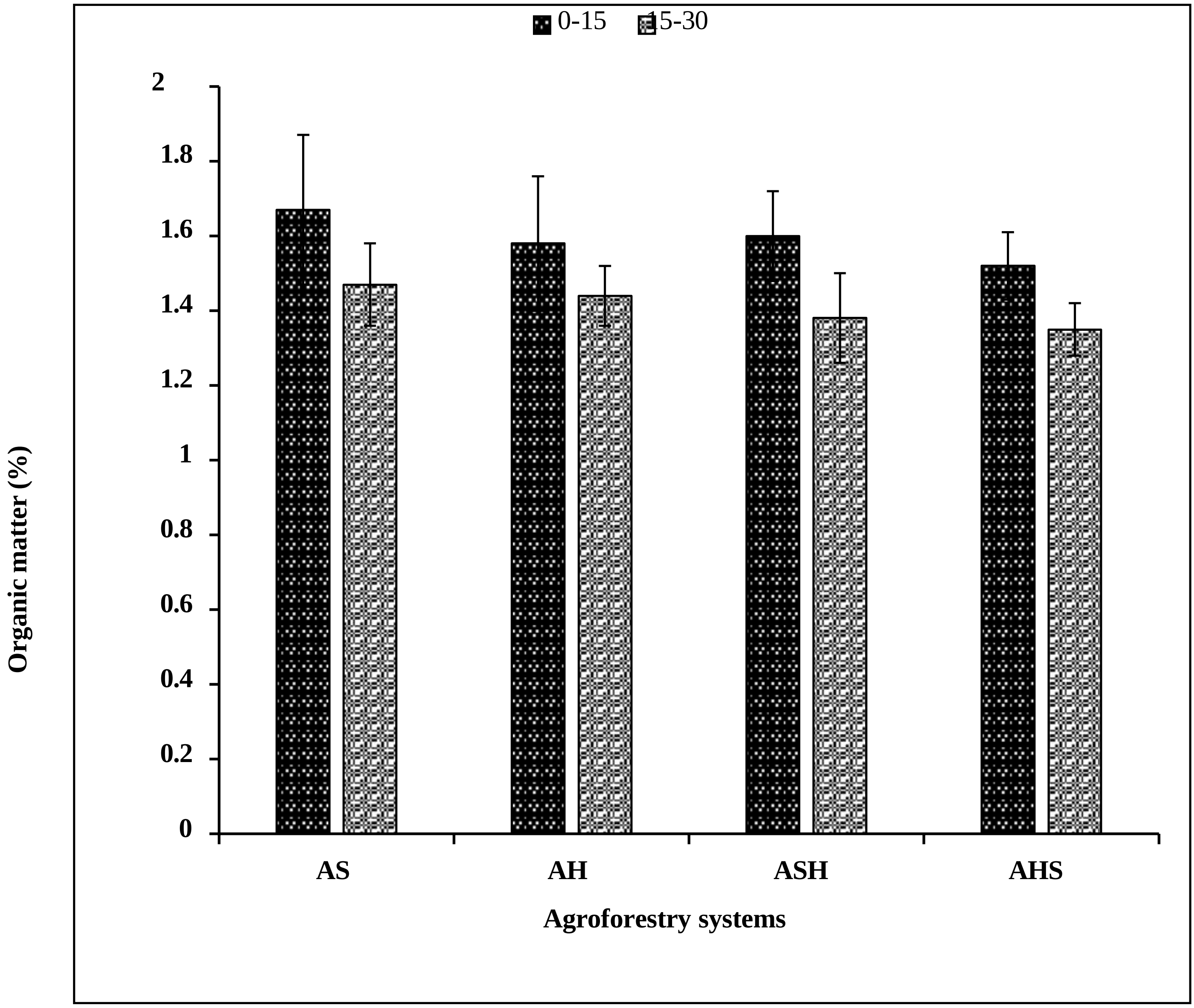

Figure 4. Effect of different agroforestry systems on soil organic matter at two depths in tehsil Dunia Pur.

3.7 Soil Nitrogen

Figure 5, explains the effect of different agroforestry systems on soil nitrogen in the study area. The results depicted that maximum soil nitrogen was estimated at 0-15 cm soil and it decreased with the increase of soil depth. At 0-15 cm depth, soil nitrogen was greater (0.68 %) in agrisilviculture system, followed by agrihortisilviculture system (0.62 %) whereas the minimum soil nitrogen was measured under agrihorticulture system: 0.57 %. However, the soil nitrogen was remarkably decreased at 15-30 cm depth. The order of soil nitrogen for 0-15 cm depth for all agroforestry system was in the order of: agrisilviculture system > agrihortisilviculture system > agrisilvihorticulture system > agrihorticulture system. The higher nitrogen (0.51 %) was computed at 15 -30 cm depth for agrisilvihorticulture system while minimum soil nitrogen at the same depth was measured for agrihortisilviculture system as depicted in figure 5.

3.8 Soil Potassium

Figure 6 explains the effect of different agroforestry systems on soil potassium in the study area. The results depicted that maximum soil potassium was estimated at 0-15 cm soil and it decreased with the increase of soil depth. At 0-15 cm depth, soil potassium was greater (172 mg kg^{-1}) in agrihorticulture system, followed by agrisilviculture system (165 mg kg^{-1}) whereas the minimum soil potassium was measured under agrisilvihorticulture system: 153 mg kg^{-1}. However, the soil potassium was remarkably decreased at 15-30 cm depth. The order of soil potassium for 15-30 cm depth for all agroforestry system was in the order of: agrihortisilviculture system > agrisilviculture system > agrihortisilviculture system > agrihorticulture system. The higher soil potassium (149 mg kg^{-1}) was computed at 15 -30 cm depth for agrihortisilviculture system while minimum soil potassium (138 mg kg^{-1}) at the same depth was measured for agrihorticulture system as depicted in figure 5.

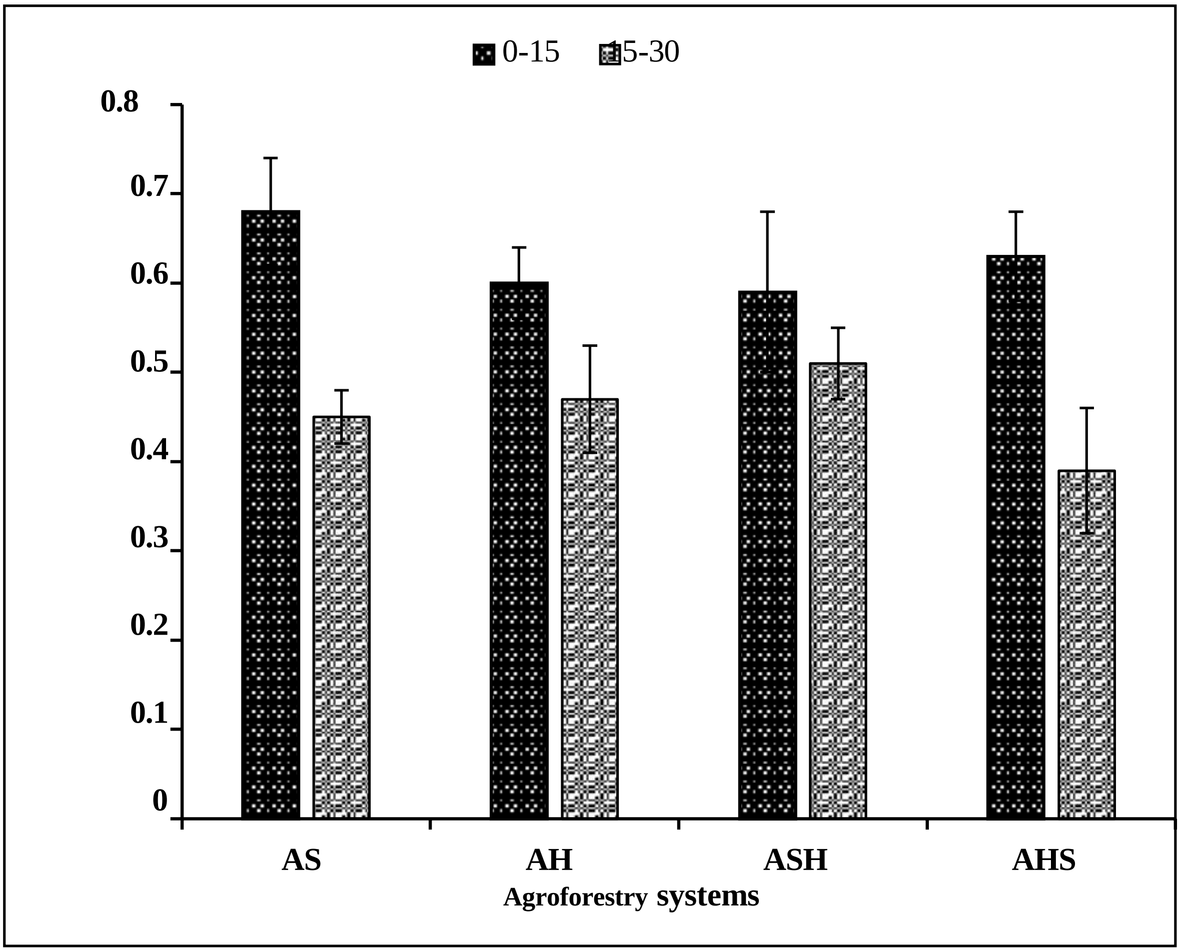

Figure 5. Effect of different agroforestry systems on soil nitrogen at two depths in tehsil Dunia Pur.

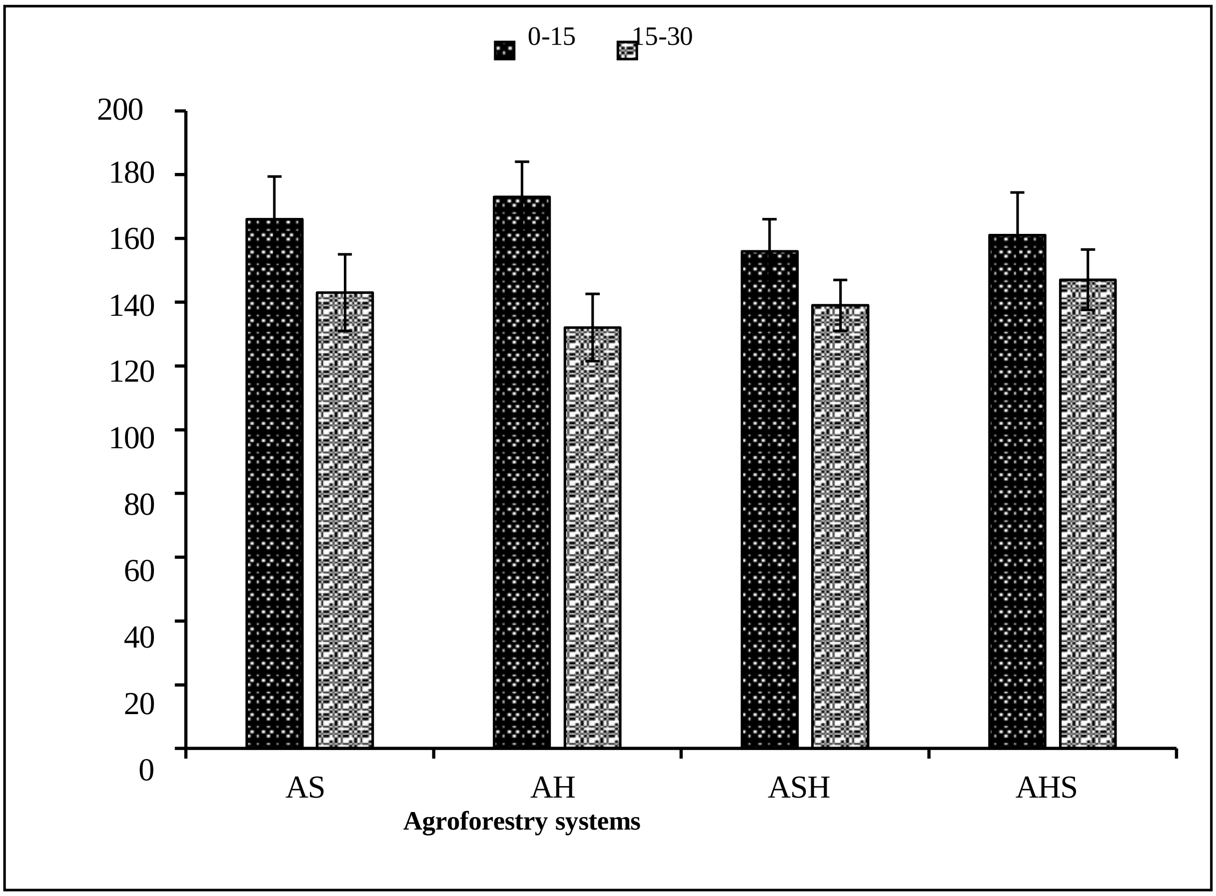

Figure 6. Effect of different agroforestry systems on soil potassium at two depths in tehsil Dunia Pur.

3.9 Soil Phosphorous

Figure 8 explains the effect of different agroforestry systems on soil phosphorous in the study area. The results depicted that maximum soil phosphorous was estimated at 0-15 cm soil and it decreased with the increase of soil depth. At 0-15 cm depth, soil phosphorous was greater (7.15 mg kg^{-1}) in agrihortisilviculture system, followed by agrisilviculture system (7.01 mg kg^{-1}) whereas the minimum soil phosphorous was measured under agrihorticulture system: 6.1 mg kg^{-1}. However, the soil phosphorous was remarkably decreased at 15-30 cm depth. The order of soil phosphorous for 0-15 cm depth for all agroforestry system was in the order of: agrihortisilviculture system > agrisilviculture system > agrisilvihorticulture system > agrihorticulture system. The higher phosphorous (6.21 mg kg^{-1}) was computed at 15 -30 cm depth for agrihortisilviculture system while minimum soil phosphorous at the same depth was measured for agrisilvihorticulture system as depicted in figure 8.

3.10 Soil pH

Figure 7 explains the effect of different agroforestry systems on soil pH in the study area. The results depicted that maximum soil pH was estimated at 0-15 cm soil and it decreased with the increase of soil depth. At 0-15 cm depth, soil pH was greater (8.32) in agrisilviculture system, followed by agri-hortisilviculture system (8.2) whereas the minimum soil pH was measured under agri-silvihorticulture system: 7.43. However, the soil pH was remarkably decreased at 15-30 cm depth. The order of soil pH for 15-30 cm depth for all agroforestry system was in the order of: agri-silviculture system > agri-horticulture system > agri-silvihorticulture system > agri-hortisilviculture system. The higher soil pH (7.8) was computed at 15 -30 cm depth for agri-silviculture system while minimum soil pH (7.29) at the same depth was measured for agri-hortisilviculture system as depicted in figure 8.

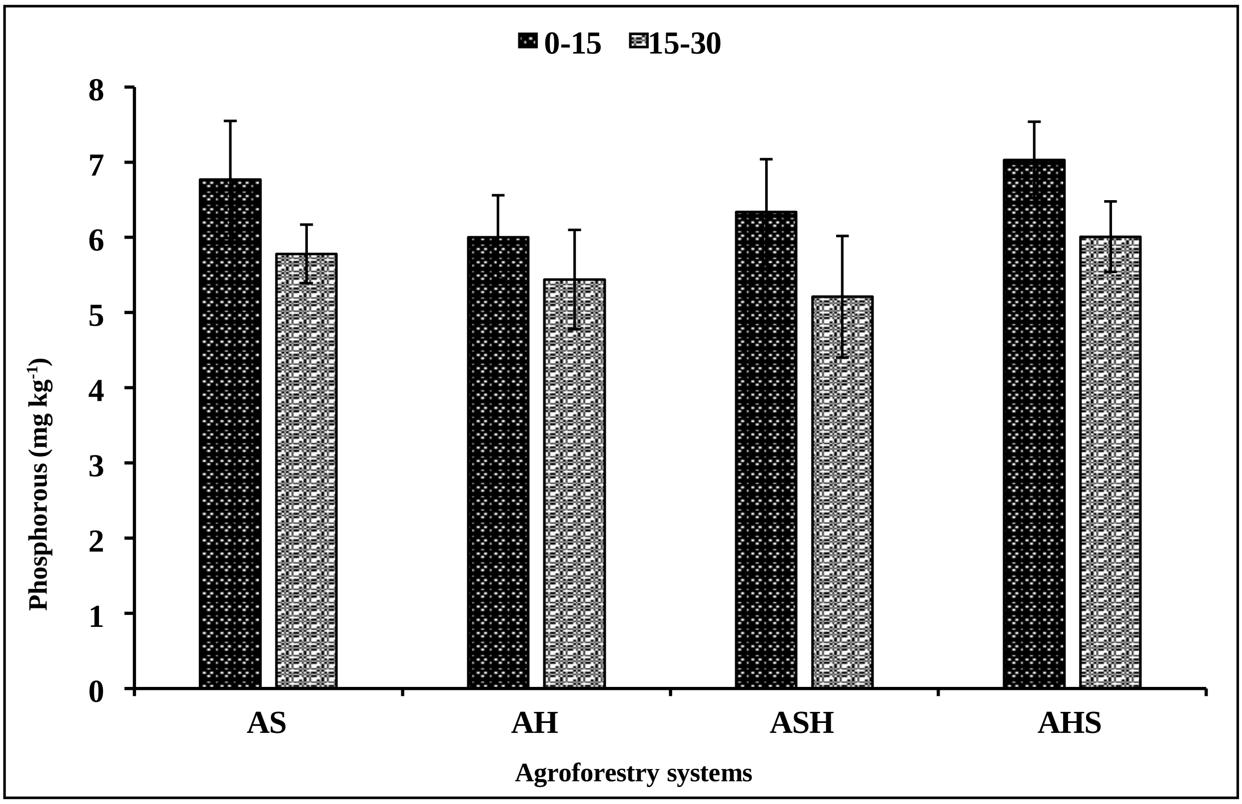

Figure 7. Effect of different agroforestry systems on soil phosphorous at two depths in tehsil Dunia Pur.

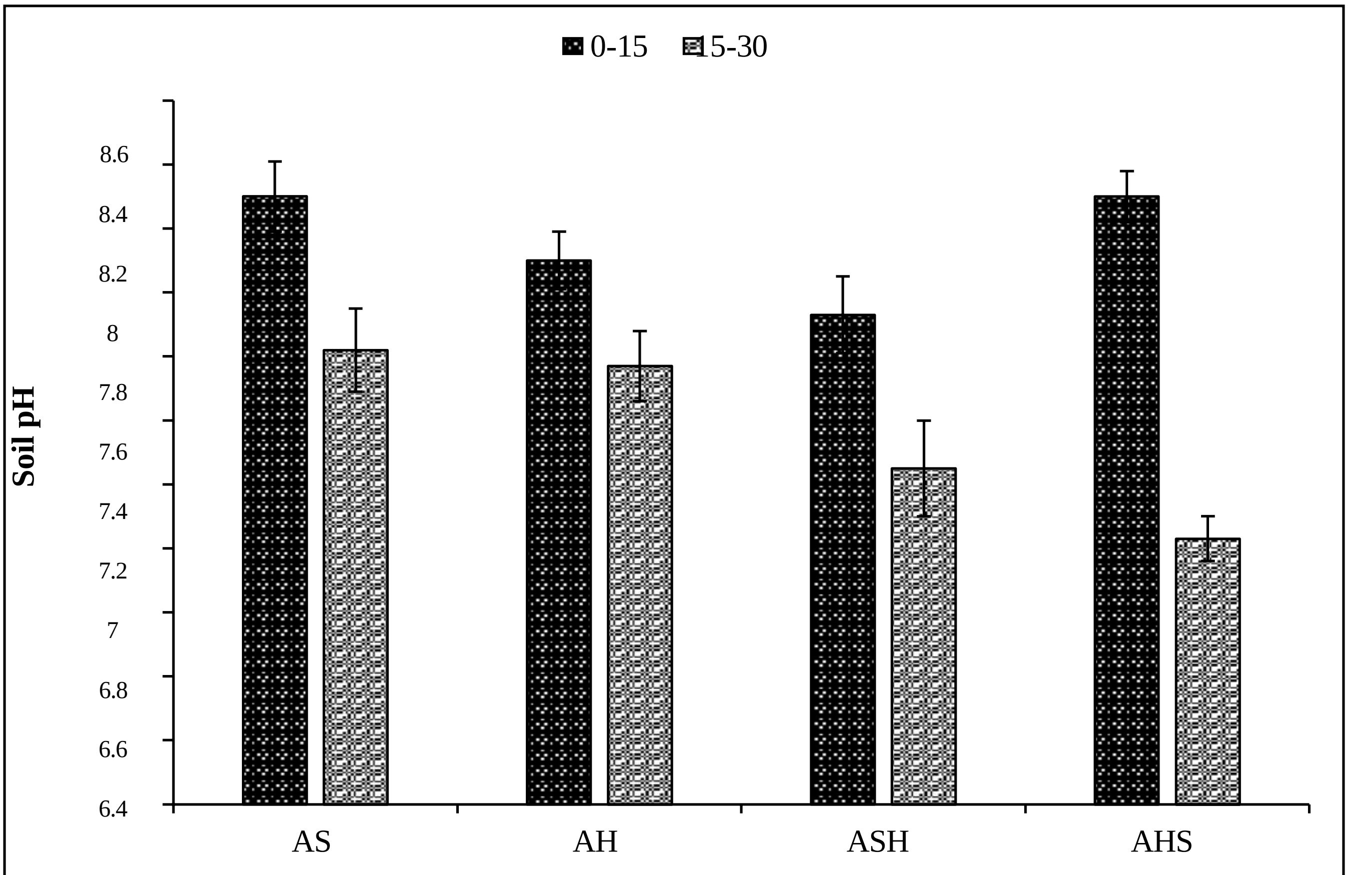

Figure 8. Effect of different agroforestry systems on soil pH at two depths in tehsil Dunia Pur.

6. Conclusions

The present study was conducted to assess the role of different agroforestry systems to combat climate change through carbon sequestration in tehsil Dunia Pur, District Lodhran. The inventory of trees is considered an improtant tree management tool for centuries. The results depicted that the DBH (cm) across all selected agroforestry systems ranged from 12.98 cm to 18.34 cm while tree height (m) ranged from 9.87 m to 12.32 m. The maximum DBH (18.34 cm) and height (12.32 m) was measured in agricilviculture system, followed by agri silvi horticulture systems (16.44 cm & 11.65 m). The minimum tree height (9.87 m) and diameter at breast height (13.24 cm) is computed for agri horticulture system.The order of biomass accumulation was: agrisilvihorticulture> agrisilviculture> agrihortisilviculture> agrihorticulture. The maximum total biomass in crop + trees is computed for agri silvihorticulture system (73.49 Mg ha^{-1}).,. In agrisilviculture system, the above ground biomass was 45.76 Mg ha^{-1} while the below ground biomass was 12.81 Mg ha^{-1}. In agri horticulture system, the above ground biomass was 30.36 Mg ha^{-1}, whereas, the belowground biomass was 8.50 Mg ha^{-1}. The aboveground measured biomass in agrisilvihorticulture system was 57.42 Mg ha^{-1} and the belowground biomass was 16.07 Mg ha^{-1}, while in agrihortisilviculture system, the above and belowground biomass was 38.64 Mg ha^{-1} and 10.81 Mg ha^{-1}, respectively. The above ground carbon in crops above and below ground carbon contributed by trees of selected agroforestry systems in this study ranged from 12.87 Mg ha^{-1} to 26.33 Mg ha^{-1}. The maximum total carbon in trees is computed for agri silvihorticulture system (26.33 Mg ha^{-1}), followed by agri silviculture system (20.53 Mg ha^{-1}) whereas, the minimum total carbon in trees is calculated for agrihorticulture system (12.87 Mg ha^{-1}). On average basis, the amount of above and belowground carbon across all the selected agroforestry systems was 14.95 Mg ha^{-1} and 4.18 Mg ha^{-1}.The maximum total carbon in crop + trees is computed for agri silvihorticulture system (35.27Mg ha^{-1}), followed by agri silviculture system (21.96 Mg ha^{-1}) whereas, the minimum total carbon in crop + trees is calculated for agrihorticulture system (18.65 Mg ha^{-1}). Soil carbon as a depth of 0-30 cm was in order of: Agrisilvihorticulture system> agrihortisilviculture> agrisilviculture> agrihorticulture. The maximum soil carbon was 55.67 Mg ha^{-1} and it was observed in Agrisilvihorticulture system, followed by agrihortisilviculture 52.38 Mg ha^{-1}, whereas the minimum amount of soil carbon 48.78 Mg ha^{-1} was measured in agrihorticulture system. Overall, the maximum total ecosystem carbon (soil + vegetation) was 90.40 Mg ha^{-1} Agrisilvihorticulture system, followed by 79.13 Mg ha^{-1} agrihortisilviculture, while the minimum ecosystem carbon was computed in agrihorticulture system and it was 67.43 Mg ha^{-1}. The order of soil EC for 15-30 cm depth for all agroforestry system was in the order of: by agrihortisilviculture system > agrihorticulture system > agrisilviculture system > agrisilvihorticulture system.At 0-15 cm depth, soil potassium was greater (172 mg kg^{-1}) in agrihorticulture system, followed by agrisilviculture system (165 mg kg^{-1}) whereas the minimum soil potassium was measured under agrisilvihorticulture system: 153 mg kg^{-1}. The order of soil potassium for 15-30 cm depth for all agroforestry system was in the order of: agrihortisilviculture system > agrisilviculture system > agrihortisilviculture system > agrihorticulture system. At 0-15 cm depth, soil pH was greater (8.32) in agrisilviculture system, followed by agrihortisilviculture system (8.2) whereas the minimum soil pH was measured under agrisilvihorticulture system: 7.43. However, the soil pH was remarkably decreased at 15-30 cm depth. The order of soil pH for 15-30 cm depth for all agroforestry system was in the order of: agrisilviculture system > agrihorticulture system > agrisilvihorticulture system > agrihortisilviculture system.

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