A comparison of soil organic carbon and total nitrogen stock capacity between cultivated, agriculture and forest soils

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Abstract

Land use type and change cause perturbation of the ecosystem and can influence the Carbon (C) stocks and fluxes. In particularly, conversion of forest to agricultural ecosystems affects several soil properties but especially soil organic carbon (SOC) concentration and stock. In this present study, main aim was to assess the differences in soil organic carbon and total nitrogen contents and stock capacities in adjacent cultivated land (wheat production-CS), agriculture (walnut garden- WS and apple garden-AS), forestland (black pine-BS) and mixture of cultivated + poplar (CS+PS) lands. Soil samples were collected from six soil depths (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, 25-30 cm) and analyzed for soil pH, soil texture, bulk density, soil organic carbon (SOC) and total nitrogen (TN) contents and stock capacities. Results showed that the BS had the highest mean SOC (9.52%), followed by the WS (4.84%), the CS + PS (4.83%), the CS (4.43%) and AS (3.85%). Mean TN content was also highest in the BS (0.63%) followed by the CS (0.157%), the AS (0.154%), the CS + PS (0.147%) and the WS (0.131%). Mean SOC stock capacity was highest for the BS (246 mg C ha^{-1}), followed by the WS (146 mg C ha^{-1}), the CS + PS (141 mg C ha^{-1}), the CS (132 mg C ha^{-1}) and the AS (111 mg C ha^{-1}). Mean total N stock capacity was 4.70 mg N ha^{-1} for the CS, 4.37 mg N ha^{-1} for the AS, 4.28 mg N ha^{-1} for the CS + PS, 4.14 mg N ha^{-1} for the BS and 3.93 mg N ha^{-1} for the WS. In conclusion, the results indicate that land use type can significantly influence the soil organic carbon and total nitrogen dynamics in the northeast part of Turkey.

Keywords: Forest soil, Agriculture soil, Soil organic carbon, Total nitrogen, Stock capacity

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1. Introduction

There has been a drastic increase in the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs) since the industrial revolution. This anthropogenic enrichment of GHGs in the atmosphere and the cumulative radiative forcing of all GHGs has led to an increase in the average global surface temperature of 0.6 ^{0}C since the late 19th century, with the warming rate of 0.17 ^{0}C/decade [1]. Human activities related to land use influence the exchange of greenhouse gases between terrestrial ecosystems and the atmosphere and hence have an impact on climate change. Land-use change (especially deforestation) has been historically responsible for a large part of the cumulative human-induced greenhouse gas (GHGs) emissions [2, 3]. Like natural disturbances such as fire and drought, land-use change affects vegetation and soil dynamics, often prompting longer term increases in carbon release or decreases in carbon uptake. Deforestation, degradation of native grazing lands, and conversion to cropland have prompted losses of 450–800 Gt of CO_2 from biomass and soil carbon pools—equivalent to 30–40% of cumulative fossil fuel emissions [4, 5]. Many studies that focused on the effects of land conversion from forest to cultivated land concluded that land-use change induces a reduction of the available soil C and a decrease in its quality. Land use change causes perturbation of the ecosystem and can influence the C stocks and fluxes. In particular, conversion of forest to agricultural ecosystems affects several soil properties but especially soil organic carbon (SOC) concentration and stock. Several changes of soil quality occur when virgin soil is cultivated; many researchers have observed changes of quantitative parameters, such as organic carbon or nitrogen content [6, 7]. Long term experimental studies have confirmed that SOC is highly sensitive to Land Use Change [8]. Thus, even a relatively small increase or decrease in soil carbon content due to changes in land use or management practices may result in a significant net exchange of C between the soil C pool and the atmosphere [9].

Different studies have shown that the effects of land use conversion on soil properties, soil organic carbon and total nitrogen stock capacity are variable, so that more researches that focus on different ecological regions and land use types are required. Turkey covers approximately 22.3 Mha forest, corresponding to 28.6% of Turkey’s land area. The greatest part of forestland in Turkey lies within high land mountain ecosystems. However, increasing public demand for various needs has led to the conversion of natural forestlands to other uses such as cropland, apple garden, walnut garden. Qualitative estimate of land use type effects on soil organic carbon and total nitrogen stock capacities are still scarce in the world and not much study available in literature from Turkey. The knowledge of soil organic carbon and total nitrogen stock capacities between cultivated, agriculture, forest and agroforestry lands under the same climate condition is more scarce and inconclusive.

In this context, main objective of this present study was to determine the differences in soil organic carbon and total nitrogen concentrations and their stock capacities under the same climate conditions with land use change using cultivated land (wheat production-CS), agriculture (walnut garden- WS and apple garden-AS), forestland (black pine-BS) and mixture of cultivated + poplar (CS+PS) lands.

2. Materials and Methods

2.1. Site description and sampling

The study was carried out in Kastamonu, northwest of Turkey (41°23′19″ N, 33°46′57″ E). The altitudes of the studied areas were at 930 m above sea-level. In the study area, terrestrial climatic conditions exist, i.e. winters are long, cold and snowy, whereas summers are short and warm. The seasonal and daily temperatures show big extreme values and precipitation is generally low. The weather data for 1975-2010 (Kastamonu Meteorology Station, at 800 m) indicate that precipitation averages 495 mm annually. Average monthly temperatures range from 20.2 ˚C in July to -0.8 ˚C in January.

We carried out the study at 5 different land use sites, which were adjacent to each other (Figure 1), named as (1) wheat cultivated site (CS), (2) walnut garden (WS), (3) apple garden (AS), (4) mixture of cultivated + poplar tree site (CS+PS), and (5) black pine (*Pinus nigra* Arnold.) stands (BS). Soil sampling was conducted in the autumn of 2016. Three adjacent subplots (replicates) were identified and sampled for each land use types. Mineral soil sampling was confined to the upper 30 cm of soils, as changes in soil C and N were expected to occur first here. A soil core device with an inner diameter of 5 cm was used for soil sampling to a depth of 20 cm. Mineral soil sample cores were taken from 6 different soil depths as 0–5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25–30 cm soil depth, and passed through a 2 mm sieve to remove stones and gravel.

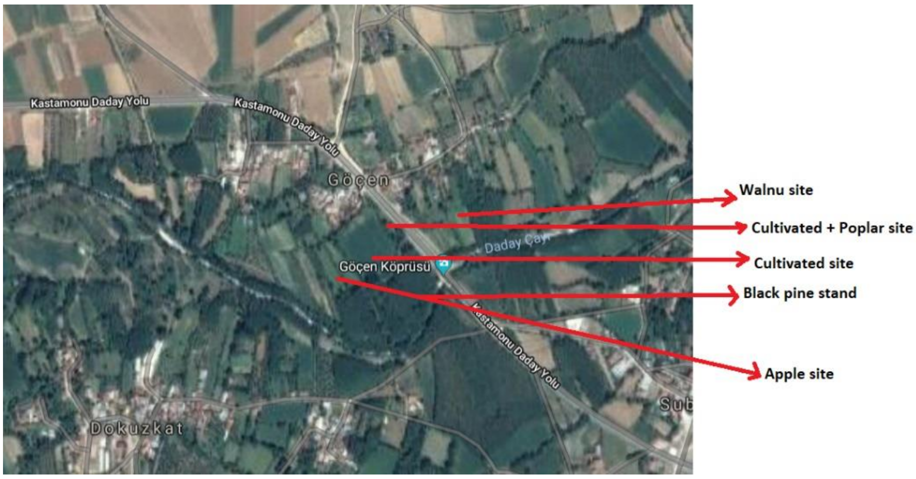

Figure 1. Location of the study area

2.2. Soil analysis

Soil pH was measured in a 1:2.5 mixture of deionized water and soil using a glass calomel electrode (Origon 420 digital pH meter), after equilibration for 1h. Soil pH was determined for soil samples from the 0–20 cm layer. Soil texture analyses were also done on soil samples from the 0–20 cm soil layer. Soil texture (sand, silt and clay) was determined using the hydrometer method of Bouyoucos [10]. The moisture content of soils was calculated by weight loss after drying aliquots of ca. 10 g of soil for 24 h at 105 ºC. Bulk density was determined by weight loss after drying the undisturbed soil core.

Soil organic carbon (C) and total nitrogen (N) concentrations in the soil samples were determined using the CNH-S elementary analyzer (Eurovector EA3000-Single) according to the dry combustion method [11]. The soil organic carbon

(SOC) and total nitrogen (TN) pools were then calculated by multiplying soil volume, soil bulk density, and SC or nitrogen content and expressed as mg ha^{-1} [12]. Soil mass is calculated as**:**

$$Mi = BDi \times Ti \times 10^4 \quad (1)$$

where Mi is dry soil mass (mg ha^{-1}), BDi is bulk density (mg m^{-3}), Ti is the thickness of the soil layer (m), and 10^4 is a unit conversion factor (m^2 ha^{-1}). The fixed depth (FD) determination of areal C or (N) stock is calculated as:

$$Ci \text{ or } Ni;fixed = Concentration\ Ci \text{ or } Ni \times Mi \quad (2)$$

where Ci;fixed is the C or N mass to a fixed depth (kg C or N ha^{-1}) and Concentration Ci or Ni is the C or N concentration (kg C or N mg^{-1}).

2.3. Data analysis

Analysis of variance (ANOVA) was applied for analyzing the differences in soil organic carbon and total nitrogen concentrations and stock capacities between the 5 different land use types and between the 6 different soil depths using the SPSS program (Version 11 for Windows). Following the results of ANOVAs, Tukey's honestly significant difference (HSD) test ($\alpha = 0.05$) was used for significance.

3. Results and Discussion

3.1. Differences in soil pH, texture and bulk density

Mean soil pH, texture and bulk density from five different land use types are given in Table 1. Soil sand content was higher under the WS (65%) and BS (66%) than the CS+PS (58%), the AS (57%) and the lowest under the CS (53%). Percent silt content was the highest under the AS (17%), and the lowest under the other sites which showed similar values ranged between 11% to 13%. In contrast to the soil sand content, the soil clay content was the highest under the CS (34%) and the lowest under the BS (22%) and WS (24%). Soil pH and soil bulk density were similar between the 5 different land use types.

3.2. Differences in soil organic C and total N concentrations

Mean soil organic carbon and nitrogen concentrations from five different land use types at the 6 soil depths are given in Table 2. At the top soil of 5 cm, the BS had the greatest SOC concentration (9.84%), followed by the CS+PS (5.56%), the WS (5.42%), the AS (4.94%) and the CS (4.75%). Similar trend was also noted for the other soil depths with the highest SOC concentration for the BS, and the lowest SOC concentrations for the AP and the CS, while the CS+PS and the WS showed medium values between the highest and the lowest values (Table 2). There was an indication that soil organic carbon concentration decreased with increasing soil depth, but this was not statistically significant.

Table 1. Description of the sites

Land use types	Age (year)	Elevation (m.a.s.l)	MAT (ºC)	MAP (mm)	Sand (%)	Silt (%)	Clay (%)	Soil Types	pH	Bulk density (g/cm³)
Wheat cultivated site	Over 100	930	9.6	489	53a	13a	34b	Clay loam	7.97a	1.00a
Walnut garden	Over 25				65b	11a	24a	Sandy Clay Loam	7.75a	1.01a
Apple garden	0ver 40				57a	17b	26a	Sandy Clay Loam	7.84a	0.97a
Black pine stand	85				66b	12a	22a	Sandy Clay Loam	7.86a	0.87a
Mixture of wheat cultivated and Poplar site	Over 100 + 20				58a	13a	29b	Clay loam	8.02a	0.96a

* Values for each land use types followed by different letters are significantly different (P<0.05) based on Tukey's test.

Table 2. Mean soil organic carbon and total nitrogen content at the 6 soil depths from 5 different land use types

Land use types	Depth (cm)	SOC (%)	Total N (%)
Wheat cultivated site (CS)	0-5	$4.75^{Aa} \pm 0.76$	$0.15^{Aa} \pm 0.03$
	5-10	$4.66^{Ba} \pm 0.28$	$0.20^{Aa} \pm 0.07$
	10-15	$4.51^{Ba} \pm 0.37$	$0.14^{Aa} \pm 0.03$
	15-20	$4.27^{Ba} \pm 0.46$	$0.14^{Aa} \pm 0.02$
	20-25	$4.08^{Ba} \pm 0.27$	$0.15^{Aa} \pm 0.02$
	25-30	$4.32^{Ba} \pm 0.71$	$0.15^{Ba} \pm 0.02$
Walnut garden (WS)	0-5	$5.42^{Bc} \pm 1.19$	$0.22^{Bc} \pm 0.02$
	5-10	$5.52^{Cc} \pm 0.71$	$0.14^{Ab} \pm 0.03$
	10-15	$4.96^{Bb} \pm 0.82$	$0.12^{Ab} \pm 0.03$
	15-20	$4.84^{Bb} \pm 0.44$	$0.12^{Ab} \pm 0.01$
	20-25	$4.33^{Ba} \pm 0.46$	$0.11^{Ab} \pm 0.04$
	25-30	$4.00^{Ba} \pm 0.93$	$0.08^{Aa} \pm 0.04$
Apple garden (AS)	0-5	$4.94^{Ab} \pm 0.42$	$0.27^{Bb} \pm 0.02$
	5-10	$3.82^{Aab} \pm 0.21$	$0.15^{Aa} \pm 0.02$
	10-15	$3.78^{Aab} \pm 0.35$	$0.13^{Aa} \pm 0.01$
	15-20	$3.56^{Aa} \pm 0.17$	$0.13^{Aa} \pm 0.03$
	20-25	$3.31^{Aa} \pm 0.21$	$0.11^{Aa} \pm 0.01$
	25-30	$3.71^{Aa} \pm 0.66$	$0.13^{Ba} \pm 0.03$
Black pine stand (BS)	0-5	$9.84^{Ca} \pm 0.25$	$0.20^{Bb} \pm 0.03$
	5-10	$9.82^{Da} \pm 0.22$	$0.18^{Ab} \pm 0.06$
	10-15	$9.62^{Ca} \pm 0.55$	$0.20^{Bb} \pm 0.02$
	15-20	$9.28^{Ca} \pm 0.65$	$0.15^{Aa} \pm 0.02$
	20-25	$9.29^{Ca} \pm 0.36$	$0.12^{Aa} \pm 0.03$
	25-30	$9.26^{Ca} \pm 0.14$	$0.13^{Ba} \pm 0.02$
Mixture of wheat cultivated and Poplar site (CS+PS)	0-5	$5.56^{Ba} \pm 0.96$	$0.15^{Aa} \pm 0.04$
	5-10	$4.73^{Ba} \pm 1.06$	$0.14^{Aa} \pm 0.06$
	10-15	$4.42^{Ba} \pm 1.09$	$0.15^{Aa} \pm 0.05$
	15-20	$4.54^{Ba} \pm 0.80$	$0.17^{Aa} \pm 0.08$
	20-25	$4.99^{Ba} \pm 1.18$	$0.12^{Aa} \pm 0.03$
	25-30	$4.74^{Ba} \pm 1.01$	$0.15^{Ba} \pm 0.02$

As for the total nitrogen concentration, at the top soil of 5 cm, the AS had the greatest TN concentration (0.27%), followed by the WS (0.22%), the BS (0.20%), the CS+PS and the CS (0.15%). At the soil depth of 5-10 cm, the CS

(0.20%) and the BS (0.18%) together showed higher total N than the other three sites which had similar total N concentration (about 0.15%). For the other soil depths, all sites had more or less similar total N concentrations. As seen for the soil organic carbon concentrations, there was also an indication that total nitrogen concentration decreased with increasing soil depth, but this was also not statistically significant.

3.3. Differences in soil organic C and total N stocks capacities

Mean soil organic carbon and nitrogen stock capacities at the 6 soil depths from 5 different land use types are given in Table 3. At the top 5 cm, the BS had the greatest SOC stock capacity (46.5 mg C ha^{-1}), whereas the AS had the lowest (21.7 mg C ha^{-1}) (Table 3). In general, the SOC stock capacity decreased with increasing soil depth for the CS, WS and AS, whereas it showed an increase with the soil depths for the BS and the CS+PS (Table 3). When 0-30 cm soil depth was considered, the SOC stock capacity was highest under the BS (246 mg C ha^{-1}), followed by the WS (146 mg C ha^{-1}), the CS+PS (141 mg C ha^{-1}), the CS (132 mg C ha^{-1}) and the lowest under the AS (111 mg C ha^{-1}) (Figure 2).

Table 3. Mean soil organic carbon and total nitrogen stock capacities at the 6 soil depths from 5 different land use types

Land use types	Depth (cm)	Soil Carbon stocks (mg C ha^{-1})	Soil Nitrogen stocks (mg N ha^{-1})
Wheat cultivated site (CS)	0-5	$24.6^{Ac} \pm 0.69$	$0.78^{Aa} \pm 0.07$
	5-10	$24.6^{Bc} \pm 0.80$	$1.07^{Cb} \pm 0.37$
	10-15	$22.2^{Bc} \pm 0.61$	$0.71^{Ba} \pm 0.09$
	15-20	$19.8^{Aa} \pm 0.64$	$0.66^{Aa} \pm 0.05$
	20-25	$20.3^{Ba} \pm 2.40$	$0.76^{Ba} \pm 0.16$
	25-30	$20.2^{Ba} \pm 3.28$	$0.71^{Ca} \pm 0.15$
Walnut garden (WS)	0-5	$24.3^{Aa} \pm 3.13$	$0.97^{Bc} \pm 0.03$
	5-10	$27.0^{Cb} \pm 4.21$	$0.68^{Bb} \pm 0.17$
	10-15	$22.7^{Ba} \pm 7.91$	$0.54^{Ab} \pm 0.18$
	15-20	$26.7^{Bb} \pm 5.63$	$0.65^{Aa} \pm 0.07$
	20-25	$23.8^{Ba} \pm 6.02$	$0.63^{Bb} \pm 0.29$
	25-30	$22.2^{Ba} \pm 4.99$	$0.45^{Aa} \pm 0.19$
Apple garden (AS)	0-5	$21.7^{Aa} \pm 3.12$	$1.20^{Cb} \pm 0.15$
	5-10	$19.5^{Aa} \pm 1.17$	$0.75^{Ba} \pm 0.08$
	10-15	$18.5^{Aa} \pm 1.71$	$0.65^{Ba} \pm 0.03$
	15-20	$16.8^{Aa} \pm 3.32$	$0.62^{Aa} \pm 0.10$
	20-25	$16.5^{Aa} \pm 1.89$	$0.54^{Aa} \pm 0.07$
	25-30	$18.0^{Aa} \pm 2.41$	$0.62^{Ba} \pm 0.11$
Black pine stand (BS)	0-5	$46.5^{Bc} \pm 5.15$	$0.91^{Bc} \pm 0.09$
	5-10	$45.2^{D} \pm 1.98$	$0.83^{Cc} \pm 0.15$
	10-15	$32.9^{Ca} \pm 13.0$	$0.67^{Bb} \pm 0.24$
	15-20	$39.7^{Cb} \pm 8.54$	$0.62^{Aa} \pm 0.14$
	20-25	$35.8^{Da} \pm 2.89$	$0.44^{Aa} \pm 0.07$
	25-30	$46.3^{Dc} \pm 4.23$	$0.46^{Aa} \pm 0.11$
Mixture of wheat cultivated and Poplar site (CS+PS)	0-5	$23.8^{Ab} \pm 6.76$	$0.64^{Aa} \pm 0.20$
	5-10	$18.9^{Ac} \pm 3.97$	$0.54^{Aa} \pm 0.23$
	10-15	$21.9^{Bc} \pm 9.55$	$0.74^{Bb} \pm 0.32$
	15-20	$23.4^{Bb} \pm 5.86$	$0.87^{Bb} \pm 0.47$
	20-25	$27.0^{Cc} \pm 10.1$	$0.67^{Ba} \pm 0.27$
	25-30	$26.4^{Cc} \pm 9.69$	$0.81^{Cb} \pm 0.21$

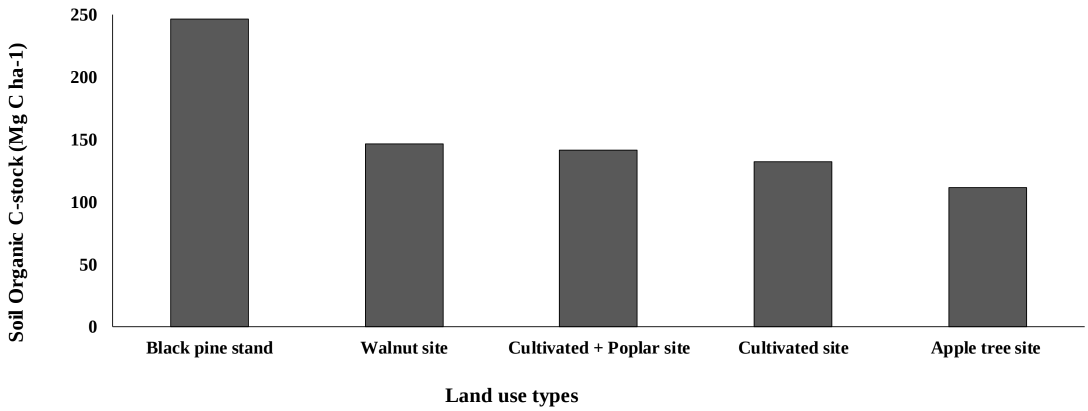

Figure 2. Mean soil organic carbon stock capacity under different land use types at the depth of 0-30 cm

The Tukey's Honestly Significant Difference (HSD) test was used to determine significantly different means between the land use types and between the soil depths. Means with the same letter are not significantly different by columns. The upper case letters for the differences between the land use types, and the lower case letters for the differences between the soil depths.

Compared to the SOC stock capacity, total nitrogen stock capacity at the top 5 cm was highest under the AS (1.20 mg N ha^{-1}) and lowest under the CS+PS (0.64 mg N ha^{-1}). Total nitrogen stock capacity also decreased with increasing soil depth, with the exception of the CS+PS which showed an increase with the soil depth. In total soil depth of 0-30 cm, the CS had the highest total nitrogen stock (4.70 mg N ha^{-1}), followed by the AS (4.37 mg N ha^{-1}), the CS+PS (4.28 mg N ha^{-1}), the BS (4.14 mg N ha^{-1}) and the lowest the WS (3.93 mg N ha^{-1}) (Figure 3).

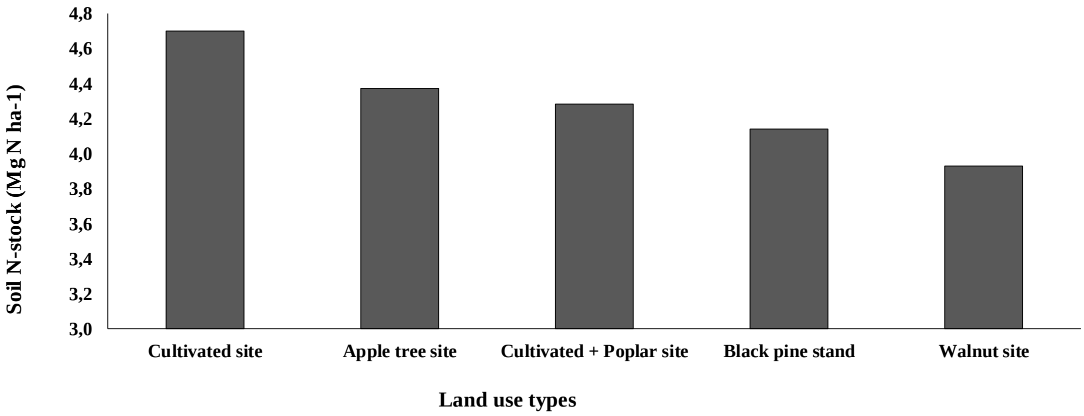

Figure 3. Mean total nitrogen stock capacity under different land use types at the depth of 0-30 cm

This present study has shown that land-use change can have significant effects on soil organic carbon and total nitrogen stock capacities. Mineral soil in forest ecosystems (presented by black pine stands) contained higher organic carbon stock than the other cultivated (presented by wheat crop), agricultural (presented by walnut and apple garden site) and agroforestry lands (presented by wheat + poplar). Those results in the present study show general trends with the other studies, i.e. larger soil organic carbon stock capacity under forest ecosystems than under cultivated, agricultural and agroforestry lands on the same soil [11, 13]. The soil organic carbon loss in cultivated and agricultural soils could be due to the organic matter reduced input, as well as to the reduced physical protection of soil from erosion and the increased decomposition rate as a consequence of tillage [13, 14]. Disturbances can deplete agricultural systems of carbon stocks [15]. Tillage is used to enhance seed beds and controls weeds, but tillage also breaks up soil aggregates, changes soil microclimate, and enhances decomposition of soil organic matter and depletion of soil carbon stocks [16]. Soil C is oxidized to CO_2 and lost to the atmosphere contributing to the increase of greenhouse gases in the atmosphere. Moreover, tillage improves soil aeration, destroys macro-aggregates and changes the hydrological cycle, with an increase of the respiration rates and ultimately an additional depletion of the C pool [17, 18]. Bare fallow enhances the water balance, but substantially reduces carbon inputs. Harvesting a large proportion of plant biomass enhances yields of useful material, but decreases carbon inputs to the soil [19]. It is widely recognized that deep ploughing exerts a strong impact on soil aggregates, increases soil erosion, brings to the surface soil material poor in organic matter and accelerates the decomposition of humus. Celik [20], in a study on soils from the southern region of Turkey, found a decrease in soil organic matter in cultivated soils, compared to forest and pasture soils, by 44% and 48% in the 0.0–0.1m layer and by 48% and 50% in the 0.1–0.2m layer over 12 years, respectively.

Forest tree species, however, produce more litters with different litter quality than agricultural species, thus the differences in the litter biochemical quality between forest tree and agricultural species affects litter decomposition rates, and eventually influence soil carbon stocks [21]. In general, tree litter contains more components that are difficult to decompose than agricultural species [22]. Especially, forest tree litters with higher lignin concentrations result in litter accumulation in the forest floor and formation of acid compounds [23]. Under these acid soils, fauna is less active, decreasing the amount of humus mixing through mineral soil [24] and leaving more material in the forest floor.

As for total nitrogen stock capacity, the wheat cultivated land showed the higher total nitrogen stocks. The higher soil total nitrogen in the wheat cultivated land soils could be due to fertilizer used to get more production by the farmer. Green manures can have the added benefit that they enhance system nitrogen balance, which further increases productivity. Some studies [25] state that the N mineralization decreases when the clay amount increases in the soil. We obtained opposite results in wheat cultivated land; soil total nitrogen stock capacity increased with the amount of clay increased. According to the paper by McLauchlan [26], clay concentration correlated positively with aggregate size and the rate of aggregate accumulation and the potential N mineralization decreases. But that was not the case in this present study.

4. Conclusion

This study has shown that under similar climate conditions, soil carbon and nitrogen contents and stock rates are significantly influenced by land-use change in the northwest of Turkey. Soil carbon is one of the principal components of soil organic matter (SOM), which also contains significant amounts of water and nitrogen—all of which are exchanged between the biosphere and the atmosphere to affect Earth's atmospheric chemistry, energy and water budgets, and climate. Therefore, improving our understanding of the factors that affect forest soil carbon storage is fundamentally important for anticipating changes in ecosystem goods and services ranging from forest products, to water resources, to greenhouse gas mitigation. Mineral soil carbon and nitrogen stocks vary with land-use change (forest to cultivated and agricultural land). Significant differences in the soil carbon stocks between forest stands and cultivated land support the general hypothesis that land-use transformation from forest to cultivated land or other usage (agriculture land) causes tremendous losses of terrestrial carbon that reduce the potential for land sustainability.

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