Original Research Article

Distribution of Forms of Carbon and Carbon Stock in Different Land Management Units of Kanginhal Sub-Watershed in Northern Dry Zone of Karnataka, India

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Abstract

A study was undertaken during 2017-18 to identify the distribution of forms of carbon and carbon stock in different land management units (LMUs) of Kanginhal sub-watershed in Gadag district of Karnataka. Horizon-wise soil samples were collected from each LMU and analyzed for organic carbon, water soluble carbon, active carbon, inorganic carbon and total carbon. Organic carbon, water soluble carbon and active carbon were decreased with dept in all the LMUs, whereas inorganic and total carbon did not follow any definite trend. Water soluble carbon and active carbon exhibited significant positive relationship with organic carbon, whereas inorganic and total carbon exhibited significant and positive relationship with CaCO$_3$. Organic, water soluble and active carbon were significantly and positively correlated with each other, whereas inorganic and total carbon was significantly and positively correlated with each other. Highest organic carbon stock was recorded in LMU-5, whereas highest inorganic and total carbon stocks were recorded in LMU-6. Inorganic carbon stock contribution was more to the total carbon stock compared to organic carbon stock.

Keywords

Land management units, Organic carbon, Water soluble carbon, Active carbon, Inorganic carbon, Total carbon and carbon stock

Introduction

The carbon cycle is a fundamental part of life on earth. Total carbon includes both organic carbon and inorganic carbon (free CaCO$_3$). However, emphasis would be more given to the organic form of carbon because inorganic form is relatively stable and is not influenced by land management practices.

Intensive cropping leads to a decrease in soil organic matter (SOM) content, particularly in arid and semiarid conditions and leads to decline in soil fertility and subsequently soil quality. The SOM not only enhances the soil quality by improving several soil properties related to physical, chemical and biological conditions but also improves environmental quality by reducing atmospheric carbon dioxide (CO$_2$). Soil organic carbon (SOC) is the amount of carbon stored in the soil is a component of soil organic matter - plant and animal materials in the soil that are in various stages of decay. SOC in soil exists mainly in two pools viz., active and passive pools. Active pool consists of living microorganisms
and their products and has short turnover rate. It includes microbial biomass carbon, water soluble carbon, active carbon, water soluble carbohydrates etc. and these are sensitive to the management practices. Therefore active pool considered as a good indicator of minor changes in the SOC (Xia et al., 2010). Passive pool is more stable having high turnover rate. Soil inorganic carbon (SIC) exists in soil as primary and secondary carbonates. Primary carbonates are formed from parent material, whereas secondary carbonates are formed from primary carbonates. Secondary carbonates formed when dissolved CO$_2$ precipitates carbonates and bicarbonates with Ca and Mg.

In rainfed, arid and semiarid regions of India, next to poor rain water management, depletion of nutrients caused by low SOC stock is an important cause of soil degradation resulting in poor soil physical quality, loss of favourable biology and occurrence of multiple nutrient deficiencies resulting in low productivity. Therefore, one of the most important determinants of the present and future condition of farmland (i.e., sustainability) is the management applied to it (Hellkamp et al., 2000). As management decisions are generally made based on the combinations of land attributes, it is important to identify the levels and geographical patterns of biophysical constraints and land degradation potential of the planned area on a spatial and temporal basis. A land management unit (LMU) is defined as: “A homogeneous block of land that responds in a similar way under similar management.” LMUs are best assessed using a combination of physical factors (e.g. soil type, slope, aspect), major management factors (e.g. dryland versus irrigated areas, different arable or horticultural crops, dairy effluent disposal areas, etc.) and history of previous use and management. Some producers will find that their property has several LMUs while others can treat their entire property as a single LMU. Knowledge about vertical distribution of nutrients in each LMU is useful to know the inherent capacity of soils to supply nutrients. As roots of most of the crop plants go beyond the surface layer and draw part of their nutrient requirements from the sub surface layers of the soil (Sangwan and Singh, 1993). Different cropping systems were followed under different LMUs. After harvesting of crops, different crops add different amount of root biomass to the soil. Therefore, it is necessary to study the amount of carbon added to the soil and carbon stock accumulated in different LMUs.

**Materials and Methods**

Kanginhal sub-watershed (Gadag taluk, Gadag district) was selected as study area and is located in Northern dry zone of Karnataka between 15°25ʹ-15°30ʹ N latitudes and 75°41ʹ-75°45ʹ E longitudes, covering an area of 3693.87 ha, bounded by Lakkundi village in the south, Neeralagi village in the north and Haralapura village in the east and Nagasamudra in the west (Fig. 1). The major parent material in the sub-watershed is weathered schist. The climate of the area is semi-arid or hot tropical and monsoonic type. The maximum temperature during summer was 38.2 °C and the minimum temperature was 14.8 °C in winter. Mean maximum temperature was 32.85 °C and mean minimum temperature was 19.18 °C. The average annual rainfall was 539.8 mm. It was well distributed with southwest monsoon (June to September) bringing 315 mm and northeast monsoon about 121 mm rain during October and November months. About 88 mm of rainfall was also received during the summer months (April-may). Entire sub-watershed is having dark grey to black colour with clay texture. The soil depth is very shallow to very deep and gradient of land was nearly level to very gently sloping. The soils come under
moderately eroded and some portion of the soils comes under slight eroded class. The sub-watershed was subjected to the detail of LRI using IRS P6 LISS IV data at 1:7920 scale in Sujala-III project. Soil resources were mapped at soil phase level and identified six LMUs (Fig. 2) (Anon., 2017). From each LMU one series was selected and for each series one representative profile was selected. From each profile horizon-wise samples were collected during 2016 to study the vertical distribution of forms of carbon and carbon stock. The organic carbon content of finely ground (0.2 mm) soil samples was determined by using Walkley and Black’s wet oxidation method (Sparks, 1996). The water soluble carbon was determined using the method as described by McGill et al., (1986). In brief, 10 g of soil was shaken for 1 hour with 20 ml of soil, followed by centrifugation (6000 rpm), filtration and titration against standard ferrous sulphate. The active carbon was determined by the modified method of Blair et al., (1995) as outlined by Weil et al., (2003). In brief, active carbon was determined by shaking 5 g air dried soil with 20 ml of 0.02 M KMnO₄ for 2 minutes (horizontal shaker-120 rpm), followed by centrifugation and measuring the light absorbance at 550 nm by colorimeter. The inorganic carbon (free calcium carbonate) content of soil samples was determined by rapid acid titration method as described by Piper (2002) and expressed in g kg⁻¹. Total carbon was determined by using CHNS analyzer (Vario EL cube model). Carbon stock for each LMU was calculated by using the formula:

\[ C_{\text{stock}} = C_{\text{conc}} \times BD \times D \times A \]

Where,

- \( C_{\text{stock}} \) \( \rightarrow \) Carbon stock (Mg)
- \( C_{\text{conc}} \) \( \rightarrow \) Carbon content in the soil (g g⁻¹)
- BD \( \rightarrow \) Bulk density (Mg m⁻³)
- D \( \rightarrow \) Depth (m)
- A \( \rightarrow \) Area of LMU (m²)

The experimental results were subjected to statistical analysis adopting Fisher’s method of analysis of variance as outlined by Gomez and Gomez (1984). Testing of significance was done by SPSS 16.0 version and values are given at 5 per cent and 1 per cent level of significance.

**Results and Discussion**

The organic carbon content ranged from 2,300 to 9,000 mg kg⁻¹ and it decreased with depth in all the LMUs (Table 1). It might be due to addition of organic materials in the surface soils through litter fall, external applications, etc. which generally occurs at the surface. Similar results were also observed by Majumdar (2014) in the soils of Northern transition zone of Karnataka and Sharma et al., (2014) in the foothill Himalayas under different land use systems. The highest organic carbon content was observed in Ap horizon of LMU-5 due to more addition of organic matter through crop residues and roots, as legumes are the main crops and lowest in Ap horizon of LMU-1 due to very shallow depth and poor management practices.

Water soluble carbon is easily degraded by microorganisms and it plays key role in soil formation. The water soluble carbon distribution is similar to the soil organic carbon in all the LMUs. The water soluble carbon values decreased with depth in all the LMUs and it ranged from 12.3 to 54.6 mg kg⁻¹ (Table 1). It may be due to decrease in organic carbon content down the depth. Similar results were also observed by Min et al., (2011) in the soils of China, Majumdar (2014) in the soils of Northern transition zone of Karnataka and Sharma et al., (2014) in the foothill Himalayas under different land use systems. The highest water soluble carbon content was observed in Ap horizon of LMU-5 due to the addition of
higher organic inputs and lowest in Ap horizon of LMU-1 due to lack of addition of organic manures, crop residues and poor management practices.

The active carbon also called reactive carbon is readily degradable by microorganisms and used as an indicator of change produced by cropping and soil management practices that manipulates SOM content. In different LMUs, active carbon content ranged from 2,810 to 5,090 mg kg\(^{-1}\) and decreased with depth due to decrease in organic carbon content, as it is in accordance with organic carbon content.

The active carbon content was highest in Ap horizon of LMU-5 and lowest in Ap horizon of LMU-1 (Table 1).

The inorganic carbon values ranged from 4,200 to 33,960 mg kg\(^{-1}\) (Table 1). It increased with depth in LMU-3, LMU-4 and LMU-6. It was due to accumulation of displaced calcium from exchange complex from of upper layers (Barade and Gowaikar, 1965). Higher inorganic carbon in LMU-2 and LMU-3 was restricted to upper horizons. The inorganic carbon content was highest in Bssk horizon of LMU-6 and lowest in Ap horizon of LMU-3. Among the Ap horizons, it was lowest in LMU-3 (4,200 mg kg\(^{-1}\)) and highest (19,680 mg kg\(^{-1}\)) in LMU-5 and LMU-6.

The total carbon values ranged from 11,600 to 37,060 mg kg\(^{-1}\) (Table 1). The total carbon content decreased with depth in LMU-2 and LMU-5, increased in LMU-6 and did not follow any definite trend in LMU-3 and LMU-4. The highest total carbon content was observed in Bssk horizon of LMU-6 and lowest in Ap horizon of LMU-3. Among the Ap horizons, it was highest (28,680 mg kg\(^{-1}\)) in LMU-5 and lowest (11,600 mg kg\(^{-1}\)) in LMU-3. The distribution of total carbon depends on both organic and inorganic carbon; however, contribution from inorganic carbon was more.

Organic carbon stock ranged from 6 to 112 Mg ha\(^{-1}\) and 667 to 2,75,579 Mg per LMU. Inorganic carbon stock ranged from 40 to 544 Mg ha\(^{-1}\) and 4,202 to 9,63,076 Mg per LMU.

**Fig.1 Location map of the study area**
Fig. 2 Land management units (LMU) of Kanginhal sub-watershed

Fig. 3 Carbon stock in different LMUs of Kanaginhal sub-watershed
### Table 1: Vertical distribution of forms of carbon in different LMUs

| LMU   | Series | Horizon | Depth (cm) | Organic -C | Water soluble- C | Active- C | Inorganic- C | Total- C (mg kg⁻¹) |
|-------|--------|---------|------------|-------------|-----------------|-----------|--------------|-------------------|
| LMU-1 | HGK    | Ap      | 0-20       | 2,300       | 12.3            | 2,810     | 14,520       | 16,820            |
| LMU-2 | NPT    | Ap      | 0-18       | 4,300       | 27.0            | 3,230     | 15,840       | 20,140            |
|       |        | Bw      | 18-46      | 3,500       | 20.7            | 3,030     | 15,000       | 18,500            |
| LMU-3 | VKP    | Ap      | 0-14       | 7,400       | 42.9            | 4,000     | 4,200        | 11,600            |
|       |        | Bw₁     | 14-39      | 7,000       | 39.6            | 3,910     | 6,000        | 13,000            |
|       |        | Bw₂     | 39-72      | 6,200       | 37.8            | 3,740     | 6,600        | 12,800            |
| LMU-4 | MVD    | Ap      | 0-19       | 7,800       | 45.6            | 4,210     | 17,040       | 24,840            |
|       |        | Bw₁     | 19-36      | 7,000       | 39.0            | 3,890     | 17,760       | 24,760            |
|       |        | Bw₂     | 36-52      | 5,800       | 35.2            | 3,570     | 18,240       | 24,040            |
|       |        | Bw₃     | 52-76      | 5,500       | 33.9            | 3,490     | 18,600       | 24,100            |
|       |        | BCk     | 76-109     | 4,300       | 26.4            | 3,220     | 19,680       | 23,980            |
| LMU-5 | NGT    | Ap      | 0-22       | 9,000       | 54.6            | 5,090     | 19,680       | 28,680            |
|       |        | Bw      | 22-62      | 5,500       | 34.2            | 3,500     | 20,280       | 25,780            |
|       |        | Bss     | 62-118     | 4,700       | 30.3            | 3,360     | 19,680       | 24,380            |
|       |        | BC      | 118-154    | 4,300       | 27.3            | 3,250     | 16,080       | 20,380            |
| LMU-6 | MGR    | Ap      | 0-17       | 7,400       | 43.2            | 4,090     | 19,680       | 27,080            |
|       |        | Bw      | 17-25      | 6,200       | 37.2            | 3,710     | 23,640       | 29,840            |
|       |        | Bss     | 25-98      | 4,700       | 30.9            | 3,410     | 26,400       | 31,100            |
|       |        | Bssk    | 98-152     | 3,100       | 15.6            | 2,900     | 33,960       | 37,060            |

### Table 2: Carbon stock in different LMUs of Kanginhal sub-watershed

| LMU   | Area (ha) | Organic carbon stock | Inorganic carbon stock | Total carbon stock | Organic carbon stock | Inorganic carbon stock | Total carbon stock |
|-------|-----------|----------------------|------------------------|--------------------|----------------------|------------------------|--------------------|
|       |           | (Mg per ha)          | (Mg per LMU)           |                    | (Mg per ha)          | (Mg per LMU)           |                    |
| LMU-1 | 105       | 6                    | 40                     | 46                 | 667                  | 4,202                  | 4,869              |
| LMU-2 | 83        | 24                   | 96                     | 119                | 1,980                | 7,938                  | 9,918              |
| LMU-3 | 83        | 66                   | 59                     | 125                | 5,494                | 4,889                  | 10,383             |
| LMU-4 | 54        | 84                   | 265                    | 348                | 4,518                | 13,784                 | 18,302             |
| LMU-5 | 2,460     | 112                  | 391                    | 504                | 2,75,579             | 9,63,076               | 12,38,655          |
| LMU-6 | 793       | 87                   | 544                    | 631                | 69,078               | 43,1,496               | 5,00,574           |
Table 3: Correlation between the forms of carbon and soil properties in different LMUs

|                | Sand  | Silt  | Clay  | CaCO₃ | CEC   | pH    | EC    | OC    |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Organic-C      | -0.385| 0.154 | 0.383 | -0.306| 0.504 | -0.151| 0.032 | 1.000**|
| Water soluble-C| -0.338| 0.119 | 0.347 | -0.291| 0.491*| -0.163| 0.027 | 0.988**|
| Active-C       | -0.380| 0.183 | 0.355 | -0.235| 0.375 | -0.132|-0.005 | 0.965**|
| Inorganic-C    | 0.199 | -0.540*| 0.130 | 1.000**| 0.044 | 0.466*| 0.520*| -0.306 |
| Total-C        | 0.107 | -0.525*| 0.239 | 0.967**| 0.181 | 0.448 | 0.554*| -0.055 |

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Table 4: Correlation amongst forms of carbon in different LMUs

|                | Organic-C | Water soluble-C | Active-C | Inorganic-C | Total-C |
|----------------|-----------|-----------------|----------|-------------|---------|
| Organic-C      | 1         | 0.988**         | 0.965**  | -0.306      | -0.055  |
| Water soluble-C|           |                 |          | -0.291      | -0.042  |
| Active-C       |           |                 | 1        | -0.235      | 0.010   |
| Inorganic-C    |           |                 |          | 1           | 0.967** |
| Total-C        |           |                 |          |             | 1       |

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Total carbon stock ranged from 46 to 631 Mg ha⁻¹ and 4,869 to 12,38,655 Mg per LMU (Table 2) (Fig. 3). Organic carbon stock (per ha and per LMU) was lowest in LMU-1 (6 Mg ha⁻¹) and highest in LMU-5 (112 Mg ha⁻¹). Inorganic carbon stock and total carbon stock were lowest in LMU-1 and highest in LMU-6 (Fig. 2). Highest carbon stock related to high carbon content whereas, lowest carbon stock related to shallow depth of the soils (Singh et al., 2007).

Organic, water soluble and active carbon recorded positive correlation with silt and clay and negative correlation with sand, CaCO₃ and pH. Organic and water soluble carbon showed positive correlation with EC and significant positive correlation with CEC (r = 0.504* and r = 0.491*, respectively). Active carbon showed positive correlation with CEC and negative correlation with EC (Table 3). Correlations of active carbon fraction to CEC suggest that soil organic matter contributed to increases in soil CEC (Papini et al., 2011). SOC showed a relationship with texture only in the top layer. Fine-textured soil contain one to two fold more soil organic carbon (SOC) (Van Gestel et al., 1991). However, the results were not consistent at different depths.

Inorganic and total carbon had significant and positive correlation with CaCO₃ (r = 1.000** and r = 0.967**, respectively). However, inorganic carbon had significant positive correlation with pH (r = 0.466*) whereas, total carbon had positive correlation with pH (Table 3). It clearly indicates that as pH increases CaCO₃ content increases.

Water soluble carbon recorded a significant positive correlation with active carbon (r = 0.962**). Similar results were also found by Majumdar and Patil (2017) in the soils of Northern transition zone of Karnataka. Organic and water soluble carbon showed negative correlation with total carbon but active carbon showed positive correlation...
with total carbon. Inorganic carbon showed negative correlation with organic, water soluble and active carbon and significant positive correlation with total carbon \( (r = 0.967**) \) (Table 4).

Water soluble carbon and active carbon showed significant positive relationship with organic carbon \( (r = 0.988** \text{ and } r = 0.965**, \text{ respectively}) \) (Table 4). It clearly indicates that increase in organic carbon content leads to the increase in water soluble carbon and active carbon content. Similar results were also reported by Sofi et al., (2012) in the soils of Jammu and Kashmir and Majumdar and Patil (2017) in the soils of Northern transition zone of Karnataka.

Water soluble carbon and active carbon were derived from soil organic carbon stocks. These relationships also corroborated the good soil health under different LMUs. Similar results were also reported by Sofi et al., (2012). Inorganic carbon was significantly and positively correlated with total carbon, indicates that inorganic carbon contributed more to the total carbon (Table 4).

From the present study, it can be concluded that, management practices influenced the amount of carbon fractions and carbon stock. Organic, water soluble and active carbon decreased with depth, whereas inorganic and total carbon did not follow any definite trend. Among the pools, inorganic carbon contributed more to the total carbon. Organic, water soluble and active carbon was positively and significantly correlated among themselves and were positively correlated with silt and clay.

However, inorganic and total carbon had shown significant positive correlation among them. Carbon stock was mainly related with carbon content, depth, bulk density and area of the LMU.

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