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Long-term impacts of planted fodder grasses on soil organic carbon pool and fractions in an acid soil of the north eastern Himalayas

G. S. Yadav . A. Das . B. Kandpal . M. Nath . V. Singh . R. C. Das

ICAR Research Complex for NEH Region, Tripura Centre, Tripura 799210, West Tripura

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ABSTRACT

Natural resources of the north eastern region (NER) of India in terms of soil, water, vegetation, and soil organic carbon (SOC) are much degraded. The information on SOC pools and its fractionation into different pools under perennial forage grasses and arable lands are lacking in the low-hills of north-east India. Thus, present study was an investigation on the dynamics of SOC in a 15-year-old planted perennial fodder grass species and natural grass in comparison to arable land. Plantation of three fodder grasses like hybrid napier (*Pennisetum glaucum × P. purpureum*), congosingal (*Brachieria rosenesis*) and combo napier (*Pennisetum purpureum*) and natural grasses increased total organic carbon (TOC) pools by 41.5 to 64.4% over the pools in soils under cultivated field (59.5 Mg/ha) over the 15 years. Soils under natural grasses had higher TOC pool (97.8 Mg/ha) and Walkey and Black carbon (69.6 Mg/ha) pool than those in soils under hybrid napier (84.6 and 61.5 Mg/ha), congosignal (84.8 and 66.3 Mg/ha) and combo napier (84.2 and 64.1 Mg/ha), respectively. Passive carbon pool in soils under natural grass (46.1 Mg/ha) was significantly higher than those in soil under hybrid napier (39.4 Mg/ha), combo napier (38.2 Mg/ha), congosignal (34.9 Mg/ha) and also in arable land (26.8 Mg/ha). The relative proportions of active carbon pools were higher than that of passive carbon pools across the treatments. In general, all the C fractions were higher in soils under grasses than those in soils under arable crops. The accumulation of more proportion of TOC pools in soils under planted fodder grasses and natural grass over longer period of time and year round addition C through root decomposition of grasses helps in rehabilitation of degraded crop lands and could effectively enhance the soil C storage and stability and on other side also reduce the decomposability of C pools present in soils.

1. Introduction

Soils and vegetation together constitutes the terrestrial system and soils composed of 0.3 to 14% carbon. The top 1-meter soil contains 2157–2296 Pg (petagram = Pg = 1 × 1015 g = billion ton) carbon (C), out of which soil inorganic carbon (SIC) is 659–748 Pg, and soil organic carbon (SOC) is 1462–1548 Pg (Lal 2018). In terrestrial ecosystems vegetation is the major source of SOC, and amount of SOC in different land use is influenced through the organic matter (OM) inputs at different soil depths (Sarkar *et al.,* 2015). Change in SOC content in terrestrial ecosystem specially soils may have a greater impact on atmospheric C and consequently affects the atmospheric chemistry. Conversion of natural ecosystem to human managed system can cause loss of ~30-50 % soil C pool (Paustian *et al.,* 2016). Further, accumulation of SOC from organic inputs is likely to be influenced by its chemical composition. Further, changes in climate, fragmentation of land holding and bringing additional land under cultivation exacerbates SOC losses (Das *et al.,* 2017). Increase in land degradation due to excessive tillage, low biomass production, inadequate nutrient supplementation *etc.* resulted in a corresponding decrease of the natural reservoir of SOC (Lal 2018). It's reported that destruction of natural forests and grasslands

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*Corresponding author: anup_icar@yahoo.com caused a historic loss of 20-30 Mg C/ha and 40-50 Mg C/ha, respectively (Paustian *et al.,* 2016). Therefore, balancing the atmospheric carbon and their storage in the terrestrial biosphere is a vital way to compensate the emission of greenhouse gasses and improve the soil health and food security (Yadav *et al.,* 2017). Restoration of degraded and marginal lands, integrated nutrient management and erosion control are important options of SOC sequestration (Yadav *et al.,* 2019a).

Globally researchers are focusing on SOC because of its potential to sequestrate a substantial amount of atmospheric carbon which helps in mitigating climate change and functioning of soils (Meena *et al.,* 2018). The C present in soils and its type (organic and inorganic) and concentration vary among the land use systems and is mostly influenced by the soil and -climatic conditions (Das *et al.,* 2016a). Off-late, the C source and sink potentials associated with different land use systems has attracted considerable attention (Yadav *et al.,* 2019b). Restoration of SOC stocks (and soil fertility) by converting agricultural land back to grass/forest land and identification of SOC fractions are mostly affected by land use patterns (Thangavel *et al.,* 2018). The knowledge on magnitude and quality of organic carbon in soil is of paramount importance for impounding atmospheric C, climate change mitigation and sustaining soil functioning (Sarkar *et al.,* 2018). Globally, various estimates to minimize C losses under grassland systems are available which mostly concentrate on C sequestration in plant parts, however, information on carbon sequestration potential in soils are scanty. Perennial grasses provide greater amounts of litter from leaf and root biomass for C storage than annual cereal crops and hence, soils under grasslands generally have higher OC than croplands (Das *et al.,* 2016b). Further, chemical composition of organic inputs influence accumulation of SOC and thus, decomposability of resident time of SOC also varies with source of OM. Chemical recalcitrance of plant biomass is mostly controlled by the lignin content or lignin: N ratios (Sarkar *et al.,* 2018). For in-depth understanding of the mechanisms of C loss or build-up in soils, the SOC stocks are partitioned into labile or actively cycling pools and stable or resistant pools with varying residence time. A range of physical, chemical and biological fractionation methods are available to quantify SOC pools with distinct characteristics, functions and turnover times. Perennial tropical grasses including hybrid Napier (*Pennisetum glaucum × P. purpureum*), congosignal (*Brachieria rosenesis*), combo napier grass (*Pennisetum purpureum*) and perennial mixed grasses grow well at low and mid-altitudes of north-east India and are identified as potential forages for livestock. These forage species are known for their high biomass production (Sarkar *et al.,* 2018) to feed the livestock, which contributes to sustaining SOC (Ghosh *et al.,* 2009) and also improving soil quality. We hypothesize that planting perennial fodder grasses may influence the size of SOC pools and their dynamics due to their vibrant and fine root system. The present study was therefore undertaken with the objective to evaluate the influence of fodder crops on SOC stocks and its various pools at different soil depths in a 15-year-old field trial compared with crop lands in on a Typic Kandiudults located in the low-hills of north-east India.

2. Material and Methods

2.1 Experimental site and design

Three fodder grass species (hybrid napier, congosignal and combo napier) suitable for the region were planted in 2003 in randomized block design with three replications to provide year round fodder to dairy animal and to restore the degraded crop land through SOC buildup at ICAR Research Complex for NEH Region Tripura Centre, Lembucherra, Tripura, India. Characteristics of fodder grasses evaluated are presented in Table 1. The soils (Fine, Kaolinitic, Typic Kandiudults) of experimental sites are classified under

Table 1. Characteristics of fodder grasses grown under experiment

Species	Scientific name	Plant Type	Planting Season	Number of tillers	Cutting per year	Fresh fodder yield (Mg ha^{-1} $year^{-1}$)	Forage dry-matter yield (Mg ha^{-1} $year^{-1}$)	Dry root Biomass (Mg ha^{-1})
Hybrid napier	*Pennisetum glaucum × P. purpureum*	Clump type, Erect and succulent	Rainy season	40-50	6-8	250	41.5	3.7
Combo napier	*Pennisetum purpureum*	Clump type, Erect and less succulent	Rainy season	30-40	4-5	110	21.5	3.8
Congo signal	*Brachieria rosenesis*	Erect and bushy	Rainy season	62-68	4-5	52	12.8	3.9

Acrisols at 40-65 m above mean see level, mostly under upland toposequence. Soils are acidic in nature with low pH (4.1 to 4.4), low organic carbon (0.5% to 0.8%) and high aluminium saturation (53% to 63%) as exchangeable cations. The study site has hot summers and dry winter, receives a rainfall of more than 2000 mm annually but most of the rain fall received between April to October. The mean maximum temperature ranged from 29.2 ºC to 36.8ºC measured at 2 pm and minimum temperature 4.1 ºC to 21.4 ºC at 5 am.

2.2 Fodder grass management practices

The fodder crops were planted in individual plots of 25 m x 20 m size. We selected three subplots of 5 m x 3 m for each fodder crop and nearby plots with continuous crop cultivation and natural grass plots for the same period as the control. Treatments (three planted fodder crops, one natural grass and the control-cultivated field) were tested in a randomized block design with three replicates. Two or three root slips (0.20–0.25 m length) of the fodder species were transplanted maintaining a distance of 0.6 m x 0.6 m from hill to hill at the end of April after receiving sufficient rains. The planting materials were collected from R. K. Nagar state cattle farm, Government of Tripura. A mixture of 50% NPK and 50% cow dung manure was applied in the individual plots at the time of planting. No other fertilizer was used in the fodder crop. The first irrigation was provided at the time of planting. The second irrigation was done after five days of planting and yearly one irrigation was provided during the dry season between the months of November to January. Cow dung manure at 5 Mg/ha was applied every year after irrigation. The first cutting was obtained after 60 – 65 days of planting and yearly 5 – 7 cuttings were done. The cutting was done at a height of 15 -20 cm above the ground. In rainy season harvesting can be done after every 40 – 45 days. Land preparation for the crop in the control plots was done by plowing three times for the initial five cropping seasons and subsequently by plowing two times to reduce the mechanical stress on the land due to the effects of tillage. Good agricultural practice was followed, including manual weeding when necessary.

2.3 Soil sampling and analysis

Soil samples were collected using 10 cm scaled soil cores with 5.6 cm inner diameter from 0–15, 15–30, 30-60 and 60–100 cm depth of each soil profile for analyzing the SOC content during September 2018. The container and samples are weighed on the electric balance in the laboratory before and after drying, the dissimilarity being the mass of water initially in the sample. The gravimetric moisture content in the soil was calculated with a correction factor for moisture content determined by oven-drying at 105°C for 24 hrs. Soil bulk density (ρb) was determined by the core method (Blake and Hartge 1986) at 0–15, 15–30, 30-60 and 60–100 cm depths after oven drying at 105±1°C. The collected bulk soil samples were air-dried at room temperature (25°C), clods were broken by gently beating with a wooden hammer, extraneous roots removed, gently ground with a wooden hammer and sieved by 2 mm sieve. The retained soil bulk passed through sieve was kept in airtight plastic bags for soil analyses of physical and chemical properties. Soil organic C content of samples was determined by wet oxidation method (Walkley and Black 1934). The proportion of active carbon (AC) and passive carbon (PC) pools were determined by a modified Walkley and Black method as prescribed by Chan *et al.* (2001).

The C fractions with varying oxidation degree were determined according to modified Walkley and Black method (Chan *et al.,* 2001). A soil samples weighing 0.5 g were placed in each of a set of 4 numbers of oven-dried Erlenmeyer of 250 mL capacity and then 10 mL of 1N $K_2Cr_2O_7$ (*i.e.* 0.167 mol/L) followed by 2, 5, 10 and 20 mL of concentrated H_2SO_4 (98%, sp. gr. 1.84) were added to the corresponding flasks resulting in respectively 6 N, 12 N, 18 N and 24 N H_2SO_4 (*i.e.* 3, 6, 9 and 12 mol/L of H_2SO_4) in the final oxidizing solution. The flasks were kept over an asbestos sheet without an external heat source. After 30 minutes of oxidation, 200 mL of distilled water was added to the flasks and the content was titrated with 0.5 N Fe $(NH_4)_2(SO_4)$ 2.6H_2O using phenanthroline as indicator. Blank titration of the corresponding acidic dichromate solutions with ferrous ammonium sulphate was performed using the same procedure with no soil added.

Organic Carbon oxidized (R) by $K_2Cr_2O_7$ is,

R (g kg-1 soil) = (V1-V2)10 x N x 0.003 x 1000/ (W x V1)

Where,

W - Weight (g) of Sample (here it is 0.5)

V1 - Blank titre value

V2 - Titre value of the sample

N - Normality of K2Cr2O7 (here it is 1)

The four soil carbon fractions with decreasing degrees of oxidation were calculated as follows:

Very labile C (VLC) fraction: C oxidized by $K_2Cr_2O_7$ under 6 N H_2SO_4

Labile C (LC) fraction: C oxidized under 12 N H_2SO_4 – oxidizable C under 6 N H_2SO_4

Less-labile C (LLC) fraction: C oxidized under 18 N H_2SO_4 – oxidizable C under 12 N H_2SO_4

Non-labile C (NLC) fraction: C oxidized under 24 N H_2SO_4 – oxidizable C under 18 N H_2SO_4

Cumulative values for VLC and LC has been considered as AP. The sum of LLC and NLC is considered as PC pool (Chan *et al.,* 2001).

The soil C pools (Mg/ha) were calculated for 0–15, 15–30, 30-60 and 60–100 cm depths based on ρb, the relative contribution of fine earth material (soil < 2 mm) to total soil mass, layer thickness as follows (Lal *et al.,* 1998).

C or N stock (Mg/ha) = (Concentration (%))/100× (Depth (cm)Xm)/100cm× (ρb Mg)/m^3 × (Area (10000 m2))/ha ……………….. (1)

2.4 Statistical analysis

The statistical analysis of all data was performed using the GLM procedure of the SPSS 24 version (IBM Corp. Released 2016) to analyze the variance and to determine the statistical significance of the treatment effects. The least significant difference (LSD) at p=0.05 was used to compare the treatment means.

3. Results and Discussion

Total organic carbon and Walkley and Black carbon pools

The planting of fodder grasses significantly affected the total organic carbon (TOC) and Walkley and Black carbon (WBC) pools in soils in comparison to crop land (Figure 1). Plantation of three fodder grasses like hybrid napier, congosignal and combo napier and natural grasses increased TOC pools by 41.5 to 64.4 % over the pools in soils under cultivated field (59.5 Mg/ha) over the 15 years. Soils under natural grasses had higher TOC (97.8 Mg/ha) and WBC (69.6 Mg/ha) pools than those in soils under hybrid napier (84.6 and 61.5 Mg/ha), congosignal (84.8 and 66.3 Mg/ha) and combo napier (84.2 and 64.1 Mg/ha), respectively. However, and TOC and WBC pools followed the order of natural grass>combo singnal> combo napier> hybrid napier> cultivated land. Growing perennial fodder crops resulted in a net increase in the SOC content of the soils compared with the crop land. Grasses have a high root biomass, which serves as a continuous source of organic C to the soil. Perennial fodder crops are reported to produce 3.8 times higher root biomass than most of the arable crops (Sarkar *et al.,* 2018). Root biomass of grassland was 6.7 and 2.7 times greater than in annual crops in 1.0 m depth (Culman *et al.,* 2010) and 0.5 m depth (Buyanovsky *et al.,* 1987), respectively, demonstrating the large allocation of belowground biomass of these perennial grasslands relative to arable crops. Accumulation of SOC results from complex interactions between biotic mechanisms influenced by plants and soil biota as well as abiotic factors regulated by environmental processes (Lal 2005). Moreover, undisturbed soil under forage crops contributes positively to conserve SOC relative to that of the tilled control. This indicates that in subtropical hill agro-ecosystems, the conversion of cropland to grassland can increase the SOC stock by a sizeable amount. Advantages of grassland compared to cropland, in terms of improved SOC accumulation, have also been reported elsewhere. From a meta-analysis of 74 data-sets, Guo and Gifford (2002) reported that land-use changes from crop to pasture increased SOC by 19%. An analysis of 385 studies from tropical countries highlighted that cropland conversion or reconversion to grassland increased SOC stocks by 26% (Don *et al.,* 2011). In this study, the average rate of SOC accumulation (in 1 m soil depth) with perennial fodder crops was 1.6 to 2.5 Mg/ha/year higher than that of soil under maize cultivation. Such a high rate for SOC accumulation is consistent with the 3.0 Mg C/ha/year reported by Lal *et al.* (1998) in grassland soils compared with soils under annual crops.

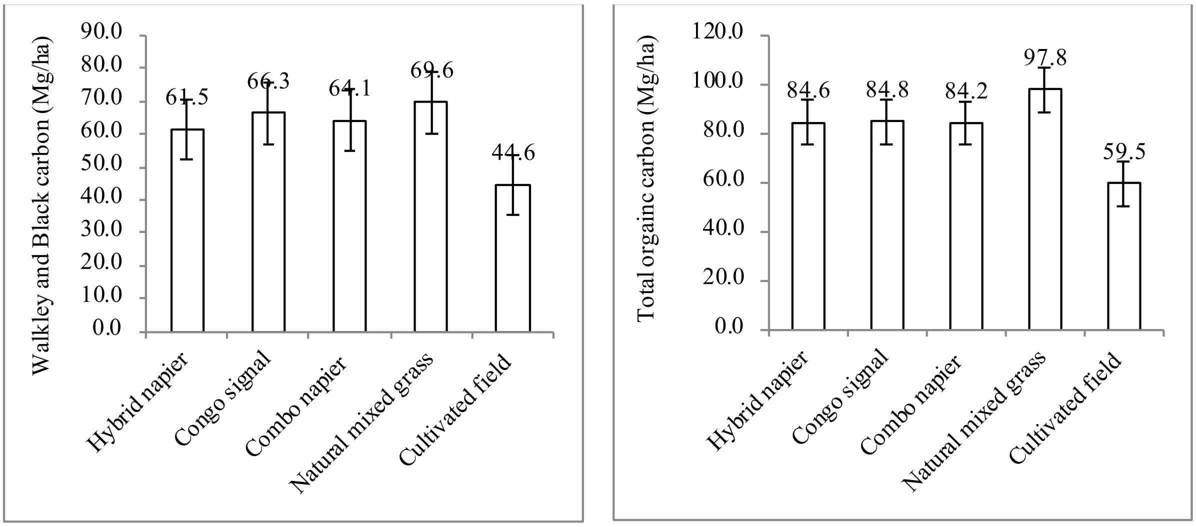

Figure 1. Long term effects of different grasses on soil organic carbon pools

Among the planted grasses, congosignal had higher TOC and WBC pools than those in soils under other planted grasses. Das *et al.* (2016b) also reported a higher efficiency of congosignal in terms of SOC accumulation than that of napier grass, broom grass and guinea grass in north-east India.

3.1 Active and passive carbon pools

Active pools of organic carbon (AC) ranged from 32.7 to 49.9 Mg/ha irrespective of treatments. However, AC pools did not change significantly due to planting of fodder grass in comparison to AC pools in soils under natural grass plots (Table 2) but significantly higher under grass plots than those under crop land. PC pool in soils under natural grass (46.1 Mg/ha) was higher than those in soils under other planted fodder grasses like hybrid napier (39.4 Mg/ha), combo napier (38.2 Mg/ha) and congosingal (34.9 Mg/ha). The relative proportions of AC pools were higher than that of PC pool across the treatments (Figure 2). Combo napier (58.9%) and congosignal (58.8%) have higher proportion of AC pools than those in soils under hybrid napier (54%) and natural grass (52.9%). In contrast to AC pools, PC pools relative proportion was higher in soils under natural grass (47.1%) and hybrid napier (46%) than those in soils under congosingal (41.2%) and combo napier (41.21). Increased allocation of SOC into the AC pools indicates higher sensitivity of C to land-use changes. Sarkar *et al.* (2015) compared the efficiency of different fallow chrono sequences under shifting cultivation in north-east India, in terms of maintaining active pools of SOC, and reported a relatively higher proportion (65.7%) of SOC in the active pools. A lower proportion AC pools under arable crops is consistent with the findings of Srakar *et al.* (2018). Land use changes affect the management practices of a system, characteristics of growing grasses, nutrient status and C pools in soils (Chen *et al.,* 2016), which may collectively reflect on the allocation of different fraction of C in soils (Sarkar *et al.,* 2015).

In addition to this relative proportion of active C (AC=VLC+LC) pools and passive C (PC=NLC+LLC) pools depends on root characteristics of species, chemical composition of litter, nutrient status of soil, mineral composition of soil, slope, gradient, and climatic conditions of the region. Microbial processes and transformations generally reduced under a nutrient rich soil because of impairment of microorganism activities (Crotty *et al.,* 2015). This is well established that soils under fodder based grass land and natural grass lands are nutrient rich because these soils receive continuous supply of nutrient through addition and decomposition of finer roots of plants (Ghosh *et al.,* 2009). The study presented herein, stored 46.6 to 49.9 Mg/ha of SOC pools in the form of AC pool under different grasses which was lower than the SOC pools allocated to PC pools (39.4 to 46.1 Mg/ha). Since, PC pools are less oxidative than AC pools (Nath *et al.,* 2018), the high proportion of PC pools may act as an indicator of the relative stability of SOC pools in a system (Das *et al.,* 2016b) and contribute to restoration of degraded land and mitigation of changing climates. The high proportion of PC pools in soil under grasses systems than crop land is attributed to the more root biomass addition (Brahma *et al.,* 2018). Moreover, low decomposition rate of roots due to low microbial activities and low oxygen level may constraint the loss of C from lower soil layers (Das *et al.,* 2016b). The production of roots and its decomposition influenced by management practices, soils disturbance, and species characteristics in a system (Lal, 2005). Both quantity as well as quality of roots effect the soil microbial biomass (Sarkar *et al.,* 2018) and its activity which further induced the SOC (Das *et al.,* 2016a) and its stability in the soil and has an effect impact on proportion of AC and PC pools in soils (Nath *et al.,* 2018). SOC fractions VLC, LC, LLC and NLC are the indicator of soil quality and stability of organic carbon in soil. Estimated SOC fractions VLC, LC, LLC and NLC were significantly influenced by the planting of fodder grasses in crop lands. The amount and relative proportion of various fraction of C changed under different grasses.

Table 2. Long term effects of different grasses on various fractions of soil organic carbon pools

Grasses	Very labile organic carbon (Mg/ha)	Labile organic carbon (Mg/ha)	Less labile organic carbon (Mg/ha)	Non labile organic carbon (Mg/ha)	Active organic carbon (Mg/ha)	Passive organic carbon (Mg/ha)
Hybrid napier	29.8	15.1	15.9	23.8	46.2	39.4
Congo signal	36.2	16.7	16.4	18.8	49.8	34.9
Combo napier	33.7	12.8	16.9	21.2	49.9	38.2
Natural mixed grass	31.4	17.3	20.2	25.8	49.7	46.1
Cultivated field	24.2	8.5	12.3	14.4	32.7	26.8
SEm±	1.1	0.8	1.0	1.6	2.2	1.9
LSD ($p=0.05$)	3.7	2.8	3.4	5.5	7.8	6.2

VLC pools ranged from 29.8 to 36.2 Mg/ha across the grasses and noticed highest under congosignal (36.2 Mg/ha) and lowest under in soil under hybrid napier (29.8 mg/ha). However, LC pools were higher in soils under natural grass (17.3 Mg/ha) followed by congosignal (16.7 Mg/ha) than those in soils under hybrid napier (15.1 Mg/ha) and combo napier (12.8 Mg/ha). Both, LLC and NLC pool were higher in soils under natural grass than those under planted fodder grasses (Table 2). Among the planted grasses, combo napier had highest LLC (16.9 Mg/ha) and hybrid napier had highest NLC (23.8 Mg/ha) than those in soils of other planted grasses (Table 2). In general all the C fractions were higher in soils under grasses than those in soils under arable crops (Table 2). In contrast to absolute amount of various fraction of C, relative proportions of SOC fraction varied among the treatments. Congosignal has the higher relative proportion of VLC (42.7%) and LC (19.7%) than those in soils under other treatments. However, relative proportion of LLC was higher under natural grass (20.7%) and NLC under hybrid napier (28.1%) (Figure 3). The variability in different pools of C like VLC, LC, LLC and NLC under different fodder and crop land systems are attributed to changes in soil quality, depth distribution of C and inherent species characteristics. The accumulation of more proportion of NLC was mainly due to minimum soil disturbance over longer period of time and year round addition of C through root decomposition. Growing of grasses on degraded crop lands could effectively enhance the soil C storage and stability reduce the decomposability of C pools present in soils (Sakar *et al.,* 2018).

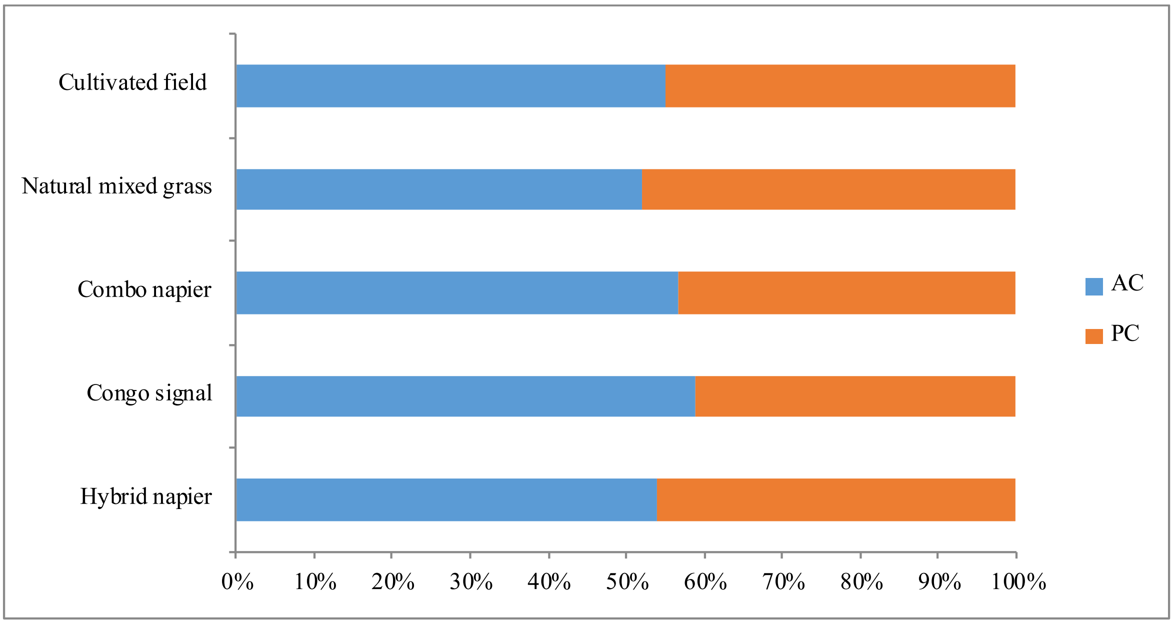

Figure 2. Effect of different grasses on proportion of active and passive carbon pools

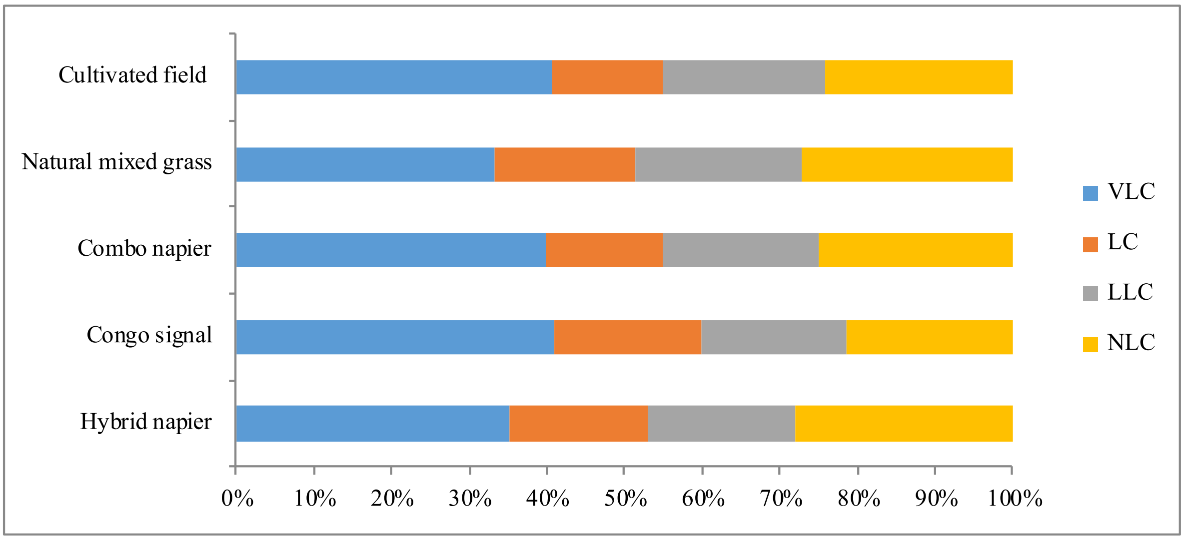

Figure 3. Effect of different grasses on relative proportion of various fractions of SOC pools

4. Conclusion

The study suggested that continuous cultivation of arable crops on sloping hills reduced a significant amount of C and had considerable effect on soil quality which may further lower the level of C in soils in comparison to C present in soils under planted fodder grasses and natural land systems. This might be attributed to the fact that properties and stability of SOC is the artifact of management practices adopted and amount of C return back through planting of perennial fodder grasses. Thus, planting of perennial fodder grasses on degraded crop lands and sloping lands could help in restoring C in soils, climate change mitigation and advancement in fodder security in the region.

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