International Soil and Water Conservation Research xx (xxxx) xxxx–xxxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr

Review Article

On-farm gains and losses of soil organic carbon in terrestrial hydrological pathways: A review of empirical research☆

Gunasekhar Nachimuthu[a,*], Nilantha Hulugalle[b]

[a] Department of Primary Industries, Australian Cotton Research Institute, Narrabri, NSW 2390, Australia
[b] Fenner School of Environment & Society, College of Medicine, Biology & Environment, Australian National University, Canberra ACT 2601 Australia

ARTICLE INFO

Keywords:
Runoff
Erosion
Deep drainage
Carbon losses
Irrigation

ABSTRACT

Theoretical estimates of soil carbon sequestration in Australian farming systems often do not coincide with measured values of soil carbon, possibly due to post sequestration carbon losses. Carbon loss through soil erosion is one of several pathways of sequestered carbon loss from agricultural systems. Specific details on different loss pathways, especially carbon loss through terrestrial hydrological pathways on a farm scale, are sparse. In this article, we review the Australian and global literature on terrestrial on farm carbon gains and losses in hydrological pathways. Catchment scale, landscape scale and modelling studies are not the focus of this review and are only briefly addressed. Carbon fractions associated with soil erosion and runoff include particulate organic and inorganic carbon, dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), dissolved CO_2-C and dissolved CH_4-C. Temperate climatic zones with approximately 500 mm of annual rainfall may receive from 6.4 to 29.5 kg ha^{-1} of DOC in rainfall (with concentration of 1.28–5.9 mg L^{-1} of DOC in rainwater). Carbon addition (net) to a field through irrigation water can range from 4.6 to 30.8 kg ha^{-1}. The carbon losses through runoff and erosion may vary from below detection limits to 1072 kg ha^{-1} yr^{-1} and these values are significant proportions of SOC sequestration rates reported in literatures. Organic carbon enrichment ratios in eroded sediments range from 0.39 to 5. Total organic carbon concentrations in deep drainage below farming lands range from negligible to 90 mg L^{-1}. Management practices that may influence soil carbon losses in erosion and runoff include changing land use, tillage, ground cover, farm layout and slope, furrow length and vegetative buffer strips in the tail end of the field. The literature surveyed indicated that a large knowledge gap existed in Australia with respect to empirical data on soil carbon lost through erosion and runoff because most studies focussed on nutrients other than carbon. The new carbon farming initiative measure means, a better understanding on the farm level carbon losses through runoff across different farming systems is essential to better predict the SOC sequestration potential. Other gaps include carbon losses in the form of carbon dioxide and methane emissions associated with the irrigation network (head ditches, tail drains etc.), on farm water bodies and sediment depositional sites, farm level carbon gains through irrigation and flooding. Carbon losses in deep drainage and its impact on whole soil profile denitrification and the associated mechanisms and biochemical changes of carbon, and carbon and nitrogen interactions during on-farm transport and storage within on-farm dams needs further investigation.

1. Introduction

Globally, soil is a reserve for approximately 300 times emissions equivalent (from fossil fuels) of soil organic carbon (SOC) (Schulze & Freibauer, 2005). Accelerated land clearing and implementation of degradative agricultural practices (e.g. burning of crop residues etc.) have, however, led to a rapid decline in soil carbon reserves (Kirschbaum, Harms, Mathers, & Dalal, 2008). Several farm scale soil carbon sequestration studies have reported declines in SOC stocks following the change from native vegetation or pasture to annual crops (Luo, Wang, & Sun, 2010). Although conservation farming practices have been implemented with the intention that that they may reverse these losses, in many instances, they have proven to be ineffective (Baker, Ochsner, Venterea, & Griffis, 2007). This may be related to the fact that pathways of carbon loss have not been well elucidated for sub-humid to arid climatic regions (Stockmann et al., 2013). Most authors have assumed that the major pathway of soil carbon loss is microbial respiration (Huon et al., 2013; Stockmann et al., 2013). While this has

Peer review under responsibility of International Research and Training Center on Erosion and Sedimentation and China Water and Power Press.

* Corresponding author.
E-mail addresses: guna.nachimuthu@dpi.nsw.gov.au (G. Nachimuthu), Nilantha.hulugalle@anu.edu.au (N. Hulugalle).

http://dx.doi.org/10.1016/j.iswcr.2016.10.001
Received 11 June 2016; Received in revised form 23 August 2016; Accepted 21 October 2016
Available online xxxx
2095-6339/

Please cite this article as: Nachimuthu, G., International Soil and Water Conservation Research (2016), http://dx.doi.org/10.1016/j.iswcr.2016.10.001

been largely overlooked in the past, recent studies suggest part of this decline is thought to be due to an unaccounted carbon loss through soil erosion and runoff (Chappell, Baldock, & Sanderman, 2015; Hulugalle, Weaver, Finlay, & Heimoana, 2013b; Kuhn, van Oost, & Cammeraat, 2012), and subsequent off-site deposition or a carbon loss mechanism associated after the erosion event (Lal, 2003). Leaching losses of dissolved organic carbon (DOC) may also be an important pathway of carbon loss from agricultural systems (Kindler et al., 2011). Lal (2003) detailed the quantities of carbon pools in the atmosphere, terrestrial ecosystems and oceans. The author suggested that soils release about 4% of their soil carbon pool (~60 Pg yr^{-1}) into the atmosphere. This is several times greater than fossil fuel combustion, and they reported a 'missing carbon amount' in the world carbon budget. This may be linked to carbon lost through soil erosion (Lal, 2005), lack of accounting of carbon in inland water bodies (Cole et al., 2007) and leaching losses (Kindler et al., 2011). The global literature on soil erosion suggests an annual discharge rate of 15–20 billion tonnes of sediments into the ocean (Lal, 2003). These sediments could carry a significant amount of soil carbon.

A recent issue of "Soil Research" (ISSN: 1838-675X) comprehensively reviewed soil carbon research in various farming systems in Australia (Baldock, Macdonald, & Sanderman, 2013). However, none of these studies addressed carbon losses through terrestrial non-gaseous pathways such as soil erosion, runoff and deep drainage. Although some research has reported the impact of soil erosion on the SOC pool and its spatial distribution at different stages of erosion (Lal, 2005; Shukla & Lal, 2005), there is a paucity of empirical information on the terrestrial hydrological pathways of SOC loss in different farming systems in Australia. Methodologies for carbon stock accounting in Australian farming systems have been proposed (e.g. SCaRP) (Baldock et al., 2013), but soil carbon losses and gains through terrestrial hydrological pathways were excluded (Chappell et al., 2015). The absence of empirical data on soil erosion and deep drainage-mediated soil carbon loss in different farming systems is one of the reasons for such an omission. Many Australian soil erosion studies failed to report particulate or dissolved carbon losses associated with soil erosion, although a few reported some carbon fractions under pasture systems (Fleming & Cox, 2001; Ghadiri, Hussein, & Rose, 2011). This review is an overview of recent empirical research in Australia and the world on soil carbon and its interaction with terrestrial hydrological and related pathways such as irrigation, erosion, runoff and drainage.

2. Review methodology

A Web of Science search (https://webofknowledge.com/) using the key words of this review along with nutrient losses was performed to select the literature for the farm scale carbon loss and soil erosion studies included in this review. The main focus of this review is field and farm-scale carbon gains and losses associated with terrestrial hydrological pathways. Catchment scale, landscape scale and modelling studies are not within the focus of this review and are only briefly referred to during discussion. In this review, we define farm scale as the fields of 10's of hectares, except pasture and grazing system where the size is 100's of hectares. Aggregates of several farms are considered as sub catchment scale where the runoff is fed into a small creek which forms a tributary of major creek or river. The rationale for this specific focus on farm scale carbon gains and losses in hydrological pathways are due to the fact, the farm scale carbon budgeting is gaining significance in recent years due to the introduction of carbon pricing mechanism and carbon farming initiative where growers are provided opportunity to trade carbon credits to offset the greenhouse gas emission from fossil fuels (CFI, 2015). This review has a major focus on Australia due to the recent introduction of carbon farming initiatives. However, due to lack of soil erosion studies with a focus on carbon loss mechanism in Australia, the relevant studies around the world are included in this review. The studies presented in this review included single event, seasonal and annual monitoring, and some rainfall simulation studies. Extrapolation of rainfall simulation or single event soil or carbon loss loads to annual basis may lead to error due to environmental variables. Therefore, for comparison and discussion of empirical studies, we considered the carbon loss loads presented as minimum loads per annum including the single event loads conducted using rainfall simulation study. A careful interpretation and reuse of the data presented in this review is warranted. The details of duration of the monitoring studies are presented in Tables 2 and 3. Fig. 1 was plotted using a synthesised data (average values) of estimated sediment carbon losses (kg ha^{-1}) in different soil types extracted from Table 5 (Supplementary data). Where there were less than three data points for a particular soil textural class, the data were excluded. Fig. 2 is estimated soil carbon losses in a single soil type under different tillage and conservation land management practices as described in legends.

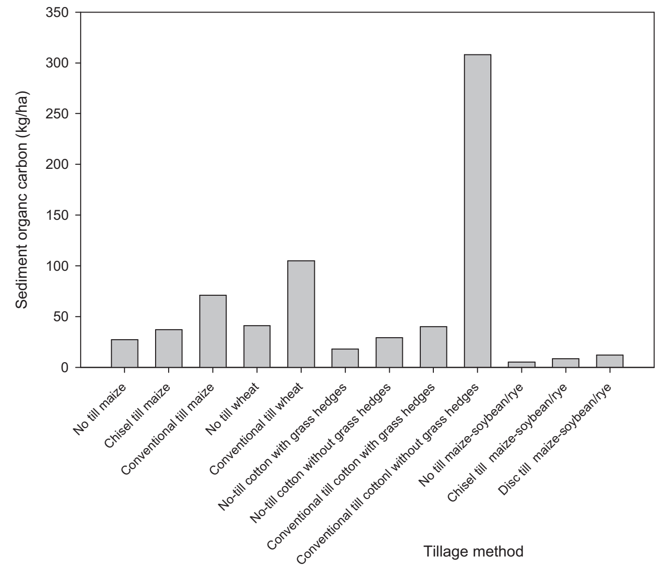

Fig. 1. Estimated sediment carbon loss (kg ha^{-1} yr^{-1}) influenced by tillage methods and conservation farming practices in a silt loam soil. The graph is plotted using average values of sediment organic carbon losses under different management.

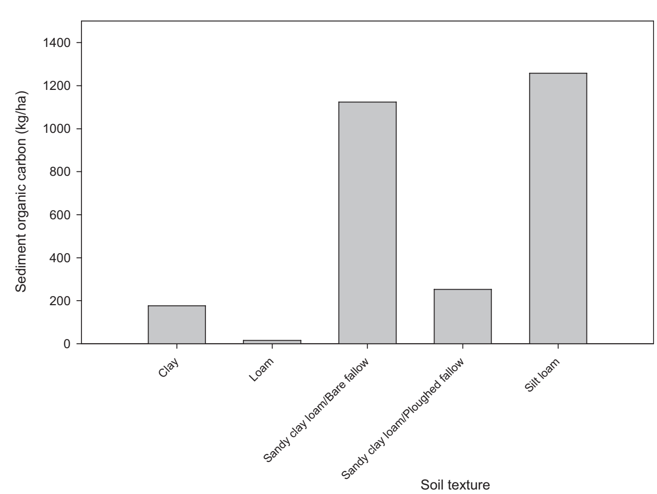

Fig. 2. Estimated sediment carbon losses (kg ha^{-1} yr^{-1}) under fallow in different soil types. The graph is plotted using average values of sediment organic carbon losses during fallow period in each soil type.