J. Agric. Res. Technol., 49 (1) : 077-089 (2024)

Losses of Soil Organic Carbon Through Terrestrial Hydrological Channels: A Review

K. M. Kokate[1], S. B. Nandgude[2], A. A. Atre[3], V. N. Barai[4] and B. K. Gavit[5]
Department of Soil & Water Conservation Engineering,
Dr. ASCAE&T, Rahuri (MH), India

(Received : 30.09.2024 Accepted : 05.10.2024)

Abstract

Post-sequestration carbon losses may be the reason why theoretical predictions of soil carbon sequestration in agricultural systems frequently differ from actual quantities of soil carbon. One of the many ways that agricultural systems lose stored carbon is through soil erosion. There is deficiency of specific information on various loss mechanisms, particularly carbon loss through terrestrial hydrological channels on farm size. In this review, we examine the various literatures on the losses and gains of terrestrial on-farm carbon in hydrological channels. This review does not specifically cover catchment size, landscape scale, or modeling research; they are just briefly mentioned. Particulate organic and inorganic carbon, dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), dissolved CO_2-C, and dissolved CH4-C are among the carbon components linked to soil erosion and runoff. Temperate climate zones having average annual rainfall of 500 mm may see rainfall containing between 6.4 and 29.5 kilogram of DOC (DOC content in rainwater ranges from 1.28 to 5.9 mg L^{-1}). It is seen a field's net carbon contribution (from irrigation water) ranges between 4.6 and 30.8 kg ha^{-1}. The carbon losses due to runoff and erosion can range from below detection thresholds to 1072 kg ha^{-1} yr^{-1}, these values represent substantial percentages of the Soil Organic Carbon sequestration rates reported in the literature. In eroded sediments, organic carbon enrichment ratios vary between 0.39 and 5. Low to 90 mg l^{-1} of total organic carbon can be probably found in deep drainage beneath agricultural regions. Changes in uses of land, tillage operations, ground covering with vegetation, layout of farm, slope of field, and length of furrow and buffer strips of vegetation are some management techniques that may affect soil carbon losses in erosion and runoff. As most research concentrated on nutrients loss other than carbon, so it reveals that there was a significant knowledge vacuum regarding actual data on soil carbon lost through erosion and runoff. According to new carbon farming initiative measure, a greater comprehension of farm-level carbon losses through runoff across various agricultural systems is necessary to more accurately anticipate the potential for Soil Organic Carbon sequestration. Other gaps include the carbon dioxide and methane emissions from irrigation networks (head ditches, tail drains, etc.), sediment deposition sites on farms, carbon benefits at the farm level from irrigation and flooding, and carbon losses in water bodies and sedimentation sites. It is essentially required to conduct more research on carbon losses with deep drainage, their effects on denitrification across the entire soil profile, the biochemical processes that accompany those changes in carbon, commerces during on-farm import between carbon and nitrogen, and related mechanisms.

Key words : Organic, Carbon, Hydrological, DOC, Sediment, Losses, Erosion, Terrestrial, Runoff, Field, Soil, Dissolved, Inorganic, Particulate.

Around 300 times the emissions of carbon (through combusted fossil fuels) equivalent of soil organic carbon (SOC) are stored in soil globally1. However, aggressive land clearing and agricultural practices, such as burning residues of crop, have caused a sharp drop in soil carbon stocks2. Some farm-scale soil carbon sequestration researches have reported fall in soil organic carbon stocks following the alteration from native vegetative cover or pasture to annual crops3. Although intentionally some conservancy farming practices are undertaken to reverse these losses, in many cases, but found ineffective4. The ways of carbon loss not neatly explained for subhumid to arid climatic regions5. Number of researchers accorded that a considerable way of soil carbon

---

1. SRF, 2. Head, 3., 4. and 5. Professor

loss is respiration by soil microorganisms5,6. While this has been largely overlooked in the past, contemporary investigations suggest that part of this fall is because of unaccounted carbon loss due to soil erosion and runoff 7-9, and resulting off-site sediment deposition or carbon loss mechanism in concern of erosion event10. Leaching losses due to dissolved organic carbon is also a considerable way of carbon loss from agro ecosystems11. Lal has given detailed quantities of carbon pools present in the spaces of atmosphere, terrestrial ecosystems, and oceans10. He reveals that soil liberates 4% (approx.) of its soil carbon pool (approximately 60 Pg/yr) into the spaces of atmosphere. This quantity is much greater when compared with carbon emissions from combustion of fossil fuel. This can be linked with carbon loss through soil erosion12, lack of terrestrial water bodies' carbon stock accountancy13, and leaching losses of carbon11. Article on soil erosion suggested per annum 15-20 BT sediments deposited into the ocean10. These sediments include considerable portion of soil carbon. However, no one among from these studies contributed inputs over carbon losses through terrestrial nongaseous routes that are soil erosion, runoff and drainage. Although some researchers have reported the impact of soil erosion on the soil organic carbon stock and its' spatial apportionment at varied stages of erosion12,14, there is insufficiency of information in concern with terrestrial hydrological ways of soil organic carbon loss through varied systems of farming. Many studies on soil erosion remained incapable to document dissolved carbon losses associated with soil erosion, else very few have reported some carbon fractions through pasture systems15,16. This article brings light on soil carbon and its association with terrestrial hydrological and concerned ways e.g. irrigation, erosion, runoff and drainage.

2. Review Methodology

The main aim of this article is to study field and farm-scale carbon losses and gains associated with terrestrial hydrological channels. The farm-scale carbon budget taking demand due to introduced carbon pricing system and carbon farming enterprise where carbon farmer have facility to commerce carbon credits to counterbalance the emission of greenhouse gas from fossil fuels17. However, there is paucity of studies on soil erosion concentrating on carbon loss mechanisms, concerned research around the globe have considered in this article. The studies reviewed here include single, seasonal and annual rainfall event monitoring and some simulative rainfall models. Extrapolated simulated rainfall or single rainfall event soil or carbon loss loads per annum may mislead because of prevailing environmental variabilities. The sediment organic carbon loss was estimated by taking multiplication the actual sediment eroded (kg ha-1) and soil organic carbon. McHunu and Chaplot reported that fractions of particulate carbon in erosion range between 88 and 98.7 per cent of the total carbon loss with runoff18. We entrusted 1 per cent to soil organic carbon using the least value documented in the article for desolated land of 2.41 per cent carbon19 and the smallest organic carbon enrichment ratio as 0.3920 (2.41 x 0.39 approx. 1 per cent). Seeing the organic carbon enrichment ratio varying between 0.3920 and 512 and the organic carbon values differing according to use of land (i.e. cropping and pastural). In this article, we lights on estimated carbon losses with runoff and erosion with sporadic literature to measured carbon misplacement values.

3. Entry of carbon into agricultural farm/field

3.1. Irrigation : In arid and semi-arid regions, irrigation facilitated agriculture is crucial for the cultivation of commercially viable crops.

Additionally, it might have both beneficial and hazardous environmental effects, including salinization and water logging, and also florish in groundcover and plant biomass. There are two opposing theories on how irrigation water affects a field's carbon stores. One of the theories holds that irrigation boosts soil carbon stocks by encouraging crop growth, which results in increased biomass and crop leftovers21. According to some authors, rise in soil organic carbon anticipated between 11 and 35%, and irrigation water initiates microbial activity and organic matter mineralization rates, peak in release of CO_2 in the atmosphere and causing a net loss of carbon22. Furthermore, increased carbon dioxide emissions occur from the energy needed to pump water for irrigation facility from water source to fields23. Aside from the effects mentioned above, supplementary water can also directly provide carbon to the soil through DOC and carbon linked with sediments in entrainment24,25. According to Olson, the net stabilization rate should be reduced to levels for any influx of carbon enriched sediments into the field during carbon sequestration estimate26. In this part, we examine the effects of irrigated agriculture fields' carbon enrichment, which was typically overlooked in investigations of soil carbon sequestration. The total organic carbon amounts in supplementary water in head channel and runoff water in tail drain should be measured in order to judge the amount of carbon that irrigation water contributes to a field. Numerous studies have found that the total organic carbon contents in supplementary water are either greater or lower than those in runoff water. Study by King discovered that regardless of high DOC loads in runoff water, overall carbon balance of farm rose due to greater loads of sediment and DOC absorbed through irrigation water, achieving net carbon input of around 30.8 kg C ha^{-1} yr^{-1}24. A study of supplementary watered maize plots revealed that the irrigation water added a net 123-124 kg DOC per hectare to the field. Inferring a net deduction of 423 kilogram total organic carbon ha^{-1}, the net deduction of dissolved organic carbon and particulate organic carbon was 96-100 kg ha^{-1} and 443 kg ha^{-1}, respectively27. Despite enrichment from supplementary water occurring in this research, a loss of total organic carbon resulted from greater particulate organic carbon losses. A study by Dong, evaluated the carbon and sediment enrichment brought on by irrigation using river water28. According to Boulal, in-field organic carbon enhancement and deduction is an example29. According to their findings, soil organic carbon was greater in superficial 50 mm layer of soil in furrows (1.51%) than it was in beds (1.40%). Identical to the previous example, the superficial 30 cm thick layer of soil inhibited 22.4 t C ha^{-1}, compared to 41.4 t C ha^{-1} for foot slope in the similar field, while the worldwide moderate range for 0-30 cm deepness was somewhere about 35.2 t C ha^{-1}. When compared to dryland systems, few irrigation facilitated systems are said to preferentially sequester carbon within micro aggregates, increasing soil carbon stocks30. Combining irrigation with minimal or no tilled condition is recommended as a viable strategy to boost carbon stabilization, macro-aggregate occluded microaggregate development, and sequestration30. In repetitive water parching and soaking patterns, an surge in organic matter was observed to be related to the production of water-stable aggregates in smectitic vertisols31, however this may be overruled for other vertisols and soil types. Thus, carbon sequestration can occur when external carbon sources are added to soil that frequently goes through alternate wetting and drying patterns32.

3.2. Rainfall : Precipitation (water) has a substantial involvement in recycling of organic substitutes in atmosphere. Considerable concentrations of DOC (430 ± 150 x 1012 g C

yr^{-1}) are available in precipitation water over oceans33. DOC in the time of summer season is documented to be originated from both the manmade beside natural sources, whereas DOC during the winter season was observed majorly because of human activities e.g. pollution. Amounts of DOC present in precipitation water have been found ranging between 0.46 and 21.3 mg L^{-1}. According to Likens, who studied the total organic carbon and dissolved organic carbon amounts found in rainfall, the annual total organic carbon amounts and loads ranged from 1.28 to 2.37 mg L^{-1} and 14 to 24.2 kg ha^{-1}, respectively35. Dissolved organic carbon was approximately 80% of total organic carbon358.

4. Loss of carbon from fields/farms : Respiration of micro organisms present in soil5, erosion and runoff14, wind erosion36, far down drainage37 are some ways through which soil carbon held in fields is lost38. There are many stages of soil erosion, including detachment, transport, and sediment deposition39,40. When it concerns erosion by water, irrigation water application frequently exceeds crop evapotranspiration requirement27. Similar events take place when there has been a lot of rain or flooding. The excess water dissolves soil carbon and other nutrients present in soil and carry them to superficial layers of surface water bodies like creeks, rivers, and inland lakes through surface runoff, as well as to underground water by far down drainage. The carbon losses related to water erosion and runoff, far down drainage, the changes that take place throughout these processes, and their effects on indirect carbon emissions are covered in the sections that follow. Land utilization and management methods including clearing land for development and intensive tillage can hasten soil erosion. Lal adopted equation of mass balance to determine how the change occurs in soil organic carbon with change in use of land:

$$SOC = (SOCa+A) - (E + L + M),$$

Where, A represents the carbon intake (often in plant residues beside organic amendments), SOCa represents the precedent stock and E represents erosion losses, L represents leaching losses, and M represents mineralization.

Various scales have been used to study soil erosion in past, including tiny, one-time assessments using simulation rainfall, seasonal, yearly, and long-term observation of plot or field scale, sub-catchment, and catchment. There were scant Australian data on the effects of various systems of annual cropping and uses of land on carbon losses due to erosive processes, including cotton, sugarcane, oil seeds, and cereals. Although some study in this area has been done in the United States41,46,47. The enrichment of soil organic carbon during the erosion process and fractions dissolved in runoff water are to blame for the discrepancy between the values of sediment organic carbon and real TOC readings. The proportion of soil carbon that is in the form of particles is probably linked to eroded sediments. Soil erosion-related issues are expected to have an impact on runoff carbon losses. A quick overview of such elements is provided in the section that follows. The following is a discussion of these elements' influences:

(a) Cultivation/tillage: As it is not consolidated, soil particles are very easily separated and entrained when cultivation is used to generate fine soil tilth. According to Boulal, in a rotation of maize and cotton, conventional tillage caused twice as much soil loss as permanent bed systems50. The sediment movement was significantly reduced as the amount of time passed after culture. A research carried in Australia found that raised beds produced larger runoff quantities than traditional and high depth cultivation methods51. The effect of tillage practices and also stubble management techniques on soil carbon loss due to irrigation-induced runoff has also been assessed in several studies. According to Mailapalli, the volume of runoff was larger in the no-tillage fallow system as compared with full-tillage cultivation with/without crop cover, which affected the DOC export ratio48. This indicates that DOC concentrations and amounts (kg/ha) might change according to the kind of tillage. Total organic carbon losses in runoff were calculated to be roughly 44 kg/ha/yr in research studies carried for farming systems for sugarcane in Australia, using conventional tillage and also low tillage techniques52. According to lengthy research carried in Australia for farming systems for cotton, minimum tillage techniques result in a slower rate of SOC decrease than maximal tillage practices, which supports the link between tillage and soil organic carbon losses53.

(b) Field topography and slope: Soil erosion and nutrient losses are significantly influenced by slope of field and topography. In Queensland's Emerald irrigation district, soil erosion rates in furrow-irrigated farms were correlated with furrow gradients54. At least four times as much carbon was lost with 5% and 10% slopes as it was with 1% slope. The same was true for carbon losses, which were minimum 2-4 times greater at 15% land slope than at 5/10 per cent land slope.

(c) Soil texture and use of land: According to Cox, soil carbon losses in case of sandy loam soil under horticultural land use varied from 0.7 - 2.9 kg ha^{-1} yr^{-1}, whereas losses found about 39 kg of C ha^{-1} for the period of two years has disclosed for silt clayey soil cultivated for vegetable55. Carbon losses rise to 30.5 kg ha^{-1} in silty loam soil during maize cultivation with various tillage practices and also with residue management were recorded in a simulated rainfall study. In Nigeria, losses of soil carbon founds around 1072 kg ha^{-1} from sandy loam soil were documented, but the amount was half that (587 kg ha^{-1}) under corn monoculture. As previously published research has shown, irrigated agricultural systems only sequester 280 kg of soil organic carbon each year, avoiding or lessening these losses from of 0.5 to 1 t C ha^{-1} might increase the soil organic carbon sequestration capacity. A clay-rich vertisol's reported DOC export was seven times more as compared with sandy scenario. Adsorption capacity and water balance of soil are two physico-chemical factors that affect how much DOC is lost in runoff. Compared to different land uses like vineyards and orchards, pasture land had larger carbon losses, with the largest total organic carbon losses of almost 369 kg ha^{-1} in single event16. The sediment carbon loss related to this soil loss equals to 71 kg ha^{-1} yr^{-1} at 1 per cent soil organic carbon concentration from farmed basins, respectively. According to a research conducted in Vietnam on six different land use systems (two forestry and four agricultural), the decline of DOC varied between 0.32 (0.16) kg C ha^{-1} for bare soil and 2.52 (1.09) kg C ha^{-1} for forest without having any leaf litter57. Under sugarcane farming patterns, several studies observed soil losses striking up to 505 t ha^{-1} with a 1% SOC concentration, the predicted particulate carbon loss would be up to 5 t C ha^{-1} yr^{-1}, and this severe scenario may only be applicable for tropical agriculture. Due to deficit information on carbon leakage from this environment, direct comparisons of observed values were not feasible. The statistics from outside indicate that carbon losses might reach 1072 kg ha^{-1} yr^{-1}.

(d) Field layout and length of furrow: Runoff and nutrient losses are reportedly impacted by on-farm cultivation factors such field length, irrigation technique, and the design of drainage ditches55. On-farm carbon losses are noticed to be directly impacted by the length of the field or furrow. Although DOC content was greater for long length furrow, the DOC export in runoff was higher with shorter field lengths, according to an examination into furrow or field length with varied tillage management techniques46. The authors found a threefold increase in field length, a decline in DOC export detected as 65-83%, and a decline in irrigation-induced runoff about 60-90%. There are occasions when the amount of water used for furrow irrigation have found greater than crop evapotranspiration. Seasonal rains and surplus water utilized for irrigation can dissolve soil carbon and other available nutrients and carry them to terrestrial water bodies like creeks, rivers and lakes through overland runoff and also through ground water with far down drainage. Hernes give an illustration of the effects of irrigation on DOC losses, showing how the DOC concentrations in nearby rivers increased from 2.75 mg L^{-1} in the winter to 5.14 mg L^{-1} in the summer57. Maximum DOC values of 10.1 mg l^{-1} and 18.9 mg L^{-1} were found in season of winter and summer, respectively60. Because of high evapotranspiration requirements of crops, irrigation often takes place in the summer. Additionally, high amount of DOC in rivers may contribute to DOC losses through irrigation-induced runoff from nearby farms and low base flow59. According to Hulugalle, rainfed cotton in tropics saw soil losses of 33 and 22 t ha^{-1} for beds of 1 m. and 2 m. length, respectively.

4.2. Deep drainage carbon losses : According to Agudelo, dissolved organic carbon is necessary for the activities of microorganisms in subterranean habitats. The majority of prior study on dissolved organic carbon leaching in far down drainage concentrated on wetlands and natural plants, with little attention paid to agricultural fields63. According to Hulugalle, yearly far down drainage losses for same field averaged as 54 mm, hence the DOC losses were calculated to be around 47 kg DOC ha^{-1}. According to a research, DOC concentrations in far down drainage were 20, 11, 5, and 7 mg l^{-1} at depths of 40, 110, and 200 m beneath the soil's surface, respectively. Carbon leaching in terrestrial ecosystems is significantly impacted by changes in use of land and the ensuing crop and soil management techniques. Deeper ploughing was used for conversion of native grass as maize, which increased DOC in leacheate observed as 4-5 times for the course of 4 years. According to Vinther, larger levels of DOC were lost through leaching water of contingency crops in comparison with fallow land soil. For sandy loam and also coarse sandy scenario, the authors recorded total leaching losses of 22-40 kg DOC ha^{-1} yr^{-1} and 174-310 kg DOC ha^{-1} yr^{-1}, respectively. Organic carbon losses were observed as 68, 127, and 174 kg ha^{-1} in a research comparing grassland, no-tillage, and chisel-ploughed maize ecosystems. The prairie DOC losses have much lower than those in maize fields, which may be in relation with large crop leftovers after application of fertilizer58. With an average debt of 2.7-3.2 g DOC m^2 yr^{-1}, Walmsley noted no variations in DOC concentrations from no tillage to conventional tillage in Ireland. A controlled lysimeter investigation on undisturbed soil cores noticed leaching of DOC varied between 330 kg/ha and 547 kg ha^{-1}. The same authors noticed that higher rates of phosphate and urea treatment resulted in more DOC leaching. In a field lysimeter research, seasonal fluctuations in DOC content were noted, and it is linked with considerable amount of rainfall variance28. DOC amounts and leaching losses with far down drainage are highly controlled by absorption in subsoils, even though the changes in DOC reported in all of the research described above were connected to the soil texture, tillage, and patter of use of land11. It has been demonstrated by author that groundwater DOC concentration and DOC leaching from various land uses are connected. Number of bore wells (about 30) in sugarcane growing region in coastal zone, and groundwater DOC values varied between 4 and 82 mg l^{-1}. By utilising a variety of techniques, including sampling at various depths and analysing seasonal fluctuation in DOC concentration under various management approaches, Thayalakumaran and others were able to link the huge amount of DOC in lower Burdekin area of Queensland with far down drainage68,69. The scientists hypothesized that either in field sugarcane waste burning or the leaching of juices lost during harvest caused elevated DOC concentrations. For understanding of mechanism of DOC dynamics with far down drainage, more research is necessary. In comparison to croplands and grasslands, the groundwater beneath forest land had greater DOC contents70. Study in Europe; also have demonstrated that grassland leached more carbon than aggressively tilled arable land11,37. According to Jahangir, DOC losses to groundwater varied between 2 and 6 kg ha^{-1} from arable areas and 3-28 kg ha^{-1} from grasslands areas. According to Kindler, the amount of carbon lost by effect of leaching from cropped land area and grass land area was almost 25% of total carbon in the ecosystem, including carbon from fertilizer and harvested carbon. Fluctuations in DOC concentrations in the aforementioned studies show the complexity of DOC loss with far down drainage and biogeochemical activities in subsurface water. With addition of geological and hydrological factors, mineralization, breakdown, adsorption, and precipitation processes affect the amount levels of DOC with far down draining water.

Although agricultural practices of land management linked with far down drainage DOC losses, research indicate that there is only a tenuous connection between far down drainage DOC concentration, soil characteristics, and practices of land management. According to the same authors, significant correlation has found between vertical DOC transfer and water flow or hydrological regime.

4.3. Changes observed during and after runoff, erosion and far down drainage : Transport and far down burial of soil may change in long-term carbon storage by slowing the decomposition of soil organic carbon. On the other side, soil erosion may expose subsurface oil and gas (SOC) to quick breakdown and emissions at the erosion site. While runoff helps with a number of processes both in place and while being transported, such as the endowment of sediments with carbon, indirect carbon emissions from runoff and far down drainage of carbon help with processes that may have an impact on emissions and denitrification in lower soil profiles. According to the prior description of soil erosion, it consists of four steps: detachment, breakdown, transport, and sediment's deposition. Soil organic carbon is impacted by each of these stages. Soils rich with fertility, such as the vertisols are valuable assets for agriculture farming industry, and also provide special management challenges. Such soils are quite erosive when the soil moisture level is high. To enhance the soil erosion response and comprehend the carbon loss process, it is crucial to understand the soil's hydrological responses to rainfall and also irrigation management technics that are regionally unique (e.g., dispersion). In addition, erosion exposes subsurface carbon that was formerly physically shielded from impact of pedological processes. Distructive erosion, which scourges the carbon-rich superficial soil layer, has a considerable effect on global carbon cycle10. Along with slaking, peeling, and causing preferential erosion of soil organic matter, raindrops and surface runoff flow also uncover the anthropologically protected organic matter to bacteria, which indirectly emits CO_2 and break up soil aggregates. Numerous studies disclosed that levels of carbon entering in rivers do not match those recorded at the head end, farm, or sub-watershed level. The carbon flow during transit can be impacted by a number of physical, chemical, and biological factors. A important source of energy for aquatic life is the heterotrophic organic carbon cycle, which transforms or removes carbon during transit in aquatic food webs. There are, however, few studies that look at how carbon changes while being transported through water at a farm scale.

4.3.1. Carbon enrichment of sediments : According to Zhang, sediments that are dislodged during erosion are frequently carbon-enriched and can contribute significantly to overall emissions55. Higher emissions have usually been recorded for sediments compared to field soils. Soil organic carbon enrichment of sediments, CO_2-C as 1419 mg kg^{-1} was released from sediment as opposed to 386 mg kg^{-1} from soils. According to Zhang, sediments that are eroded away are frequently carbon-enriched sediments that can contribute significantly to global emissions. Sediments often report greater emissions as compared to field soils. As disclosed by sediments' SOC enrichment, CO_2-C as 1419 mg kg^{-1} was released from them as opposed to 386 mg kg^{-1} from soils. According to Lal and also Martnez-Mena, the ratio of organic carbon enrichment of erosion impacted sediment is greater than one, even also it reach to five. Bertol, found that conventionally tilled plots (1.17) had greater levels of organic carbon enrichment in erosion impacted sediments than did conservation tillage plots (1.0). Watershed areas that weren't burned, burning of natural vegetation increased the carbon matter of the sediments.

4.3.2. Relationship between enrichment of sediment and characteristics of rainfall : Empirical findings suggest the endowment of dangling sediments with organic carbon, although the connection to rainfall features is less definite. According to Beguera, eroded sediments have a greater carbon content than their origin material (e.g. progenitor soil). They proposed that the mobilization of labile carbon components was significantly aided by splash. According to several research, eroded sediments resulted from rainfall events of low intensity contained more carbon than sediments from high intensity rainfall events. For instance, Jacinthe noticed that the organic carbon content of sediments dislodged by rainfall storms of low intensity was greater (37 g kg^{-1}) than that of sediments dislodged by rainfall storms of high intensity (22 g kg^{-1}). The organic carbon enrichment ratios found greater for rainfall events of low intensity while events of high intensity led to soil erosion with sediments contributing lower organic carbon concentrations. Nie also noted that rainfall events of low intensity had greater carbon concentrations than rainfall events of high intensity. Difference of flow rates, which led to greater organic matter concentrations, was another reason why Panuska with Karthikeyan found that snow-induced runoff had an approximately 10-fold higher organic matter enrichment than rainfall-induced runoff. The first sediments to erode during a runoff event are those with a high clay content and a carbon content86. In comparison to the sediments which impacted by erosion during first phase of runoff events, the sediments which have impacted by erosion in latter phase are less rich in carbon. Raindrop impact had little bearing on the embellishment of organic carbon, according to Schiettecatte, but rill and also inter-rill erosion had different impacts on the embellishment of organic carbon in carried sediment. According to Wang, the carbon enrichment ratio fluctuate within 1.3-4 throughout different phases of erosion, transport, and deposition.

4.3.3. Changes during deep drainage : The DOC content of agricultural soil and its capacity for denitrification are strongly connected. An indirect evaluation of the potential for denitrification might be made by simultaneously measuring DOC and nitrogen losses with far down drainage beneath root zone level58. After DOC enters groundwater present beneath the its' related area, microbial activity furthermore redox potential are key factors in influencing subsequent reactions, carbon concentrations, and speciation, which can lead to additional DOC breakdown to CO_2 together with CH4 production88. According to Thayalakumaran, any soil management techniques that result in lower DOC loads in groundwater which could do detrimental effect on de-nitrification of groundwater present beneath topo-surface, which might then cause nitrate to flow to terrestrial water pools located in coastal regions. Anyhow, it has been shown that there is no correlation between well depth and DOC content in well water ($r^2=0.27$)70, which may be a result of sorption processes and heterotrophic degradation at deeper depths.

4.4. Imminent climate change together with carbon losses by runoff : Runoff is expected to rise by 4% with a 1% increase in global annual temperature, while this tendency may vary with region to region. A research study forecasted a 12% reduction in runoff and a 5% reduction in rainfall. Van Vliet proposed a case of imminent climate that possibly affect carbon in terrestrial flows and anticipated a elevated amount of nutrients along with pollutants existing in river flows as a consequence of drought owing to poor flow along with lengthy halt hours in waterways. The effects of escaped air CO embellishment on growth and yield of crop are the subject of ongoing research worldwide, but existent few studies that examine the effects of elevated levels of climatic CO_2 on carbon losses in terrestrial runoff. In an experiment, Guo assessed the DOC concentration in terrestrial water associated with paddy field and discovered an 18% surge, which may have consequences for carbon losses in subsequent overland flow.

5. Conclusion and research gap

Loss and addition of carbon through terrestrial hydrological channels, along with the losses from microbial respiration, determine the total carbon quantum at a farm level. Terrestrial hydrological loss mechanisms for carbon include far down drainage carbon losses, indirect diffusions from water bodies, and runoff caused by irrigation and rainfall (the detection limit has been reached 1072 kg ha/yr) (a perfect value is difficult to determine at farm level with current literature). Rainfall (6-29 kg of carbon per hectare), irrigation (5-31 kg of carbon per hectare), erosion, and floods are part of processes that add carbon. One explanation for this exclusion is the scant availability of factual data on soil erosion and far down drainage-mediated soil carbon losses in numerous farming systems. To reliably assess the carbon balances of various farming systems, farm level investigations of carbon losses in runoff, erosion, and far down drainage is necessary. For assessing carbon losses via erosion, runoff, and by far down drainage, future carbon accounting approaches along with different models have to be improved.

As a result, we have discovered several knowledge chasms and suggest distinct research areas as follow:

1. Net carbon losses on farms are made up by carbon emissions linked to irrigation networks.

2. Various agricultural systems were used in free-to-air CO_2 embellishment experiments that included runoff and far down drainage losses of soil carbon to examine how imminent climate change may affect the carbon balance in terrestrial hydrological channels.

3. Gains in agricultural carbon emissions from floods and irrigation.

4. Carbon transport with far down drainage affects denitrification over the entire soil profile.

References

Agudelo, C., R. M., Jaramillo, M. L. and Peñuela, G. Comparison of the removal of chlorpyrifos and dissolved organic carbon in horizontal sub-surface and surface flow wetlands. Science of The Total Environment 431, 271-277 (2012).

Aravena, R., Wassenaar, L. I. and Spiker, E. C. Chemical and carbon isotopic composition of dissolved organic carbon in a regional confined methanogenic aquifer. Isotopes in Environmental and Health Studies 40, 103-114 (2004).

Baker, J. M., Ochsner, T. E., Venterea, R. T. and Griffis, T. J. Tillage and soil carbon sequestration—What do we really know? Agriculture, Ecosystems and Environment 118, 1-5 (2007).

Balla, D., Papageorgiou, A. and Voutsa, D. Carbonyl compounds and dissolved organic carbon in rainwater of an urban atmosphere. Environ Sci Pollut Res 21, 12062-12073 (2014).

Beguería, S., Angulo-Martínez, M., Gaspar, L. and Navas, A. Detachment of soil organic carbon by rainfall splash: Experimental assessment on three agricultural soils of Spain. Geoderma 245-246, 21-30 (2015).

Beniston, J. W. *et al*. Carbon and macronutrient losses during accelerated erosion under different tillage and residue management: Soil C, N and P losses during erosion. Eur J Soil Sci 66, 218-225 (2015).

Bertol, I., Engel, F. L., Mafra, A. L., Bertol, O. J. and Ritter, S. R. Phosphorus, potassium and organic carbon concentrations in runoff water and sediments under different soil tillage systems during soybean growth. Soil and Tillage Research 94, 142-150 (2007).

Boulal, H. and Gómez-Macpherson, H. Dynamics of soil organic carbon in an innovative irrigated permanent bed system on sloping land in southern Spain. Agriculture, Ecosystems and Environment 139, 284-292 (2010).

Boulal, H., Gómez-Macpherson, H., Gómez, J. A. and Mateos, L. Effect of soil management and traffic on soil erosion in irrigated annual crops. Soil and Tillage Research 115-116, 62-70 (2011).

Bravo-Garza, M. R., Bryan, R. B. and Voroney, P. Influence of wetting and drying cycles and maize residue addition on the formation of water stable aggregates in Vertisols. Geoderma 151, 150-156 (2009).

Brye, K. R., Norman, J. M., Bundy, L. G. and Gower, S. T. Nitrogen and Carbon Leaching in Agroecosystems and Their Role in Denitrification Potential. J. Environ. Qual. 30, 58-70 (2001).

Bukaveckas, P. A. *et al*. Effects of Point Source Loadings, Sub-basin Inputs and Longitudinal Variation in Material Retention on C, N and P Delivery from the Ohio River Basin. Ecosystems 8, 825-840 (2005).

Carroll, C. *et al*. A Paddock to reef monitoring and modelling framework for the Great Barrier Reef: Paddock and catchment component. Marine Pollution Bulletin 65, 136-149 (2012).

Carroll, C., Halpin, M., Bell, K. and Mollison, J. The effect of furrow length on rain and irrigation-induced erosion on a vertisol in Australia. Soil Res. 33, 833 (1995).

Chaplot, V. and Poesen, J. Sediment, soil organic carbon and runoff delivery at various spatial scales. CATENA 88, 46-56 (2012).

Chappell, A., Baldock, J. and Sanderman, J. The global significance of omitting soil erosion from soil organic carbon cycling schemes. Nature Clim Change 6, 187-191 (2016).

Cole, J. J. *et al*. Plumbing the Global Carbon Cycle: Integrating Inland Waters into the Terrestrial Carbon Budget. Ecosystems 10, 172-185 (2007).

Dawson, J. J. C. and Smith, P. Carbon losses from soil and its consequences for land-use management. Science of The Total Environment 382, 165-190 (2007).

Don, A. and Schulze, E.-D. Controls on fluxes and export of dissolved organic carbon in grasslands with contrasting soil types. Biogeochemistry 91, 117-131 (2008).

Dong, L. *et al*. Long-term effect of sediment laden Yellow River irrigation water on soil organic carbon stocks in Ningxia, China. Soil and Tillage Research 145, 148-156 (2015).

Fleming, N. K. and Cox, J. W. Carbon and phosphorus losses from dairy pasture in South Australia. Soil Res. 39, 969 (2001).

Gerke, H. H., Rieckh, H. and Sommer, M. Interactions between crop, water, and dissolved organic and inorganic carbon in a hummocky landscape with erosion-affected pedogenesis. Soil and Tillage Research 156, 230-244 (2016).

Ghadiri, H., Hussein, J. and Rose, C. W. Effect of pasture buffer length and pasture type on runoff water quality following prescribed burning in the Wivenhoe Catchment. Soil Res. 49, 513 (2011).

Gillabel, J., Denef, K., Brenner, J., Merckx, R. and Paustian, K. Carbon Sequestration and Soil Aggregation in Center-Pivot Irrigated and Dryland Cultivated Farming

Systems. Soil Sci. Soc. Am. J. 71, 1020-1028 (2007).

Gregorich, E. G., Greer, K. J., Anderson, D. W. and Liang, B. C. Carbon distribution and losses: erosion and deposition effects. Soil and Tillage Research 47, 291-302 (1998).

Guo, J. *et al*. Responses of dissolved organic carbon and dissolved nitrogen in surface water and soil to CO2 enrichment in paddy field. Agriculture, Ecosystems and Environment 140, 273-279 (2011).

Harper, R. J., Gilkes, R. J., Hill, M. J. and Carter, D. J. Wind erosion and soil carbon dynamics in south-western Australia. Aeolian Research 1, 129-141 (2010).

Hernes, P. J. *et al*. The role of hydrologic regimes on dissolved organic carbon composition in an agricultural watershed. Geochimica et Cosmochimica Acta 72, 5266-5277 (2008).

Holland, J. E., Johnston, T. H., White, R. E. and Orchard, B. A. An investigation of runoff from raised beds and other tillage methods in the high rainfall zone of south-western Victoria, Australia. Soil Res. 50, 371 (2012).

Holland, J. M. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment 103, 1-25 (2004).

Hulugalle, N. R. and Scott, F. A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006. Soil Res. 46, 173 (2008).

Hulugalle, N. R., Rohde, K. W. and Yule, D. F. Cropping systems and bed width effects on runoff, erosion and soil properties in a rainfed Vertisol. Land Degrad. Dev. 13, 363-374 (2002).

Hulugalle, N. R., Weaver, T. B. and Finlay, L. A. Soil water storage and drainage under cotton-based cropping systems in a furrow-irrigated Vertisol. Agricultural Water Management 97, 1703-1710 (2010).

Hulugalle, N. R., Weaver, T. B., Finlay, L. A. and Heimoana, V. Soil organic carbon concentrations and storage in irrigated cotton cropping systems sown on permanent beds in a Vertosol with restricted subsoil drainage. Crop Pasture Sci. 64, 799 (2013).

Huon, S. *et al*. Long-term soil carbon loss and accumulation in a catchment following the conversion of forest to arable land in northern Laos. Agriculture, Ecosystems and Environment 169, 43-57 (2013).

Jacinthe, P. A. and Lal, R. A mass balance approach to assess carbon dioxide evolution during erosional events. Land Degrad. Dev. 12, 329-339 (2001).

Jacinthe, P. A. and Lal, R. A mass balance approach to assess carbon dioxide evolution during erosional events. Land Degrad. Dev. 12, 329-339 (2001).

Jacinthe, P.-A., Lal, R., Owens, L. B. and Hothem, D. L. Transport of labile carbon in runoff as affected by land use and rainfall characteristics. Soil and Tillage Research 77, 111-123 (2004).

Janeau, J.-L. *et al*. Soil erosion, dissolved organic carbon and nutrient losses under different land use systems in a small catchment in northern Vietnam. Agricultural Water Management 146, 314-323 (2014).

Jin, K. *et al*. Residue cover and rainfall intensity effects on runoff soil organic carbon losses. CATENA 78, 81-86 (2009).

Jin, K. *et al*. Soil management effects on runoff and soil loss from field rainfall simulation. CATENA 75, 191-199 (2008).

Kindler, R. *et al*. Dissolved carbon leaching from soil is a crucial component of the net ecosystem carbon balance: DISSOLVED CARBON LEACHING. Global Change Biology 17, 1167-1185 (2011).

King, A. P. *et al*. Annual carbon and nitrogen loadings for a furrow-irrigated field. Agricultural Water Management 96, 925-930 (2009).

Kinnell, P. I. A. The influence of raindrop induced saltation on particle size distributions in sediment discharged by rain-impacted flow on planar surfaces. CATENA 78, 2-11 (2009).

Kirschbaum, M. U. F., Harms, B., Mathers, N. J. and Dalal, R. C. Soil carbon and nitrogen changes after clearing mulga (Acacia aneura) vegetation in Queensland, Australia: Observations, simulations and scenario analysis. Soil Biology and Biochemistry 40, 392-405 (2008).

Kuhn, N. J., van Oost, K. and Cammeraat, E. Soil erosion, sedimentation and the carbon cycle. CATENA 94, 1-2 (2012).

Labat, D., Goddéris, Y., Probst, J. L. and Guyot, J. L. Evidence for global runoff increase related to climate warming. Advances in Water Resources 27, 631-642 (2004).

Labrière *et al*. - 2015 - Soil erosion in the humid tropics A systematic qu.pdf.

Lal, R. Soil erosion and carbon dynamics. Soil and Tillage Research 81, 137-142 (2005).

Lal, R. Soil erosion and the global carbon budget. Environment International 29, 437-450 (2003).

Lentz, R. D. and Lehrsch, G. A. Manure and Fertilizer Effects on Carbon Balance and Organic and Inorganic Carbon Losses for an Irrigated Corn Field. Soil Science Society of America Journal 78, 987-1002 (2014).

Likens, G. E., Edgerton, E. S. and Galloway, J. N. The composition and deposition of organic carbon in precipitation. Tellus B 35B, 16-24 (1983).

Luo, Z., Wang, E. and Sun, O. J. Soil carbon change and its responses to agricultural practices in Australian agro-ecosystems: A review and synthesis. Geoderma 155, 211-223 (2010).

Maïga-Yaleu, S. *et al*. Soil crusting impact on soil organic carbon losses by water erosion. CATENA 107, 26-34 (2013).

Mailapalli, D. R., Wallender, W. W., Burger, M. and Horwath, W. R. Effects of field length and management practices on dissolved organic carbon export in furrow irrigation. Agricultural Water Management 98, 29-37 (2010).

Martínez-Mena, M. *et al*. Organic carbon enrichment in sediments: Effects of rainfall characteristics under different land uses in a Mediterranean area. CATENA 94, 36-42 (2012).

Martinezmena, M., Lopez, J., Almagro, M., Boixfayos, C. and Albaladejo, J. Effect of water erosion and cultivation on the soil carbon stock in a semiarid area of South-East Spain. Soil and Tillage Research 99, 119-129 (2008).

Mchunu, C. and Chaplot, V. Land degradation impact on soil carbon losses through water erosion and CO2 emissions. Geoderma 177-178, 72-79 (2012).

Mora, J. L. *et al*. Mineralization rate of eroded organic C in Andosols of the Canary Islands. Science of The Total Environment 378, 143-146 (2007).

Moran, N. P., Ganf, G. G., Wallace, T. A. and Brookes, J. D. Flow variability and longitudinal characteristics of organic carbon in the Lachlan River, Australia. Mar. Freshwater Res. 65, 50 (2014).

Nachimuthu, G. and Webb, A. A. On-farm soil conservation measures in cotton farming systems of Australia: A sustainability analysis. Journal of Soil and Water Conservation 71, 75A-80A (2016).

Nie, X. *et al*. Enrichment of organic carbon in sediment under field simulated rainfall experiments. Environ Earth Sci 74, 5417-5425 (2015).

Nie, X. *et al*. Soil Organic Carbon Loss and Selective Transportation under Field Simulated Rainfall Events. PLoS ONE 9, e105927 (2014).

Oh, N.-H. *et al*. The role of irrigation runoff and winter rainfall on dissolved organic carbon loads in an agricultural watershed. Agriculture, Ecosystems and Environment 179, 1-10 (2013).

Olson, K. R. Soil organic carbon sequestration, storage, retention and loss in U.S. croplands: Issues paper for protocol development. Geoderma 195-196, 201-206 (2013).

Olsson, A., Campana, P. E., Lind, M. and Yan, J. Potential for carbon sequestration and mitigation of climate change by irrigation of grasslands. Applied Energy 136, 1145-1154 (2014).

Panuska, J. C. and Karthikeyan, K. G. Phosphorus and organic matter enrichment in snowmelt and rainfall-runoff from three corn management systems. Geoderma 154, 253-260 (2010).

Park, E.-J., Sul, W. J. and Smucker, A. J. M. Glucose additions to aggregates subjected to drying/wetting cycles promote carbon sequestration and aggregate stability. Soil Biology and Biochemistry 39, 2758-2768 (2007).

Poch, R. M., Hopmans, J. W., Six, J. W., Rolston, D. E. and McIntyre, J. L. Considerations of a field-scale soil carbon budget for furrow irrigation. Agriculture, Ecosystems and Environment 113, 391-398 (2006).

Poeplau, C. and Don, A. Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. Geoderma 192, 189-201 (2013).

Polyakov, V. O. and Lal, R. Soil organic matter and CO2 emission as affected by water erosion on field runoff plots. Geoderma 143, 216-222 (2008).

Raupach, M. R., Haverd, V. and Briggs, P. R. Sensitivities of the Australian terrestrial water and carbon balances to climate change and variability. Agricultural and Forest Meteorology 182-183, 277-291 (2013).

Rochester, I. J. Sequestering carbon in minimum-tilled clay soils used for irrigated cotton and grain production. Soil and Tillage Research 112, 1-7 (2011).

Ruark, M. D. *et al*. Seasonal Losses of Dissolved Organic Carbon and Total Dissolved Solids from Rice Production Systems in Northern California. J. Environ. Qual. 39, 304-313 (2010).

Sainju, U. M., Stevens, W. B., Caesar-TonThat, T. and Jabro, J. D. Land Use and Management Practices Impact on Plant Biomass Carbon and Soil Carbon Dioxide Emission. Soil Sci. Soc. Am. J. 74, 1613-1622 (2010).

Schiettecatte, W., Gabriels, D., Cornelis, W. M. and Hofman, G. Enrichment of Organic Carbon in Sediment Transport by Interrill and Rill Erosion Processes. Soil Sci. Soc. Am. J. 72, 50-55 (2008).

Schilling, K. E., Jacobson, P. J. and Vogelgesang, J. A. Agricultural conversion of floodplain ecosystems: Implications for groundwater quality. Journal of Environmental Management 153, 74-83 (2015).

Scott, J. T. *et al*. Carbon and nitrogen leaching under high and low phosphate fertility pasture with increasing nitrogen inputs. Agriculture, Ecosystems and Environment 202, 139-147 (2015).

Shukla, M. and Lal, R. Erosional effects on soil organic carbon stock in an on-farm study on Alfisols in west central Ohio. Soil and Tillage Research 81, 173-181 (2005).

Stockmann, U. *et al*. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, Ecosystems and Environment 164, 80-99 (2013).

Thayalakumaran, T., Bristow, K. L., Charlesworth, P. B. and Fass, T. Geochemical conditions in groundwater systems: Implications for the attenuation of agricultural nitrate. Agricultural Water Management 95, 103-115 (2008).

Thayalakumaran, T., Lenahan, M. J. and Bristow, K. L. Dissolved Organic Carbon in Groundwater Overlain by Irrigated Sugarcane. Groundwater 53, 525-530 (2015).

The 10th International Conference on Future Internet. (Association for Computing Machinery, 2015).

Van Gaelen, N. *et al*. Controls on dissolved organic carbon export through surface runoff from loamy agricultural soils. Geoderma 226-227, 387-396 (2014).

van Vliet, M. T. H. and Zwolsman, J. J. G. Impact of summer droughts on the water quality of the Meuse river. Journal of Hydrology 353, 1-17 (2008).

Vinther, F. P., Hansen, E. M. and Eriksen, J. Leaching of soil organic carbon and nitrogen in sandy soils after cultivating grass-clover swards. Biol Fertil Soils 43, 12-19 (2006).

Walmsley, D. C. *et al*. Dissolved carbon leaching from an Irish cropland soil is increased by reduced tillage and cover cropping. Agriculture, Ecosystems and Environment 142, 393-402 (2011).

Wan, Y. and El-Swaify, S. A. Sediment Enrichment Mechanisms of Organic Carbon and Phosphorus in a Well-Aggregated Oxisol. J. environ. qual. 27, 132-138 (1998).

Willey, J. D., Kieber, R. J., Eyman, M. S. and Avery, G. B. Rainwater dissolved organic carbon: Concentrations and global flux. Global Biogeochem. Cycles 14, 139-148 (2000).

Zhang, G., Zhang, X. and Hu, X. Runoff and soil erosion as affected by plastic mulch patterns in vegetable field at Dianchi lake's catchment, China. Agricultural Water Management 122, 20-27 (2013).

Zheng, F., Huang, C. and Norton, L. D. Vertical Hydraulic Gradient and Run-On Water and Sediment Effects on Erosion Processes and Sediment Regimes. Soil Sci. Soc. Am. J. 64, 4-11 (2000).

Zhong, S., Liang, W., Lou, Y., Li, Q. and Zhu, J. Four years of free-air CO_2 enrichment enhance soil C concentrations in a Chinese wheat field. Journal of Environmental Sciences 21, 1221-1224 (2009).

Zou, X. *et al*. Greenhouse gas emissions from agricultural irrigation in China. Mitig Adapt Strateg Glob Change 20, 295-315 (2015).