Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(2): 59-69
Received: 11-01-2019
Accepted: 15-02-2019

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Conservation agriculture effects on aggregates carbon storage potential and soil microbial community dynamics in the face of climate change under semi-arid conditions: A review

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Abstract
Soil organic carbon plays the crucial role in maintaining soil quality. The impact carbon and nitrogen dynamics and rate of SOC sequestration in tillage and crop residue application is still in investigation in this environment. The soil organic carbon build up was affected significantly by tillage and residue level in upper depth of 0-15 cm but not in lower depth of 15-30 cm. Higher SOC content of 19.44 gkg^{-1} of soil was found in zero tilled residue retained plots followed by 18.53 g kg^{-1} in permanently raised bed with residue retained plots. Whereas, the lowest level of SOC content of 15.86 g kg^{-1} of soil were found in puddled transplanted rice followed by wheat planted under conventionally tilled plots. Zero tilled residue retained plots sequestrated 0.91$gkg^{-1}yr^{-1}$ SOC which was 22.63% higher over the conventionally tilled residue removed plots after seven seasons of experimentation. Soil microbial biomass carbon (SMBC) was highest (66.05 µg g^{-1}) in treatments FYM @10 ton ha^{-1}+PSB + Azotobactor and it was lowest (51.71μgg^{-1}) in treatments having farmers' practices. Microbial biomass carbon significantly increased with the integrated application of organic manure (FYM @ 10 tonnes ha^{-1}) and mineral fertilizer (100% NPK) over control. Development of management practices that favour C sequestration or prevent further losses will help to reduce the potential SOC decline due to the climate change and because of the importance of SOC to soil health and plant productivity, maintenance or restoration of SOC will help to reduce the threats of food security due to climate change. Enhancing the soil organic carbon pool also improves agro-ecosystem resilience, eco-efficiency, and adaptation to climate change.

Keywords: climate change, soil microbial communities, soil organic carbon

Introduction
Soils represent the most diverse and important ecosystem on the planet (Roger-Estrade *et al*., 2010) [47]. Most of the biodiversity of agro-ecosystems is found in the soil (Young and Crawford, 2004) [58], and the functions performed by soil biota have considerable direct and indirect effects on crop growth and quality, nutrient cycle quality and the sustainability of soil productivity (Roger-Estrade *et al*., 2010) [47]. Soil biota also contributes substantially to the resistance and resilience of agro-ecosystems to abiotic disturbance and stress (Brussaard *et al*., 2007) [4]. The microbial members of soil communities are the most sensitive and rapid indicators of perturbations and land use changes. In this sense, a quantitative description of microbial community structure and diversity has aroused great interest as a potential tool for soil quality evaluation (Zornoza *et al*., 2009) [60].

Agricultural land management is one of most significant anthropogenic activities that greatly alter soil characteristics, including physical, chemical, and biological properties (Jangid *et al*., 2008) [25]. This fact is particularly relevant in Mediterranean environments, where unsuitable land management together with climatic constraints (scarce and irregular rainfall and frequent drought periods) can contribute to increased rates of erosion and other degradation processes of agricultural land (Caravaca *et al*., 2002) [6]. These conditions can lead to a loss in soil fertility and a reduction in the abundance and diversity of soil microorganisms. Agricultural management influences soil microorganisms and soil microbial processes by changing the quantity and quality of plant residues entering the soil and their spatial distribution, through changes in nutrients and inputs (Christensen, 1996) [10]. The excessive use of pesticides can drastically modify the function and structure of soil microbial communities, thereby altering the normal functioning of terrestrial ecosystems, which in turn has important implications for soil quality (Pampulha and Oliveira, 2006) [39].

Management practices have a direct effect on soil micro-biota, and the direct increases microbial biomass (Feng *et al*., 2003) [14]. Soils subjected to disturbance by tillage, however, can be more susceptible to seeding of extensive crops reductions in soil micro-biota due to desiccation, mechanical destruction, soil compaction, reduce pore volume, and disruption of access to food resources (Giller, 1996) [15]. A better understanding of SOC stability and the role of microbial community structures and function on SOC stability are needed, and will be useful to predict future impacts of climate change on SOC dynamics.

Agricultural soils play a major role in climate change mitigation (Robertson *et al*., 2000) [46]. Changes in management and/or land use increase or decrease the stocks of SOC. In agro-ecosystems the amount of SOC stored within the soil profile is a result of the balance between C gains, mainly from crop residues, and C losses from the decomposition of soil organic matter (SOM) by microorganisms. Among management practices, the intensification of cropping systems through the suppression of long fallowing has permitted the increase of significant amounts of crop residues returned to soils (Álvaro-Fuentes *et al*., 2008) [44]. Similarly, the conversion from dry-land to irrigated agriculture involves an increase in crop productivity and in greater C inputs (Denef *et al*., 2008) [13]. Furthermore, the reduction in tillage intensity has been recognized as a viable option to increase SOC stocks through decreasing SOC decomposition (Plaza-Bonilla *et al*., 2010) [44]. Nevertheless, the effects of agricultural management on SOC dynamics could potentially be affected by climate change due to increases in the anthropogenic CO_2 emissions.

Since climate is one of the main driving factors in SOC turnover (Paul, 1984), changes in soil temperature and moisture due to climate change might impact SOC stocks and changes. Increases in soil temperature have been associated with higher decomposition rates (Davidson and Janssens, 2006) [12], but experimental data showed that decreases in soil moisture slow down microbial activity and thus SOC decomposition (Skopp *et al*., 1990) [51]. Moreover, despite the effects of climate on microbial activity, the increase in atmospheric CO_2 has been associated with changes in net primary productivity (NPP) and changes in the C:N ratio of the plant material produced. This paper reviews the potential impact of conservation agriculture (CA)under climate change conditions made in Indian agro-ecosystems on aggregates carbon storage potential by synthesizing the knowledge of carbon and nitrogen cycling in agriculture; summarizing the influence of tillage, residue management, and crop rotation on soil microbial community dynamics; and compiling the existing case study information. To evaluate the C sequestration capacity of farming practices, their influence on emissions from farming activities should be considered together with their influence on soil C stocks.

Carbon levels in soil are determined by the balance of inputs, as crop residues and organic amendments, and C losses through organic matter decomposition (Paustian *et al.*, 1997) [42]. Upon cultivation of previously untilled soils, this balance is disrupted and generally 20% to 40% of the soil C is lost, most of it within the first few years following initial cultivation (Murty *et al.*, 2002) [35]. Afterwards, the rate of decrease levels off, and some decades later a new, management dependent soil humus level is attained (Sauerbeck *et al.*, 2001; Fig.1a) [48]. Following an improvement in agricultural management practices, soil organic carbon will gradually approach anew steady state that depends on the new suite of practices (Marland *et al.*, 2003, Fig. 1a). Estimates of the time necessary to reach the new steady state range from 20–40 years (West and Marland, 2002) [56] to 50–100 years (Sauerbeck, 2001) [48]. It is important to remember that the use of agricultural inputs such as fertilizer, irrigation, pesticides and liming carry a 'hidden' carbon cost, so any effort to estimate the effect of changing tillage practice on the net flux of CO_2 to the atmosphere should consider both the C sequestered in soil and the emissions from fossil-fuel use in the affected system (West and Marland, 2002) [56].

The SOC stock will evolve out of steady state for a certain period, to eventually reach the new equilibrium value. Fig.1b also showed that an annual OC inputs are constant in a given period, SOC stocks can increase or decrease during that period. SOC stocks were probably not yet at equilibrium at the start of the monitoring. Furthermore the C accumulation rate was found to decline with stand age (Jonard *et al*., 2017) [26], what could be interpreted as getting closer to an equilibrium between the soil C stock and C input. This result among others stresses the need to have good constraints on the soil past land-uses when studying its OC stock evolution. However, in the context of a continuously changing climate SOC values at equilibrium may also continuously change. The reduction of C outputs can be achieved by reducing SOC mineralization by soil micro-organisms or SOC erosion. The role of microorganisms as drivers of soil C cycling, storage and sequestration in soil is not conceptually new, but is increasingly acknowledged as crucial (Lehmann and Kleber, 2015) [29]. Microorganisms contribute both to the biodegradation and mineralization of soil organic substrates, and to the genesis of new organic metabolites.

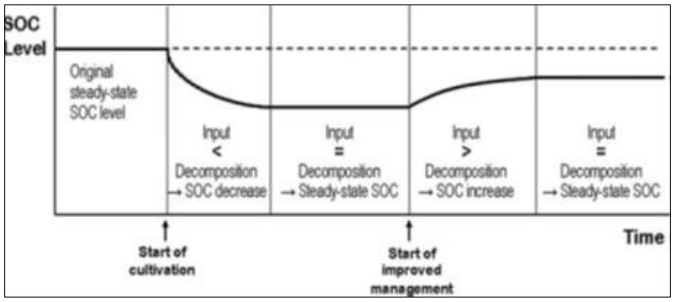

Fig 1(a): Long-term soil organic carbon level changes depending on carbon input and decomposition in agricultural ecosystems

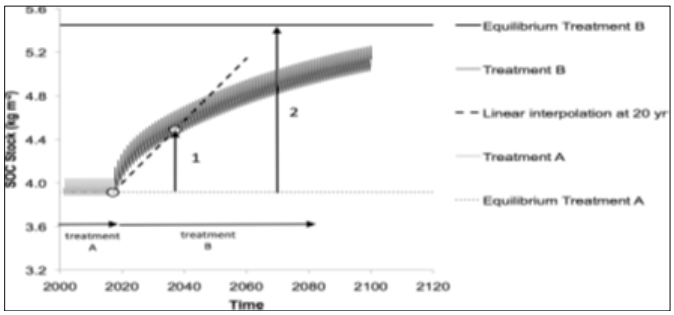

Fig 1(b): Schematic increase in SOC stocks following changes in land-use or management practices (Increased OC inputs or decreased OC outputs)

The breakdown and biosynthesis rates of the various biochemical components of OM are determined by the microbial community dynamics and by their functional traits. These rates are limited by physical accessibility of substrate to microbes or to their enzymes and by the micro-habitat

conditions (oxygen, pH, water content, nutrient resources) (Pinheiro *et al*., 2015; Fig. 1b) [43].

Ogle *et al.* (2005) found that management impacts were sensitive to climate in the following order from largest to smallest changes in SOC: tropical moist >tropical dry >temperate moist >temperate dry. For example, converting from conventional tillage to zero tillage increased SOC storage over

20 years by a factor of 1.23 ± 0.05 in tropical moist climates, which is a 23% increase in SOC, while the corresponding change in tropical dry climates was 1.17 ± 0.05, temperate moist was1.16 ± 0.02, and temperate dry was 1.10 ± 0.03.

Naresh *et al*. (2018) [37] revealed that the SOC pool was the highest in the100 per cent RDF + VC (56.8 Mg C ha^{-1}), and it was on par with 50 per cent RDF +VC (52.8 Mg C ha^{-1})>75 per cent RDF +VC (51.4 Mg C ha^{-1})>VC (49.4Mg C ha^{-1}) >RDF (39.3 Mg C ha^{-1})> control (35.9 Mg C ha^{-1}) treatments. A higher percentage of C build-up was observed in 100 per cent RDF + VC treatment (43.6 per cent) followed by 50 per cent RDF+VC treatment (40.7 per cent), which was reflected in the profile SOC concentration of respective treatments (Table 1). The SOC build-up rate also followed a similar trend as C build-up. The C budgeting shows that 36.8 per cent of the C applied as VC was stabilized. Higher SOC sequestration was observed with the application of vermin-compost along with 100, 75 and 50 per cent recommended rate of RDF. Cultivation of a crop without using any organic and/or inorganic fertilizer inputs (control) caused a net depletion of SOC pool by 12.0 Mg C ha^{-1}.Maintaining the SOC pool above the critical level is necessary to sustain agronomic productivity and to minimize environmental degradation (Lal, 2010c) [28]. However, maintaining or improving the SOC pool in light-textured soils of arid and semi-arid regions is a major challenge (Srinivasarao *et al*., 2012) [53].

Table 1: Profile organic C (OC), C build-up, C build-up rate, C sequestered, C: N ratio and wet aggregate stability (WAS)in the soil profile as affected by 7 years of tillage crop residue and nutrient management practices [Naresh *et al*., 2018] [37]

Treatments	Profile OC Mg ha^{-1}	C build-up %	C build-up rate Mg C ha^{-1} y^{-1}	C Sequestrated Mg C ha^{-1}	C:N Ratio	WAS (%)
Tillage crop residue practices						
T_1	43.5±3.1^{d}	27.9±0.7^{c}	1.06±0.08^{e}	6.7±0.2^{d}	14.5^{ab}	93.4^{c}
T_2	51.7±2.5^{c}	34.2±1.8^{b}	1.36±0.07^{cd}	8.2±0.1^{c}	12.7^{b}	92.9^{c}
T_3	69.4±3.3^{a}	36.6±0.6^{b}	1.46±0.09^{b}	8.6±0.8^{bc}	9.43^{c}	95.7^{ab}
T_4	63.3±2.8^{b}	31.8±0.6^{bc}	1.33±0.04^{d}	7.6±0.8^{b}	13.5^{ab}	94.5^{bc}
T_5	72.9±3.7^{a}	41.0±2.2^{a}	1.63±0.09^{a}	9.2±0.2^{ab}	12.3^{b}	96.9^{a}
T_6	73.0±3.6^{a}	41.2±2.3^{a}	1.64±0.10^{a}	9.6±0.2^{a}	9.28^{c}	97.6^{a}
T_7	41.5±2.9^{d}	22.4±1.2^{c}	0.89±0.06^{f}	5.3±0.5^{e}	15.3^{a}	89.7^{d}
Fertilizer Management Practices						
F_1	35.9±1.6^{c}	-	-	-12.0±0.7^{d}	16.2^{a}	93.7^{d}
F_2	39.3±1.8^{c}	29.8±0.06^{d}	1.28±0.007^{d}	-0.61±0.8^{c}	15.3^{ab}	92.3^{bc}
F_3	52.8±0.02^{ab}	40.7±2.4^{a}	1.82±0.006^{a}	9.3±0.8^{a}	14.5^{bc}	90.1^{b}
F_4	51.4±2.1^{ab}	37.3±0.06^{b}	1.73±0.021^{b}	8.5±0.5^{b}	13.7^{c}	89.9^{b}
F_5	56.8±1.9^{c}	43.6±0.09^{a}	1.88±0.001^{a}	9.6±0.7^{a}	8.99^{e}	87.4^{a}
F_6	49.4±2.3^{b}	34.2±1.8^{c}	1.46±0.07^{c}	7.9±0.3^{c}	10.8^{d}	91.1^{bc}

Treatment CT with rice-wheat rotation has higher C: N ratio as compared to different ZT and FIRB management systems are likely due to the contribution of residue and root inputs system (Table 1).The non-significant increase of C: N ratio under ZT compare to FIRB probably is related tome chanical redistribution when residues and roots in soil homogenized and distributed in soil profile (Wright *et al*., 2007) [57]. Application of high fertilizer N rate in high C: N residue amended soils lowers the C: N ratio of the residue which avoids net immobilization but enhances the mineralization process (Pathak *et al*., 2006) [40]. This N remained in the soil after harvest and helped to maintain inorganic N concentrations in soil.

The WAS under ZT without residue retention (93.4%) significantly increased by 4% compared to CT system (89.7%). A similar trend was observed under fertilizer management practices where control (91.7%) significantly increased WAS by 2.3% compare to 100% VC (93.9%). The 50%RDF +50%VC and 75%RDF +25%VC decreased WAS by 4% compared to under 100% RDF system (Table 1). The study reported that mechanical tillage increased the breakdown of soil macro-aggregates and that CT disrupted soil macro-aggregates into micro-aggregates or individual particles. In addition, soil under CT system distributed aggregates during the plowing event by bringing protected aggregates to the soil surface. The degree of macro-aggregation in this soil was much lower than in most other agricultural systems, due primarily to the puddling of soil which tends to destroy aggregates. The ZT system likely improved the physical protection of organic carbon from decomposition and therefore, generally had higher SOC. In contrast, CT disrupts aggregates and exposing them to microbial decomposition (Tan *et al*., 2007; Saygn *et al*., 2017) [54, 49].

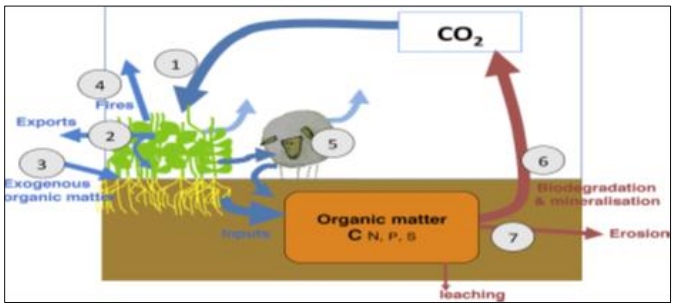

Fig 2(a): Levers associated with agricultural practices that may influence SOC stocks

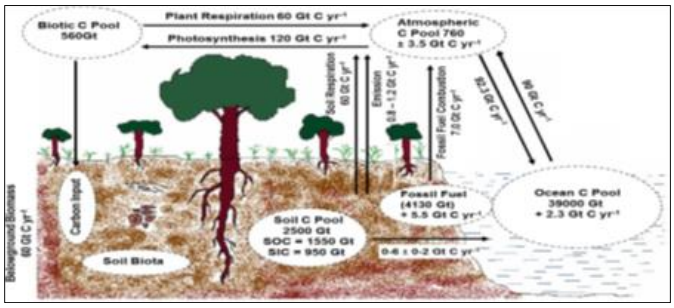

Fig 2(b): Sources and sinks of carbon from different pools under terrestrial and aquatic ecosystems.

Several organic cropping systems, characterized by a diversified rotation including legume cover crops, exhibited similar or higher SOC stocks than their conventional counterparts, while fresh OC inputs to soil were not higher and tillage was more frequent (Autret *et al*., 2016) [3] (a process not represented in Fig. 2a). Kallenbach *et al*. (2015) [30] showed that in an organic cropping system, soil microorganisms had a higher carbon use efficiency and higher growth rates than under the reference conventional system. This should result in more microbial necromass being formed per unit of C input. Microbial necromass represents a significant fraction of soil organic matter and a major constituent of SOM stabilized in the long term (Cotrufo *et al*., 2013) [11], which would explain the increased or preserved SOC stocks.

Each year, an estimated 25–40 billion tons of fertile soil are lost globally (FAO and ITPS, 2015). Hence, improving soil health through sustainable land management should be a common goal for farmers and land managers, to protect, maintain and build their most vital resource – soils. Soils are the major reservoir of C in terrestrial ecosystems, and soil C plays a dynamic role in influencing the global C cycle and climate change (Fig. 2b) while regulating soil health and productivity (Singh *et al*., 2018) [37]. Soil contains C in two forms: soil organic C (SOC) and soil inorganic C (SIC), with most soils (except calcareous soils) having more SOC than SIC (Fig. 2b). Thus far, enormous scientific progress has been attained in understanding soil functional characteristics relating to SOC stocks and C dynamics in agro-ecosystems.

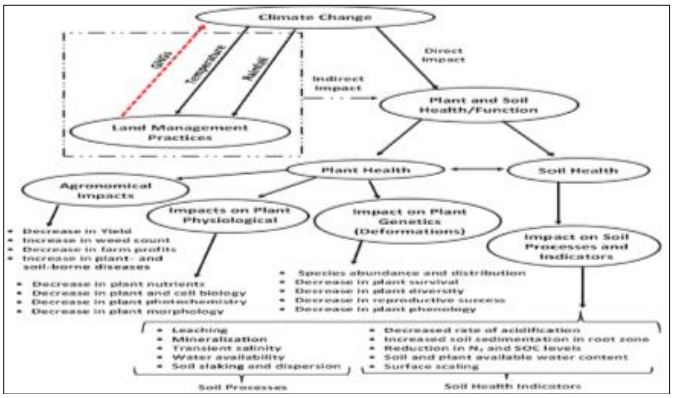

Fig 3: A conceptual figure showing soil–climate interactions and their impact (direct or indirect) onplant and soil properties/processes that are aligned with soil health.

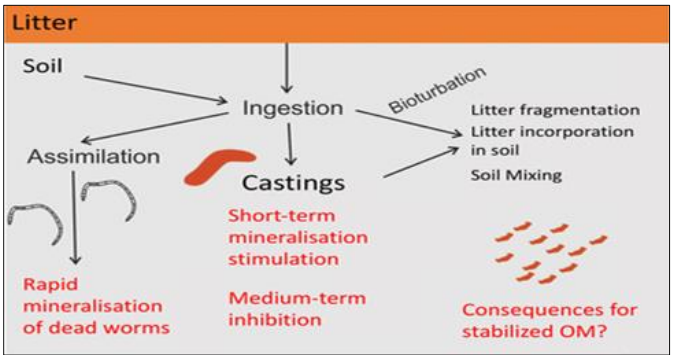

Fig 3(b): Earthworm activity affects organic matter dynamics via litter consumption and soil particle ingestion

The diversity of organisms hosted in soils is huge in terms of size and function, encompassing megafauna, macrofauna, microfauna and microorganisms. Soil macrofauna includes organisms larger than 2 mm with high taxonomic diversity, including millipedes (diplopoda and centipedes), woodlice, earthworms, some springtails, numerous spiders and insects (ants, beetles, termites), in addition to vertebrates such as rodents (mice) and insectivores (moles, shrews). Functionally, these animals can be grouped according to their diet (Zoophagous, herbivorous, root-feeding, saprophagous, soil-feeding, etc.) or to their impact on their physical and chemical environment. The best known group includes 'ecosystem engineers' (earthworms, ants and termites). These organisms often represent a large biomass in soils (individually for earthworms or socially for termites and ants), having a substantial influence on soil OM dynamics (Chevallier *et al*., 2001) [9] (Fig. 3b).

Naresh *et al*. (2018) [37] reported that WSC was found to be 5.48% higher in surface soil than in sub-surface soil (Table 2). In both the depths, T_6 treatment had the highest WSC as compared to the other treatments studied. Compared to CT, FIRB and ZT coupled with 6tha^{-1} CR increased 35.6% WSC in surface soil and 33.1% in sub surface soil. Among all the treatments, T_6 had significantly higher (19.73%) proportion of WSC than the other treatments compared. Irrespective of tillage practices, residue retention resulted in 22.56% and 25.61% higher WSC as compared to the non-residue treatments in surface and sub-surface soil, respectively. The WSC content in surface soil (0–15 cm) was significantly higher in 100% RDN as CF+ VC@ 5tha^{-1}(F_5)treatment (32.5 mg kg^{-1}) followed by 75% RDN as CF+ VC@ 5tha^{-1} (F_4) (29.8 mgkg^{-1}) and least in unfertilized control plot [(F_1) (21.9 mgkg^{-1}) (Table 2)]. However, similar significant effect was observed in sub-surface soil (15-30 cm) and the magnitude was relatively lower. The increase in WSC in 0–15 cm soil depth was 37.2 and 28.4% in 100% RDN as CF+ VC@ 5tha^{-1} (F_5) and 75% RDN as CF+ VC@ 5tha^{-1}(F_4) treated plots over control.

The higher MBC was observed in the ZT and FIRB with residue retention plots than the CT plot under the RWCS suggests that abandonment of the cropland had substantial beneficial effects on the activity of microbial organisms probably caused by the accumulation of organic C compounds at the soil surface. A possible reason for this difference is that in the absence of growing plants other labile Cfractionsmay provide food for microbes, and thus maintain MBC. Another possible reason could be related to the soil moisture status. Under the CT treatment, in which biomass production would inevitably deplete much more soil moisture, the microbes in the plot would be stressed at the time of sampling (wheat maturity).

The microbial biomass carbon (MBC) is an important component of the SOM that regulates the transformation and storage of nutrients. The soil MBC regulates all SOM transformations and is considered to be the chief component of the active SOM pool. It is evident that the MBC contents in both surface and sub-surface soil were significantly higher in plots receiving 100% RDN as CF+ VC@ 5tha^{-1}(F_5) and 75% RDN as CF+ VC@ 5tha^{-1}(F_4) treated plots compared to 100% RDN as CF (F_2) fertilizer and unfertilized control plots (Table 2). The values of MBC in surface soil varied from 116.8 mgkg^{-1} in unfertilized control plot to 424.1 mgkg^{-1} in integrated nutrient use of 100% RDN as CF+ VC@ 5tha^{-1} plots, respectively; while it varied from 106.6 mgkg^{-1} (control) to 324.9 mgkg^{-1} (100% RDN as CF+ VC@ 5tha^{-1}F_5) in sub-surface (15-30 cm) soil layer. The values of MBC increased by 72.5 and 58.4% fewer than 100% RDN as CF+ VC@ 5tha^{-1}(F_5) and 75% RDN as CF+VC@ 5tha^{-1}(F_4)

treatment in surface soil over control. While, there were 34.4% increase of MBC over 100% RDF as CF (F_2) fertilizer, respectively. The highest value of MBC due to integrated use of FYM and RDN fertilizer might be due to higher turn-over of root biomass produced fewer than100% RDN as CF+ VC@ 5tha^{-1} treatment. Although MBC content in soil represent a small fraction i.e. about 2-4% of TOC, however, variation in this pool due to management and cropping systems indicate about the quality of soil, because the turn-over of SOM is controlled by this pool of SOC which can provide an effective early warning of the improvement or deterioration of soil quality as a result of different management practices. Hao *et al*. (2008) [20] who observed that the microbial biomass was considerably greater in soils receiving FYM along with NPK fertilizer than in plots receiving merely NPK fertilizer in three subtropical paddy soils. Mandal *et al*. (2008) [32] reported that the microbial biomass was greater in soils due to addition of straw plus inorganic NPK for 34 years than that of inorganic NPK fertilizers.

Table 2: Concentrations of different soil organic matter carbon fractions fPOM and cPOM at different soil depths as affected by tillage and nutrient management to the continuous RW cropping system [Naresh *et al*., 2018] [37].

Treatments	0-15 cm layer					15-30 cm layer				
	WSC (mgkg^{-1})	MBC (mgkg^{-1})	LFC (mgkg^{-1})	$_f$POM (g Ckg^{-1})	$_c$POM (g Ckg^{-1})	WSC (mgkg^{-1})	MBC (mgkg^{-1})	LFC (mgkg^{-1})	$_f$POM (g Ckg^{-1})	$_c$POM (g Ckg^{-1})
Tillage crop residue practices										
T_1	16.9^{d}	311.4^{c}	81.3^{d}	0.44^{d}	0.92^{cd}	15.7^{d}	193.9^{cd}	65.1^{d}	0.32^{cd}	0.58^{bc}
T_2	18.9^{c}	345.2^{bc}	107.8^{bc}	0.62^{bcd}	1.82^{bc}	17.8^{cd}	219.8^{c}	94.1^{bc}	0.55^{de}	1.31^{bcd}
T_3	20.8^{ab}	481.7^{a}	155.2^{a}	0.88^{ab}	2.54^{a}	19.6^{bc}	294.8^{ab}	132.6^{a}	0.83^{c}	1.93^{a}
T_4	18.7^{d}	306.5^{c}	95.7^{c}	0.53^{cd}	1.03^{d}	17.6^{cd}	187.5^{cd}	87.6^{c}	0.35^{bc}	0.94^{ab}
T_5	21.4^{bc}	398.6^{b}	128.8^{b}	0.86^{bc}	2.21^{ab}	20.3^{ab}	240.9^{bc}	102.9^{b}	0.72a	1.64^{a}
T_6	23.2^{a}	535.8^{a}	177.8^{a}	1.30^{a}	2.38^{ab}	21.6^{a}	361.8^{a}	141.2^{a}	1.19^{e}	1.89^{cd}
T_7	14.2^{e}	266.7^{c}	52.7^{e}	0.38^{d}	0.94^{d}	13.8^{e}	145.9^{d}	49.8^{e}	0.26^{f}	0.61^{d}
Fertilizer Management Practices										
F_1	21.9^{e}	116.8^{c}	89.2^{c}	0.41^{d}	0. 64^{d}	15.1^{e}	106.6^{d}	47.9^{f}	0.28	0.48^{d}
F_2	28.4^{d}	189.2^{c}	123.5^{bc}	0.60^{cd}	0.93^{d}	18.8^{d}	166.8^{cd}	66.7^{e}	0.45	0.59
F_3	29.2^{cd}	239.9^{bc}	146.4^{c}	0.71^{cd}	1.52^{cd}	20.2^{cd}	196.8^{bc}	85.9^{d}	0.52	0.74^{cd}
F_4	29.8^{c}	280.7b	160.5^{b}	1.33^{ab}	2.81^{ab}	21.9^{bc}	219.9^{bc}	103.2^{bc}	0.72	1.64^{ab}
F_5	32.5^{a}	424.1^{a}	183.9^{a}	1.89^{a}	3.78^{a}	26.4^{a}	324.9^{a}	152.9^{a}	0.92	2.34^{a}
F_6	28.9	210.3	133.2^{c}	0.66	1.19	19.8	178.2	76.4	0.51	0.63

** Different letters within columns are significantly different at P=0.05 according to Duncan Multiple Range Test (DMRT) for separation of means. WSC = water soluble carbon, MBC = microbial biomass carbon, LFC = labile fraction carbon, $_c$POM= coarse particulate organic carbon,$_f$POM= fine particulate organic carbon

The largest differences among tillage systems were found at the soil surface (Table 3). In the upper 15 cm depth, the $_f$POM content was between 1.9 and 2.8 times higher under ZT and FIRB with residue retained than under CT. The lower cPOM content under ZT with residue removal than under CT in the two soil layers (2–2.6 times less) can be explained by the farmer's practice of removing crop residues from the ZT field (Table 2). These values represent between 50.7 and 64.8% more $_f$POM with residue retained ZT and FIRB, averaging about 76.5% more. For cPOM, this range varied from 56.9% and 59.1% more, with an average value of 58% more. For both cPOM and $_f$POM fractions, the decreasing pattern in OC concentration with depth was more prominent under CT, especially ZT, and FIRB in such a way that the average concentrations in the 0–30 cm profile were narrow significantly different from those under CT. The marked stratification of $_C$POM- is generally observed under continuous ZT management and is produced by the maintenance of crop residues at the soil surface and the absence of soil disturbance. Ibrahim *et al*. (2015) [22] indicated that higher C input induced by fertility management practices resulted in significantly larger physically uncompleted organic carbon ($_f$POM,c POM and LFC) pools (Table 2). Gosling *et al*. (2013) [17] also indicated that $_f$POM, cPOM and LFC were strongly influenced by factors related to the recent history of organic matter addition.

Radford *et al*. (1995) [45] also showed there was a fourfold increase in earthworm numbers with zero tillage as compared to conventional tillage. Spedding *et al*. (2004) [52] found that residue management had more influence than tillage system on microbial characteristics, and higher SMB-C and N levels were found in plots with residue retention than with residue removal, although the differences were significant only in the 0-10 cm layer. Wuest *et al*. (2005) [57] observed that Residue retention can have a varying effect on earthworms, however, depending on their ecological niche, as tillage may benefit endogenic (horizontal-burrowing) earthworms if residue is incorporated into the soil, providing a food source. Ha *et al*. (2008) reported that different residues resulted in different levels of POM, which cultivate distinct microbial communities. James *et al*. (2010) [24] revealed that long-term notilled soils have significantly greater levels of microbes, more active carbon, more SOM, and more stored carbon than conventional tilled soils. A majority of the microbes in the soil exist under starvation conditions and thus they tend to be in a dormant state, especially in tilled soils. Wang *et al*. (2012) reported increased microbial biomass carbon with crop residue application in comparison to no crop residue application. Moharana *et al*. (2012) [34] revealed that the highest values of TOC (11.48 g kg^{-1}) and WBC (7.86 g kg^{-1}) were maintained in FYM treated plot, while the highest values of LBC (1.36 g kg^{-1}) and MBC (273 mg kg^{-1}) were found in FYM + NPK. The magnitude of change in pools of SOC in sub-surface (15–30 cm) soil was low as compared to the surface soil (0–15 cm). Significant increase in all the pools of SOC in FYM treated plots indicates the importance of application of organic manure like FYM in maintaining organic carbon in soil. Zhu *et al*. (2014) [59] found that Soil TOC and labile organic C fractions contents were significantly affected by straw returns, and were higher under straw return treatments than non-straw return at (0–7, 7–14 and 14– 21 cm) depths. Kumar *et al*. (2016) [27] reported that application of fertilizer N, P; farmyard manure (FYM) and crop residues enhanced total organic C from 4.5 g kg^{-1} in control to 6.4 gkg^{-1} in surface layer and from 3.3 to 4.4 g kg^{-1} in subsurface layer after 4 years in CA practices. Other soil health attributes like labile C and N fractions such as water-soluble C (38.9 mg kg^{-1}), particulate (1483 mgkg^{-1}) and light fraction (209 mgkg^{-1}) organic matter, potentially mineralizable N (23.3 mg kg^{-1} 7d^{-1}) and microbial biomass carbon (283 mg kg^{-1}) were also the highest under this integrated inorganic and organic treatment in conjunction with no tillage. Naresh *et al*. (2016) [36] also showed that in 3-year experiment LFON content in 0 - 5 cm soil layer of CT systemT_1, and T_5 treatments increased LFOC content from 5.1 mgkg^{-1} in CT (T_9) to 7.9 and 9.6 mgkg^{-1} without CR, and to

10.3,11.5 and 13.1mgkg^{-1}with crop residue @ 2,4 and6 tha^{-1},respectively.Compared to conventional tillage (CT), no-tillage and reduced tillage could significantly improve the SOC content in cropland. The enhanced microbial activity induces the binding of residue and soil particles into macro-aggregates, which could increase aggregates stability thus improving the concentration of SOC and increasing C sequestration (Liqun *et al*., 2014) [31].

Table 3: Positive and negative effects of global climate change [Source: Casper, 2010]

Positive Effects of Climate Change	***Negative Effects of Climate Change***
According to a report in ***National Geographic News* (2002)**, as greenhouse gas levels climb higher in the atmosphere, crop yields may increase in certain areas, such as fruits, vegetables, seeds, and grains. Although this may initially sound like a good thing, the positive effect is short-lived because it also results in a decrease in the crop's nutritional value.	In fact, researcher **Frank Mitloehner** of the University of California has eight cows confined inside what he refers to as a "bio-bubble" (a big white tent) to answer an extremely important question: How much gas does a cow actually emit?
Peter S. Curtis, an ecologist at Ohio State University, says, "But there's a trade-off between quantity and quality. While crops may be more productive, the resulting produce will be of lower nutritional value."	According to **Mitloehner**, one of the most surprising results of the experiment was that the most significant greenhouse gas emissions were not a result of the manure. According to him, "We thought it was the waste that would lead to the majority of the [greenhouse gas] emissions, but it seemed to have been the animals."
Robert Mendelsohn, an environmental economist at Yale University, says, "There is no doubt but that quality matters. If scientists can demonstrate a distinct loss of quality, this would be important and could change our impression of the global impact of climate change on agriculture from benign to harmful."	The major contributor to greenhouse gases was the ruminating process. During a cow's digestion process, as food enters the stomach, it mixes with bacteria, which breaks the food down and produces methane. Roughly 20 minutes later, the food returns to the cow's mouth as cud, which it chews, thereby releasing methane into the air. In addition to methane, it also releases methanol and ethanol, as well as VOCs.
One of the key concepts **Peter Curtis** wanted to focus on was the overall reproductive traits of plants such as the number of seeds and fruit, their size, and their nutritional quality because researchers had already confirmed that increasing CO_2 levels did increase the growth of the plant's leaves, stems, and roots.	Another negative impact concerns manure management. The decomposition of animal waste in an anaerobic environment produces methane. According to the Environmental Protection Agency (EPA), manure storage and treatment systems are responsible for about 9 % of the total methane emissions in the United States, and 31 percent of the methane emissions coming from the agricultural sector alone.
The results of **Curtis** study showed that with a doubling of CO_2, total seed weight increased 25 %, the number of flowers increased 19 %, individual seed weight increased 4 %, and the number of seeds increased 16 %. The study did have some unexpected results, however. According to Curtis, "The surprise is that nitrogen levels actually go down with elevated CO_2 levels, which reduces the nutritional value of these foods because it lowers the protein content. In some cases, nitrogen levels were 15 – 20 % lower."	Methane has an enormous greenhouse gas potential. It is about 21 times more effective at trapping heat than CO_2. In fact, 10 % of the warming in the United States caused by global warming is due to methane alone. More than 80 percent of the methane emissions that originate from animal wastes come from liquid-based manure management systems that include: anaerobic lagoons, holding tanks, and manure ponds.
Irakli Loladze, an ecologist at Princeton University, says, "The increase in crop productivity does not make up for the fall in nutritional value of the crops—plants today provide 84 % of the calories people eat worldwide and are also the source of major essential nutrients." He also noticed that levels of micronutrients (such as Fe, Zn, and I_2) also dropped as CO_2 levels rose.	According to the EPA, one solution that has been suggested to combat this problem is the use of anaerobic digester systems. An anaerobic digester is a container similar to a covered lagoon that is designed to hold decomposing manure under warm, oxygen-free conditions that promote the growth of naturally occurring bacteria. The purpose of the bacteria is to digest the manure, producing methane and an effluent that farmers can use in place of untreated manure.
A study conducted by **Ramakrishna Nemani (2003)** at the University of Montana marked the first vegetation inventory and the effects of global warming as it relates to temperature and precipitation from a global perspective. They showed that global vegetation had	The by-product (methane) produced by these digesters is called "biogas," and it can now be used effectively as an energy source. Depending on how much they generate, they may also have the option to sell "extra" electricity directly to local utility companies. Secondary benefits

increased 6 % from 1982 to 1999. In the Amazon region, Nemani says a major cause of vegetation growth is due to less cloud cover, resulting in increased solar radiation. The Amazon region accounts for 42 % of the global increase. The atmospheric scientist **Dave Schimel**, who works at the National Center for Atmospheric Research in Boulder, Colorado, keyed in on the impacts due to absence of cloud cover and its significance for increased vegetation. According to Schimel, "Most studies of the effects of climate change have addressed temperature effects; some have also addressed water effects. But some of the most robust observed changes in climate have been in cloudiness and almost no studies have examined trends in solar radiation. So this is a really interesting new perspective."	include a reduction of odors, methane emissions, and surface/groundwater contamination. Farmers can also sell the resulting high-quality fertilizer. These related business opportunities help the overall position of U.S. agribusiness. Fertilizer management is another area of concern. Based on information collected by the EPA, the use of synthetic *nitrogen* and organic fertilizers has contributed to about 36 % of total U.S. nitrous oxide (N_2O) emissions. Nitrous oxide is about 310 times more effective at trapping heat in the atmosphere than CO_2. While most N_2O is produced naturally through microbial processes in the soil, it is the addition of synthetic N_2O introduced through fertilizers that has led to an increase in emissions from agricultural lands. According to the IPCC, if fertilizer applications are doubled, emissions of N_2O will double. Therefore, the IPCC has recommended that N-fertilizer be used more efficiently in order to reduce N_2O emissions.

It is well known that soil and environmental conditions interact to define regional patterns in agricultural systems creating agricultural ecological differing homogeneous regions. It appears that current uptake of organic (and other alternative) agricultural system is driven by a combination of factors in both the physical and socio-economic environment which interact with personal farmer motivational factors. Hendrickson *et al.* (2008) [21] suggested that there are other factors, such as landform, length of growing season coupled to the availability of irrigation that predispose farmers to adopt integrated low-input systems as a strategy to provide economic stability in variable conditions. While climatic regions set some constraints to the adoption of particular practices or agricultural systems, it is clear that the direct impacts of climate change will be only one driver of change in farming systems; changes in markets and agricultural policy will have an equally significant impact.

Table 4: Timescale for changes in soils with change in climate [Source: Bullock, 2005] [5]

Timescale categories	Soil parameter	Properties and characteristics	Regimes
$< 10^{-1}$ years	Temperature; moisture content; bulk density; total porosity; infiltration rate; permeability; composition of soil air; nitrate content	Compaction; drainage; workability	Aeration; heat regime
10^{-1}–10^{0} years	Total water capacity; field capacity; hydraulic conductivity; pH; nutrient status; composition of soil solution	Microbiota	Microbial activity; human controlled plant-nutrient regime; erosion
10^{0}–10^{1} years	Wilting percentage; soil acidity; cation exchange capacity; exchangeable cations	Type of soil structure; annual roots biota; mesofauna; litter, fluvic, gleyic, stagnic properties; slickensides	Moisture; natural fertility; salinity–alkalinity; desertification; permafrost
10^{1}–10^{2} years	Specific surface; clay mineral association; organic matter content	Tree roots; soil biota; salic, calcareous, sodic, vertic properties	
10^{2}–10^{3} years	Primary mineral composition; chemical composition of mineral part	Tree roots; color (yellowish/reddish); iron concretions; soil depth; cracking; soft powdered lime; indurated subsoil	
$> 10^{3}$ years	Texture; particle-size distribution; particle density	Parent material; depth; abrupt textural change	

In terrestrial ecosystems and agro-ecosystems, soil structure determines soil physical fertility which is the capacity of the soil to support and sustain plant production in relation to its physical properties. Hence, soil structure plays a fundamental role in controlling physical soil health, productivity and environmental quality (on-site as well as off-site) of agricultural land. However, soil structure in agro-ecosystems is sensitive to human disturbance and therefore to management practices. Soil structure refers to the architecture and hence the arrangement of the solid phase of the soil and of the pore space located between its constituent particles. This architecture of soil (the structural form) determines not only the density of packing of the solid phase (bulk density) and hence total porosity, but more importantly also pore size distribution and pore continuity of the soil profiles. The importance of surface soil structure in controlling processes at the interphase of atmosphere, hydrosphere and geosphere, such as the processes of infiltration, and runoff, cannot be over-emphasized (Chan, 2011) [50].

Climate change scenarios considered by Intergovernmental Panel on Climate Change (IPCC) prediction include increase in atmospheric CO_2 concentration, increases in air temperature, changes in precipitation and prevalence of extreme climate events. For instance, global temperature change of 1.6–6.4 ºC by 2100, atmospheric CO_2 concentration increases by up to 550 ppm and precipitation change by at least 20% have been predicted (IPCC, 2007a) [23]. However, the predicted changes vary geographically and with future greenhouse gas (GHG) emission control. Therefore, the actual magnitude of changes of these parameters and consequences of these changes will therefore be location specific and be dependent on the extent of future success in reducing emission of GHG. Changes in precipitation are likely to be different for different parts of the world (Fig.4a).

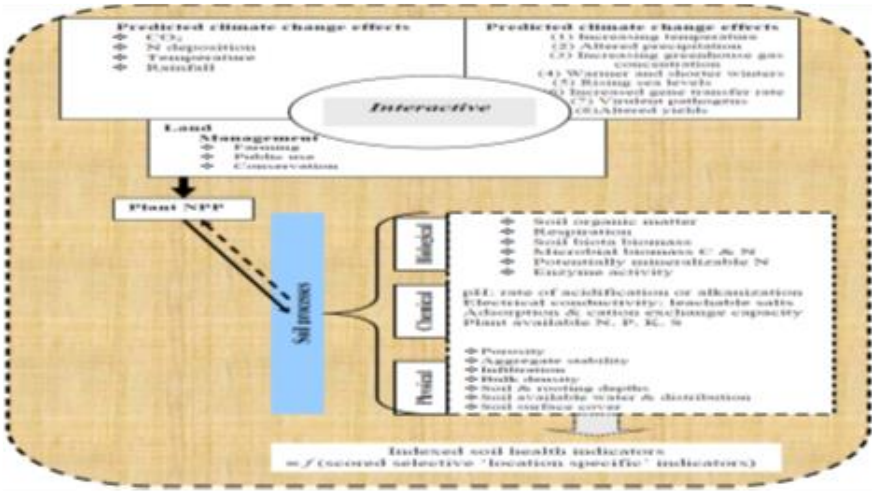

Fig 4(a): Potential links between climate change, land use and management change, and soil health indicators (Source: Allen *et al*. 2011) [1]

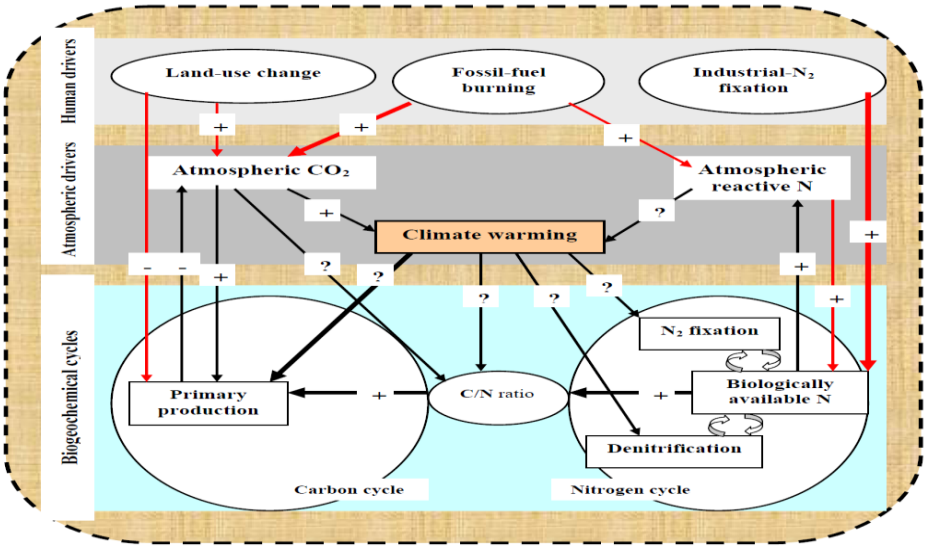

Fig 4 (b): Potential nitrogen–carbon-climate interactions (Source: Gruber and Galloway, 2008) [18]

Chapin *et al*. (2009) [8] reported that soil biota is a critical element in the search for new knowledge leading to improved prediction and management of adverse impacts of global change. There are outstanding needs and challenges that must take account of three key facts: (1) soil is the most diverse ecosystem on the planet, (2) only 1% of the soils microbial diversity is catalogued and (3) ecological concepts that apply to aboveground plant communities do not always apply belowground.

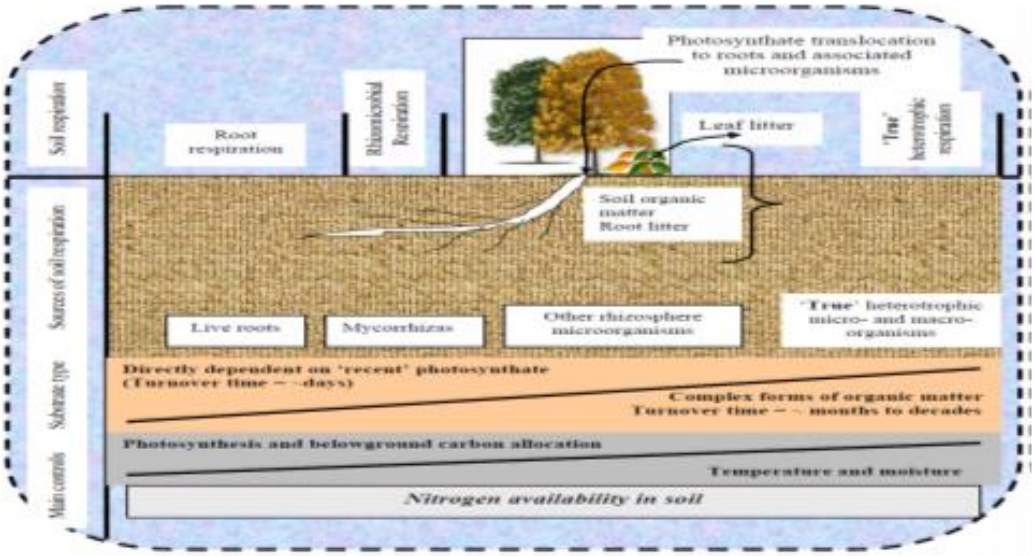

Fig 5(a): Soil respiratory components, autotrophic and heterotrophic respiration, (Source: Singh *et al*., 2011) [50]

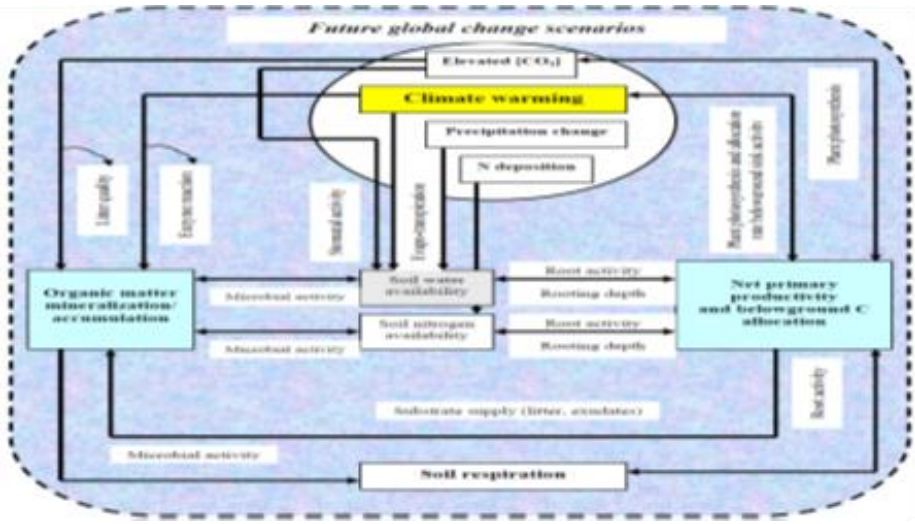

Fig 5(b): Schematic of direct or indirect influences of future global change scenarios on soil respiration via a series of closely interrelated processes and factors affecting the activities of roots and microbes in soil (Source: Singh *et al*. 2011) [50]

It is established that, soil organic matter (SOM) is essential in maintaining physical, chemical and biological functions in soil. In fact, SOM is the key indicator of soil health. It contains both living and non-living components. Living components include soil microbial biomass and living roots. Non-living SOM is a heterogeneous organic matter, variously described as labile, slow and recalcitrant SOM, light fraction (free or occluded) and heavy fraction, particulate (> 53 mm) and non-particulate SOM. It is also described by its chemical constituents such as proteins, lipids, starch, carbohydrates, hemicelluloses, celluloses, lignins, polyphenols, pectins and tannins or by humic acid, fulvic acid and humins. Soil organic carbon (SOC) constitutes about 50% of SOM and contains labile, slow and recalcitrant C pools. It could be also considered that, the influence of atmospheric N deposition, an important component of global environmental change; the rates of N deposition have increased by threefold to fivefold over the past century and may continue to increase rapidly in densely populated areas. The increasing rates of atmospheric N deposition may play a major role in modulating climate change impacts (Fig.4b).

It is well known that, soil respiration is one of the important measures of soil health, because it reflects the capacity of soil to support life (micro- and macro-organisms and plant roots) and is directly related to other functions, such as organic matter decomposition, nutrient mineralization–immobilization and microbial activity in general. Fast rates of soil respiration are indicative of intense biological activity in soil with consequences for plant growth and the environment, e.g. through increased rate of nutrient cycling in soil. Slow rates may indicate little or suppressed biological activity, which may be due to management-induced stresses and/or climate perturbations, or limitations of the resources (such as substrates, nutrients, O_2) required for such biological activity. Soil respiration usually increases following cultivation of lands as a result of increased accessibility of previously protected organic matter within soil aggregates to soil micro-organisms, and this may adversely affect soil C balance. On the other hand, land use and management practices such as conservation tillage, manure and crop residue application, and perennial and deep-rooted crops, which increase organic matter input to soil, may also increase the rate of soil respiration, especially under non-limiting environmental (soil moisture and temperature) conditions. In anaerobic environments, incomplete turnover of soil organic matter may reduce CO_2 emissions, but increase emissions of non-CO_2 greenhouse gases, such as nitrous oxide and methane. Clearly, there are instances where soil respiration may not be a good indicator of changes in net greenhouse gas emissions from soil, and even overall soil health (Singh *et al*. 2011) [50]. Such global changes have consequences for the functioning of terrestrial ecosystems, including soil respiration (Fig. 5a and 5b), and a greater understanding of their interactive effects is required to accurately estimate uncertainties in global climate change projections and predict ecosystem feedbacks to atmospheric CO_2 levels.

Conclusions

Soil organic matter content seems to be the main agent responsible for the different microbial community structure under the different soil management practices. The most intensively managed soils had the highest relative abundance of bacteria and action-bacteria. The abandonment of agriculture has led to increase in microbial biomass and shifts in the microbial community structure, most likely due to the cessation of tillage, increases in organic matter and changes in organic matter quality, which led to increase in fungal populations. The application of residue retention increased the organic carbon content, microbial biomass and fungal populations, with a microbial community structure close to the soil used as reference under residue coverage. Thus, the application of organic residues could represent an adequate solution for the sustainable maintenance of agricultural soils under semi- arid conditions. Plant residues supply intermediate and labile soil C pools, and, through their chemical composition, control their dynamics. They also indirectly act on the stable C pool by promoting aggregate formation through roots and mycorrhizal associations. Microorganisms and soil fauna have a central role in soil C storage/destocking mechanisms because they consume and transform OM. Soil organisms are also essential for nutrient recycling, and preserving ecosystem balance and biodiversity. All of these co-benefits tend to indicate that soils with high biological activity have a higher C storage potential.This influences soil microbial diversity; ultimately resulting in increased mineralization rates and faster nutrient recycling. In due course, these factors could eventually result in increased soil quality and fertility, resulting in a significantly beneficial effect on the sustainability of agricultural management practices.

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