Article

Transformation to Conservation Agriculture shows reduced soil CO_2 emissions and improved soil aggregate stability in the first season in rain-fed areas in India

Saeed Karbin*[1], Hossein Ali Alikhani[1], Pramod Sahu[2], Bharat Mogare[2], Bhaskar Mitra[2], Sandeep Viswakarma[2], Jitendra Singh[2], RamKrishna Mahajan[2], Sunil Malviya[2], Pankaj Badole[2], Naveen Patidar[2], Amir Kassam*[3]

1- Department of soil science engineering, University of Tehran, Karaj, Iran

2- Aga Khan Rural Support Programme, India

3- School of Agriculture, Policy, and Development, University of Reading, United Kingdom

*Correspondence: e-mail: saeed.karbin@ut.ac.ir, amirkassam786@googlemail.com

Abstract: Conservation Agriculture (CA) is capable of improving soil health and ecosystem functions. Soil carbon sequestration is one of the ecosystem processes that is of importance in sustainable land management involving reduction in greenhouse gas emissions and adaptation to climate change. In this study, we wanted to determine, during the first year of the process of establishing a CA cropping system in rain-fed areas in Madhya Pradesh state of India, which soil health indicators show measurable signs of improvement. Four field trials were selected, each comprising two neighboring plots. One plot (15×15 m) was managed conventionally under farmer practice and was tilled before sowing seeds, and in the adjacent plot Conservation Agriculture practices were applied. No mineral fertilizers or pesticides were applied in both treatments. Soil health indicators of soil aggregate stability, soil-atmosphere CO_2 fluxes, water infiltration, soil moisture, potentially mineralizable nitrogen, soil organic content and bulk density were measured. Results demonstrate that soil CO_2 emissions in CA soils decreased and soil aggregates stability improved in the first year. Generally, in CA soils, there were measurable improvements in all soil health indicators but only some of them were statistically significant.

Key words: Conservation Agriculture, Greenhouse Gases, Soil Health

1. Introduction

Soil organic matter has an important role in improving soil health and fertility. Tillage leads to depletion of soil organic matter in agricultural soils compared with soils under natural vegetation. The main reason for this loss is the increased rate of decomposition of soil organic matter. Also, tillage removes plant residues from the soil surfaces and causes soil organisms to starve. Consequently, soil structure and aggregate stability become weaker over time, increasing the risk and actual of soil erosion. This loss process leads to decreases in soil water holding capacity, nutrient content, rainfall infiltration, and leads to increased soil compaction and loss of soil biodiversity [1-4]. Conservation Agriculture (CA) as a strategy in agricultural land management can improve soil health and biology [5, 6]. CA is an agroecoloogical approach to agricultural production based on three interlinked principles: a) no or minimum mechanical soil disturbance, b) permanent soil cover by crop residues and cover crops, and c) diversified cropping with annuals and perennials, including legumes, and involving rotations or sequences or associations.

By applying these three principles through locally formulated practices, along with other good agricultural practices, soils are able to recuperate over time from degradation and remain stable as in natural ecosystems. The process of regeneration may take several years depending on the initial In CA systems, soils are not disturbed mechanically except for opening a narrow slit and placing seeds or fertilizers, and are protected by a layer of mulch from crop residues and cover crop biomass [7]. Diversified cropping provides a source and presence of biomass for the accumulation of soil organic carbon [4]. Moreover, in CA systems, the decomposition rate of soil organic matter is reduced by soil organic carbon becoming sequestered and included in soil aggregates due to low mechanical soil disturbance [8]. Soil protection during dry seasons in semi-arid regions is particularly relevant and necessary because it reduces soil erosion, water evaporation, surface crusting and temperature fluctuations [9]. Soil aggregate stability is improved by increasing organic materials such as humified organic matter, bacterial waste products, organic gels, fungal hyphae, especially mycorrhizae which produces a cementing compound known as glomalin, and worm secretions and casts [10]. When the soil is mechanically disturbed, micro-biota consume the young carbon pool through decomposition and mineralization, depleting the major binding agents in macro and micro soil aggregates.

Soil mulch cover in CA systems protects soils and improves water capture and water use efficiency and productivity through increased water infiltration and retention and reduction in evaporation from the soil surface. This leads to reduced water runoff and soil erosion, and to higher soil moisture content. This higher soil moisture level improves productivity especially in seasonally dry regions [11, 12]. This is the results of three main processes: a) soil organic matters retaining water at lower moisture potentials, b) the increased presence of soil organic matter and higher amount of water-stable soil aggregates improves soil resistance against water and soil erosion [13], and c) water infiltration rate has a direct relation with initial water content and soil pore volume. Distribution of soil porosity depends on soil texture and structure, aggregate stability and soil organic matter [7]. Average aggregates size changes with depth layer. For instance, average aggregate size increases with depth, in both grassland and forest land use [14].

Tillage has a significant impact on CO_2 emission. Generally, it boosts the loss of soil organic carbon by increasing its decomposition rate and through soil loss by soil erosion [15]. Moreover, in mechanized systems, tillage is a high energy-consuming operation that needs a high amount of fossil fuel consumption per hectare. Anthropogenic greenhouse gas (GHG) emissions have increased due to global population and economic growth, but also because of conventional tillage-based agriculture. Thus, there is a vital need to identify potential C sinks to store atmospheric CO_2 while at the same time reducing the use of fossil fuel. Terrestrial ecosystems are considered to have a high sink potential for carbon sequestration. When natural ecosystems such as grasslands or forests are converted to an agricultural field, high amount of soil organic carbon is lost mainly in form of CO_2 [7, 16]. In contrast to tillage-based agricultural systems, CA systems can increase both soil carbon sequestration and production intensification, as well reduce fossil fuel requirement. Whereas, tillage over time can induce losses of soil organic carbon content by 50% or more because of increases in aerobic processes of microbial respiration [17]. Many studies have investigated the effects of conventional and CA systems on soil carbon loss by soil respiration [6, 8-10, 12] and the results are equivocal. Many authors have reported that CO_2 emissions are higher in conventional tillage agriculture compared to no-till CA systems [18-20]. In CA systems, air diffusion into the soils and air-filled pores are reduced compared to conventional tillage agriculture, causing low or minimum CO_2 emission [21]. On the other hand, in no-tillage systems, soil CO_2 emission can increase due to increased soil water content in the soil surface layers which can stimulate soil biological activity and CO_2 emission [1, 2].

The aim of the study reported in this paper was to detect measurable effects on soil health and CO_2 emissions in rain-fed areas in Madhya Pradesh, India, during the first year of the transformation process of changing from tillage agriculture to CA. To transform a conventional tillage system to CA system requires an initial rehabilitation phase of some five years, followed by a second phase of enhancement of soil health and functions. Many studies have investigated the longer-term effects of CA transformation but the effects of CA transformation in the initial years of implementation are not well studied. For this reported study, on-farm field trails consisting of two neighboring fields were established. One field was managed conventionally using farmer practice and the other with CA practices.

2. Materials and methods

2.1 Study area and treatment details:

The study site was located in Madhya Pradesh state at Khandwa district in central India. The area is under the monsoon environment with rainfall during the period of June to September followed by a dry and cooler period until January. During the February to May period, temperature increase considerably until the start of the monsoon rains. In Khandwa, the average annual temperature is 26.6 °C. In a year, the average rainfall is 932 mm. The driest month is February, with 2 mm of rain. The greatest amount of precipitation occurs in July, with an average of 282 mm. The variation in temperatures throughout the year is 14.5 °C [22].

Four on-farm field trials were established, each consisting of two neighboring plots. The distance between sites was about 1 Km and plots were scattered across an area with about 1,000 ha of agricultural land. One plot (15×15 m) per pair was selected randomly and managed conventionally with farmer practice and tillage was applied to prepare the land for crop establishment. Farmers applied tillage practices by hand or animal for more than 20 years in conventional plots and the plowing depth was between 10-16 cm. Maize and gram (chick pea) were planted in last 20 years in the selected field trials. In the adjacent plot, CA practices were applied. Soil surface was covered with plant residues (maize and wheat leaves and stems) and no cover crops were planted. No-till seeding was carried out using a jab-planter (dibbler, Khedut Agro Co., Gujarat, India) on May 18, 2014 to minimize soil disturbance. The main crop in the Kharif (monsoon) season was maize, and for Rabi (dry) season gram was planted on November 7, 2014. No mineral fertilizers or pesticides were applied to any of the treatments.

2.2 Soil sampling:

Each plot was uniform and flat and soil sampling was done using a grid. The field was divided into cells by means of a coarse grid (50 × 50 cm). A horizontal coarse cell was selected in the top row and kept the X coordinate the same but randomly select a new Y coordinate. The process was repeated for all the coarse cells in the top row [23]. 2 to 3 cm of topsoil with coarse plant residues were removed and soil samples in 10 cm depth were collected. Generally, 3 soil samples were taken in each plot (n=8) on February 10, 2015 (268 days after sowing date). There were 4 blocks (4 field trials) consisting of two neighboring plots (CA and Non-CA plots).The soil samples were placed in cold boxes and transported to the laboratory within two hours.

2.3 Soil texture:

Soil texture has profound effect on soil behaviors such as ability to retain nutrients and water. Coarser soils generally have a lesser ability to hold and retain nutrients and water than finer soils. Texture also affects water permeability, and heavier finer soil can suffer from drainage problems, if soil structure is poor. Soil texture is determined in order to characterize the particle size composition of the soil. To determine soil moisture, 10 g of the soil samples (3 samples per plot), was dried in an oven at 60 °C and then sieved with 2 mm mesh size and weight of the evaporated water from oven drying was calculated to determine soil texture, another subsample about 14 g (+/- 0.1g) of sieved soil was taken and added to a 50 ml centrifuge tube containing 42 ml of 3% soap (sodium hexametaphosphate) solution. This tube was placed on a shaker for 2 hours to fully disperse the soil into a suspension. In the next step, the entire content of the centrifuge tube was washed onto a 0.053 mm soil sieve assembly. The sieve assembly consisted of 0.053 mm sieve on top of a plastic funnel above a 600 ml beaker. Sand captured on top of the sieve was washed into a tared metal can and set aside. Silt and clay particles collected in the 600 ml beaker were re-suspended by stirring and allowed to settle for 2 hours. The clay in suspension was then carefully decanted. The settled silt at the bottom of the beaker was washed into a second tared can. Both tared cans (one containing the sand fraction and the other the silt fraction) were dried overnight at 105 °C to constant weight before weighing [24]. Clay, silt and sand content were calculated as below:

$$\text{Sand (\%)} = \text{dry wt sand (g) / dry wt (g) soil added to centrifuge tube}$$
$$\text{Silt (\%)} = \text{dry wt silt (g) / dry wt (g) soil added to centrifuge tube}$$
$$\text{Clay (\%)} = 100\% - \text{Sand (\%)} - \text{Silt (\%)}$$

2.4 Aggregate stability:

Aggregate stability is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by raindrops. It is related to soil structure stability and affects soil's load bearing capacity. In CA soils, aggregate stability improves with time as soil micro-biota and soil organic matter content increases. Aggregate stability can be measured using a rain simulation sprinkler that steadily rains on a sieve containing the known weight of soil aggregates between 0.5 mm and 2 mm. The unstable aggregates slake (fall apart) and pass through the sieve. The fraction of the soil that remains on the sieve is used to calculate the percent aggregate stability.

Gugina *et al*. [25] protocol was used to measure aggregate stability. 10 g of the soil samples was oven-dried at 40 °C. Using stacked sieves of 2.0 mm and 0.25 mm with a catch pan, the dried soil was shaken for 10 seconds on a Tyler Coarse Sieve Shaker to separate it into different size fractions; small (0.25 - 2.0 mm) and large (2.0 - 8.0 mm). Then a single layer of small aggregates (0.25 - 2.0 mm) was spread on a 0.25 mm sieve (sieve diameter is 200 mm. Sieves are placed at a distance of 500 mm below a rainfall simulator, which delivers individual drops of 4.0 mm diameter. The test was run for 5 minutes and delivers 12.5 mm depth of water as drops to each sieve. This was equivalent to a heavy thunderstorm. A total of 0.74 J of energy thus impact each sieve over this 5 minute rainfall period. Since 0.164 mJ of energy was delivered for each 4.0 mm diameter, it can be calculated that 15 drops per second impact each sieve. The slaked soil material that fell through during the simulated rainfall event, and any stones that were remaining on the sieve were collected, dried and weighed, and the fraction of stable soil aggregates was calculated using the following equation:

$$WSA = W_{stable} / W\ total$$
$$W_{stable} = W_{total} - (W_{slaked} + W_{stones}) \quad [25]$$

where W = weight (g) of stable soil aggregates (stable), total aggregates tested (total), aggregates slaked out of sieve (slaked), and stones retained on the sieve after the test (stones). Corrections were made for stones.

2.5 Water infiltration:

Infiltration rate is a measure of how fast water enters the soil. Water entering too slowly may lead to waterlogging and ponding or to surface runoff and soil erosion. It is the downward entry of water into the soil. The velocity at which water enters the soil is the infiltration rate. Infiltration rate is typically expressed in mm per hour. Water from rainfall or irrigation must first enter the soil for it to be of value to the crop and to the catchment.

To measure water infiltration, a metal ring with 15 cm diameter was inserted about 20 cm vertically into the soil by using a hammer. To minimize the disturbance to the soil surface inside and outside the ring a block of wood was placed on top of the ring to avoid direct hammering to the ring. The ring was lined with plastic wrap. As next step, the soil surface was lined inside the ring with a sheet of plastic wrap to completely cover the soil and ring. This procedure prevented any disturbance to the soil surface when adding water. The plastic bottle was filled with the 500 ml mark with distilled water and the 500 ml of water was gently poured into the ring. Then the wrap was removed and time was recorded. Time-keeping was stopped when the soil surface was just glistening. The infiltration test was repeated 3 times in each plot in 3 different randomly selected spots. The test was done on February 12-14, 2015 (270-272 days after the sowing date)

2.6 Bulk density:

Bulk density is the weight of the soil in the given volume and it has a direct relation with soil aggregate stability and pore space. In well-aggregated soils pore content is higher and bulk density is low. In our study, bulk density was measured near (between 30 and 60 cm) the sites of the respiration measurement and the infiltration tests on February 10, 2015 in 3 randomly selected spots in each plot. The ring was driven into the soil using the hand sledge and block of wood. The ring with 12 cm diameter was inserted about 8 cm into soils. Four measurements (evenly spaced) were taken of the height from the soil surface to the top of the ring and the average was calculated. In the lab, the volume of the placed soil in the tube was calculated. In the next step, samples were placed in a bag and labeled. The samples were transported to the laboratory with as little touching as possible. In the lab, samples were weighed. To calculated water content of the soils, two sub-samples (20 g) were oven-dried at 105 °C and water content was calculated. Bulk density was calculated as below:

$$\text{Dry soil weight (g)} = W_{\text{soil}} - W_{\text{ater}}$$
$$\text{Bulk density (g/cm}^3\text{)} = \text{Dry soil weight (g)} / \text{Soil volume (cm}^3\text{)}$$

2.7 Potentially mineralizable nitrogen:

Immediately after sampling, the mixed composite bulk soil sample (stored at 4°C) was sieved and two 8 gm soil samples were removed and placed in 50 ml centrifuge tubes. Then 40 ml of 2.0 M potassium chloride (KCl) was added to one of the tubes, shaken on a mechanical shaker for 1 hour, centrifuged for 10 minutes, and then 20 ml of the supernatant was collected and analyzed for ammonium concentration ("time 0" measurement).

In the next step, 10 ml of distilled water was added to the second tube, it was hand shaken and stored (incubated) for 7 days at 30°C. After 7 days of anaerobic incubation, 30 ml of 2.67 M KCl was added to the second tube (creating a 2.0 M solution), the tube was shaken on a mechanical shaker for 1 hour, centrifuged for 10 minutes, and then 20 ml of the supernatant was collected and analyzed for ammonium concentration ("time 7 days" measurement). The difference between the time 0 and time 7-day ammonium concentration was the rate at which the soil microbes are able to mineralize organic nitrogen in the soil sample.

2.8 Soil organic matter content:

The percent of soil organic matter was measured using the method of weight loss on ignition. For this purpose, 10 g of soil sample was dried at 105°C to remove all soil water. The sample then ashed for two hours at 500°C and the percent of weight loss was calculated. The % loss on ignition [26] was converted to % organic matter (OM) using the following equation:

$$\% \text{ OM} = (\% \text{ LOI} \times 0.7) - 0.23 \qquad [25]$$

2.9 Soil respiration rate:

The Kirita [27] procedure of measuring soil respiration rate was followed. Three static chambers were inserted about 7 cm into the soils in each plot. In conventional agriculture treatment plots before placing the chambers between row spaces, soil was tilled up to 12 cm depth by a traditional animal-drawn wooden hoe plough. A sponge (11.6 cm in diameter, 2.5 cm in height) containing up to 25 ml of 2 N NaOH solution for a CO_2 absorbent was placed on a wire holder in a chamber (12.6 cm in diameter, 23 cm in height). The chamber was quickly covered and tightly sealed with plastic tape. Measuring periods were normally 24 h to avoid any daily influence on the soil respiration estimate. After measuring, the NaOH solution was squeezed from the sponge, stored in a vial, and carried to the laboratory. A part of this solution (5.0 ml) was titrated with 0.2 N HCl using a titration device. This measurement was done in 3 randomly selected spots in each plot on February 10, 2015 (268 days after sowing date).

2.10 Statistical analysis:

The unit of replication in the study was the field plot. We analyzed data in this study using one-way ANOVA with CA as a fixed effect and field blocks (n=4) as replicates in R 3.3.3. Effects with $P<0.05$ are referred to as significant, effects with $P<0.1$ as marginally significant.

The relation between CO_2 emission, aggregate stability, soil organic content, water infiltration, potentially mineralizable nitrogen, and bulk density was tested by generalized linear models (GLM). For instance, we tested whether water infiltration rate can be influenced by soil aggregate stability or soil organic content. CO_2 emission data were log-transformed to meet the requirements of parametric statistical tests.

3. Results

3.1 Soil texture:

Soils were mostly clay to sandy clay loam. Details for each plot are in Table.1

Table 1: Soil texture results for each plot

Plot number	*Silt (%)*	*Sand (%)*	*Clay (%)*	*Soil texture*
Plot1	*5.2*	*57.8*	*36.9*	*sandy clay loam*
Plot2	*4.8*	*34.8*	*60.6*	*Clay*
Plot3	*3.8*	*56.5*	*39.8*	*sandy clay*
Plot4	*3.8*	*41.0*	*55.2*	*Clay*

3.2 Soil aggregate stability:

Soil aggregate stability was 30% higher in CA treatment compared with conventional agriculture treatment. This elevation was statistically significant ($p < 0.0001$).

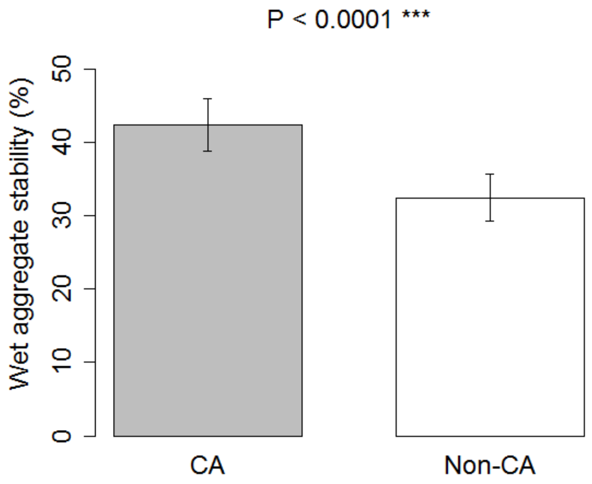

Figure 1: Wet aggregate stability in CA and traditional agriculture (Non-CA) treatments

3.3 Water infiltration:

Infiltration rate was higher (64%) in plots with CA treatment but this difference was not statistically significant (p=0.228).

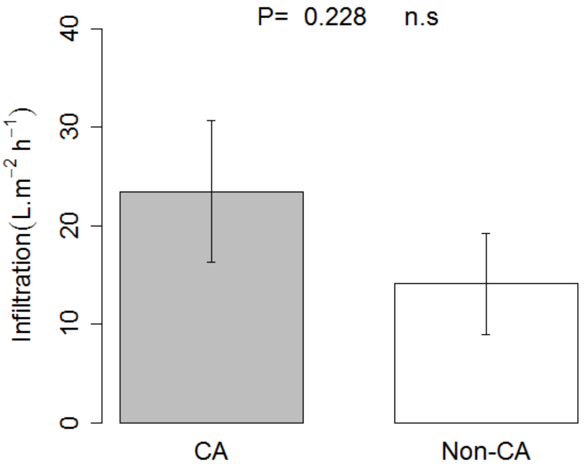

Figure 2: Water infiltration in CA and traditional tillage agriculture (Non-CA) treatments

3.4 Bulk density:

Soil bulk density in CA plots was about 3% less than in conventional agriculture plots and this difference was not statistically significant (p=0.38).

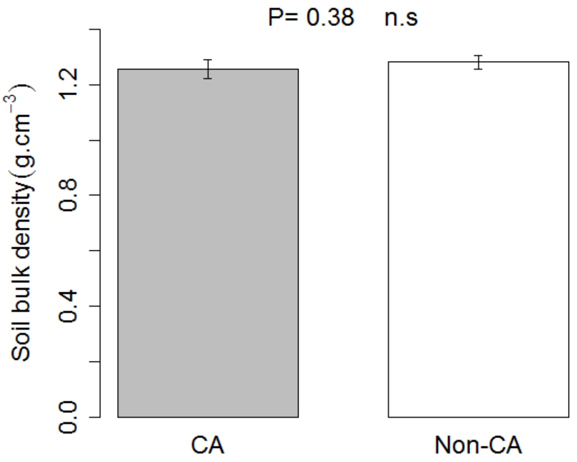

Figure 3: Soil bulk density in CA and traditional agriculture (Non-CA) treatments

3.5 Potentially mineralizable nitrogen:

Potentially mineralizable nitrogen in soils in CA plots was higher by about 27% than in soils in conventional agriculture plots and this difference was not statistically significant (p=0.346).

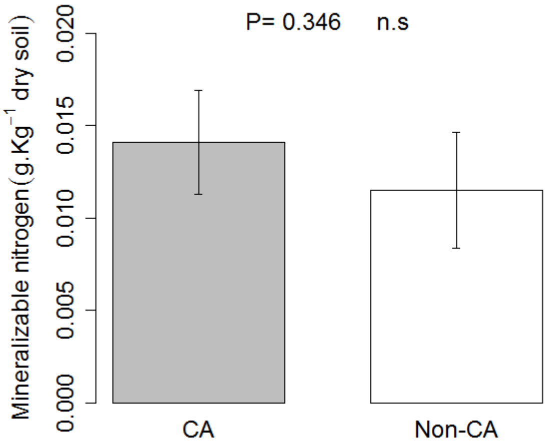

Figure 4: Potentially mineralizable nitrogen in CA and traditional agriculture (Non-CA) treatments

3.6 Organic matter content:

Organic matter content was higher in soils from CA plots by about 38% than soils from plots under conventional agriculture but this elevation was not statistically significant (p=0.16).

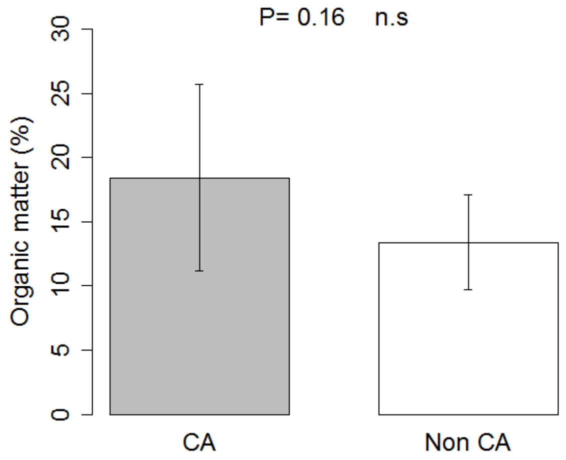

Figure 5: Organic matter content in CA and traditional agriculture (Non-CA) treatments

3.7 Soil respiration rate:

CO_2 emission in soils from conventional agriculture plots was about 16 % higher than that from soils in CA plots and this difference was statistically significant (p=0.00948).

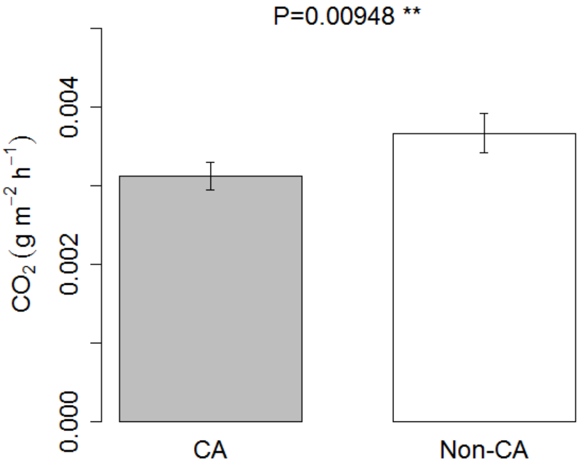

Figure 6: Soil respiration in CA and traditional agriculture (Non-CA) treatments

3.8 Interactions:

Generalized linear modelling (GLM) with quasipoisson error model was used to analyze the interspecific relationships between water infiltration rate, CO_2 emission, soil organic content and soil moisture. CO_2 emission and soil organic content decreased significantly by water infiltration rate (F=14.1, P < 0.001, R^2=0.34 and F=11.08, P < 0.001, R2= 0.26).

4. Discussion

CA practices of no-till and soil mulch cover began to show measurable difference in major soil health indicators after the first Kharif season of the study. CO_2 emission and soil aggregate stability were significantly higher in CA treatment plots, and all other soil health indicators such as soil organic content, water infiltration, potentially mineralizable nitrogen, and bulk density showed an improvement but the differences were not statistically significant. Soil moisture content in CA treatment plots was about 9% greater than in plots under conventional agriculture treatment, but this difference was not statistically significant.

CO_2 emission and soil organic content decreased by water infiltration rate. Water infiltration is related to aggregate numbers in soils. In well-aggregated soils water storage and transmission is facilitated by increased soil porosity. In addition, CO_2 emission resulting from decomposition is reduced due to soil organic carbon inclusion in soil aggregates [15], although basal soil respiration can also be higher in soils that are rich in microorganisms and organic matter compared with soils that are low in carbon and microorganisms as is the case with regularly tilled soils. However, well-aggregated soils show higher infiltration rate and low soil CO_2 emissions and soil organic content appear to be protected in soil aggregates.

Tillage increases air diffusion into the deeper soil layers which leads to increase in organic matter decomposition (similar to 'stocking the fire') leading to increased soil respiration and CO_2 emission. In the study, respiration rate of soils in CA plots was significantly less than from soils in plots under conventional agriculture. The results agreed with several other studies [2, 3, 12, 20] which have reported that CA practices can decrease CO_2 emissions from soils and enhance their sink capacity for carbon. CA practices increase micro and macro soil aggregate number and related soil quality aspects such as soil structure and aeration, water infiltration and retention, and load bearing capacity. Maintenance of soil mulch cover with biomass can improve carbon sequestration in the soil. Improved soil aggregate stability also reduces soil respiration rates and CO_2 fluxes. Moreover, rhizodeposition of organic carbon compounds by plant roots can increase soil carbon storage [3] that roots are a major source of carbon for sequestration and can add to carbon stock as soil organic matter pool. Further, organic soil cover and soil organic matter in CA makes higher nitrogen levels accessible to plant roots and thus over time can lead to lower mineral fertilization requirements and N_20 emissions. Moreover, by using less fuel energy input due to no-till seeding and weeding, CA systems can reduce CO_2 emissions further [15].

Results from soil aggregate test showed an improvement in soil aggregate stability in CA treatment as has been shown in most studies [9, 15, 28]. Organic materials as a soil mulching substance or cover crops as a source of biomass for soil cover in CA soils increases soil microbial activities. A Higher presence of fungal hyphae, bacterial waste products, organic gels, worm secretions and casts in CA soils can improve aggregate formation [10]. Yang *et. al* [29] have reported that microbial-derived carbohydrates in silts and clay fractions in no-tilled soils were higher compared with conventionally tilled soils. Arbuscular mycorrhizal fungi (AMF) play a key role in soil aggregate formation and stabilization by a network around soil particles and the hyphal exudation as an aggregate binding agent called glomalin. Glomalin acts as biological glue and bind soil particles into small aggregates and the accumulation of glomalin in soils plays a pivotal role for the soil aggregate stability [30]. Aggregate protection is important in land management in general. In soils where aggregates are mechanically disrupted regularly, soil bacteria and fungi consume young carbon pool and consequently, the binding agents that are produced by microorganisms, especially mycorrhiza, which hold soil mineral particles together into micro and macro aggregates, are lost and the soils aggregates are dispersed. When macropores are disrupted, carbon pool with soil cations creates cohesion forces that contribute to soil compaction [7].Land management under CA can affect soil organic matter accumulation. CA practices as a sustainable land management system foster the buildup of new soil organic carbon by protecting soil surface via plant residues or cover crops [4]. Further, decomposition rate and carbon loss have been shown to be reduced by the inclusion of soil organic carbon in soil aggregates [8]. Soil organic content accumulation in soils is a reversible process and even a single event of soil disturbance every growing season may lead to substantial loss of soil carbon over the years. Stable soil aggregate formation in conventional agricultural systems is inhibited by tillage-based agricultural practices [15]. Results showed a similar pattern of increased soil organic matter in CA treatment as many other studies [1-4] although the difference between non-CA treatment was not statistically significant.

Soil moisture content in CA soils was higher compared with tilled soils but this difference in the first year of study was not statistically significant. Soil protection by the mulch layer decreases water evaporation from the soil surface and over time improves rainfall infiltration and water retention. Further, as soil erosion and runoff are decreased in CA fields, more available water can be accessible to plants during the dry season [12]. Soil organic matter can improve these process in three different ways: a) it absorbs water at lower moisture potentials, b) it fosters aggregate formation and enhances resistance against water and wind erosions [13], and c) it fosters soil aggregate formation and improves water infiltration rate [31].

Potentially mineralizable nitrogen was higher in CA soils in the study but the difference was not statistically significant. Many studies have documented increased nutrient availability in CA soils [3, 6, 7, 13, 16]. N availability has a direct relation with carbon mineralization rate. In CA systems, N availability can be low due to higher immobilization by plant residues, but the net immobilization rate is higher and this temporary immobilization of N in CA systems over the long term decreases soil N leaching and denitrification losses [32]. In addition, plant residues from leguminous cover crops provide more carbon and nitrogen in soils under CA compared with soils under tillage systems.

Generally, in CA treatment plots, soil organic content, water infiltration rate, potentially mineralizable nitrogen, and bulk density showed an improvement but the differences were not statistically significant. None the less, the positive pattern in soil quality parameters is consistent with other studies [4, 7, 20, 31]. In these studies long-term effect of CA treatment were investigated. For instance, Thierfelder and Wall [29] showed that after 4 years there was a significant improvement in water infiltration rate and soil moisture content during the dry season in Zambia and Zimbabwe. Information on the effects of CA treatment in the first year of conversion on the soil health indicators are rarely discussed in the research literature. The results in this study confirm that it is possible already to detect in the first year of the process of conversion to CA a measurable change in some of the soil health indicators.

5. Concluding remarks

In most studies, longer term changes in soil parameters resulting from the transformation to CA are normally investigated while shorter term effects have not been adequately examined. The results reported in this paper demonstrated that All the soil health indicators measured in this study, such as soil CO2 emissions, soil aggregate stability, water infiltration, potentially mineralizable nitrogen, soil organic content and bulk density, showed a change in the first year of the process of transformation from conventional tillage system to CA but the changes were not statistically significant for all the parameters. Only the soil CO_2 emissions decreased and soil aggregates stability improved significantly in CA soils in the first year of the transformation from conventional tillage agriculture to CA.

6. Acknowledgment

Authors gratefully acknowledge the opportunity provided by the Aga Khan Rural Support Programme India (AKRSP-India) and Aga Khan Foundation India AKF-India) to undertake the work reported in the paper. Special thanks are extended to Mr. Apoorva Oza, General Manager of AKRSP-India, and to Mr. Matt Reed, CEO of AKF-India and to Ms Tinni Sawhney, Programme Officer, AKF-India, for their support and goodwill.

9. References

1. Bilandžija D, Zgorelec Ž, Kisić I. The Influence of Agroclimatic Factors on Soil CO2 Emissions. Collegium Antropologicum. 2014;38(1):77-83.
2. Hendrix P, Han C-R, Groffman P. Soil respiration in conventional and no-tillage agroecosystems under different winter cover crop rotations. Soil and tillage research. 1988;12(2):135-48.
3. Kassam A, Friedrich T, Shaxson F, Pretty J. The spread of conservation agriculture: justification, sustainability and uptake. International journal of agricultural sustainability. 2009;7(4):292-320.
4. Stagnari F, Ramazzotti S, Pisante M. Conservation agriculture: a different approach for crop production through sustainable soil and water management: a review. Organic farming, pest control and remediation of soil pollutants: Springer; 2009. p. 55-83.
5. Gibbon D. Save and grow: A policymaker's guide to the sustainable intensification of smallholder crop production. Experimental Agriculture. 2012;48(1):154.
6. Hobbs PR, Sayre K, Gupta R. The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society of London B: Biological Sciences. 2008;363(1491):543-55.
7. Corsi S, Friedrich T, Kassam A, Pisante M, Sà JdM. Soil organic carbon accumulation and greenhouse gas emission reductions from conservation agriculture: a literature review: Food and Agriculture Organization of the United Nations (FAO); 2012.
8. de Moraes S, Carlos J, Cerri CC, Dick WA, Lal R, Solismar Filho PV, et al. Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. Soil Science Society of America Journal. 2001;65(5):1486-99.
9. Tebrügge F, Düring R-A. Reducing tillage intensity—a review of results from a long-term study in Germany. Soil and tillage research. 1999;53(1):15-28.
10. Bot A, Benites J. The importance of soil organic matter: key to drought-resistant soil and sustained food production: Food & Agriculture Org.; 2005.
11. Bationo A, Kihara J, Kimetu J, Waswa B. Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities: Springer; 2007.
12. Knowles T, Singh B. Carbon storage in cotton soils of northern New South Wales. Soil Research. 2003;41(5):889-903.
13. Puget P, Chenu C, Balesdent J. Total and young organic matter distributions in aggregates of silty cultivated soils. European Journal of Soil Science. 1995;46(3):449-59.
14. Karbin S, Hagedorn F, Hiltbrunner D, Zimmermann S, Niklaus PA. Spatial micro-distribution of methanotrophic activity along a 120-year afforestation chronosequence. Plant and Soil. 2017;415(1-2):13-23.
15. Pisante M, Stagnari F, Acutis M, Bindi M, Brilli L, Di Stefano V, et al. Conservation agriculture and climate change. Conservation Agriculture: Springer; 2015. p. 579-620.
16. Lal R. Sequestering carbon and increasing productivity by conservation agriculture. Journal of Soil and Water Conservation. 2015;70(3):55A-62A.
17. Birkás M, Jolánkai M, Schmidt R. Environmentally-sound adaptable tillage–Solutions from Hungary. 2008:191-4

18. Al-Kaisi MM, Yin X. Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn–soybean rotations. Journal of Environmental Quality. 2005;34(2):437-45.
19. Bauer PJ, Frederick JR, Novak JM, Hunt PG. Soil CO 2 flux from a Norfolk loamy sand after 25 years of conventional and conservation tillage. Soil and tillage research. 2006;90(1):205-11.
20. Curtin D, Wang H, Selles F, McConkey B, Campbell C. Tillage effects on carbon fluxes in continuous wheat and fallow–wheat rotations. Soil Science Society of America Journal. 2000;64(6):2080-6.
21. Ball BC, Scott A, Parker JP. Field N 2 O, CO 2 and CH 4 fluxes in relation to tillage, compaction and soil quality in Scotland. Soil and tillage research. 1999;53(1):29-39.
22. Climate-Data.org. Climate: Khandwa 2017; Available from: https://en.climate-data.org/location/2822/.
23. Wollenhaupt N, Wolkowski R. Grid soil sampling. Better Crops. 1994;78(4):6-9.

24. Kettler T, Doran JW, Gilbert T. Simplified method for soil particle-size determination to accompany soil-quality analyses. Soil Science Society of America Journal. 2001;65(3):849-52.

25. Gugino BK, Omololu JI, Robert RS, Harold MvE, David W. W, Moebius-Clune, et al. Cornell Soil Health Assessment Training Manua. New York: New York State Agricultural Experiment Station; 2009.

26. Metay A, Oliver R, Scopel E, Douzet J-M, Moreira JAA, Maraux F, et al. N 2 O and CH 4 emissions from soils under conventional and no-till management practices in Goiânia (Cerrados, Brazil). Geoderma. 2007;141(1):78-88.

27. Kirita H. Re-examination of the absorption method of measuring soil respiration under field conditions. IV. An improved absorption method using a disc of plastic sponge as absorbent holder. Japanese journal of ecology. 1971.

28. Tisdall JM, Oades JM. Organic matter and water-stable aggregates in soils. European Journal of Soil Science. 1982;33(2):141-63.

29. Puget P, Angers D, Chenu C. Nature of carbohydrates associated with water-stable aggregates of two cultivated soils. Soil Biology and Biochemistry. 1998;31(1):55-63.

30. Yang Y, He C, Huang L, Ban Y, Tang M. The effects of arbuscular mycorrhizal fungi on glomalin-related soil protein distribution, aggregate stability and their relationships with soil properties at different soil depths in lead-zinc contaminated area. PloS one. 2017;12(8):e0182264.

31. Thierfelder C, Wall P. Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. Journal of Crop Improvement. 2010;24(2):113-21.

32. Campbell C, McConkey B, Zentner RP, Selles F, Curtin D. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Canadian Journal of Soil Science. 1996;76(3):395-401.