THE EFFECT OF IRRIGATION AND CROPPING SYSTEMS ON CARBON STOCKS IN SEMI-ARID LANDS

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ABSTRACT

Increasing competition for a limited water supply is leading to changes in irrigated cropping practices. This study was conducted to evaluate the impact of irrigation and cropping systems management on total C and N stocks in a semi-arid environment. Soil samples were collected at six different depths at the Agricultural Research and Development Center of Colorado State University (ARDEC). Four cropping systems with variable irrigation inputs were evaluated: fully irrigated alfalfa-corn (Full AC), limited irrigation alfalfa-corn (Ltd AC), limited irrigation wheat-corn-forage sorghum (Ltd WCFs), and dryland wheat-corn (Dry WC)]. The objectives of this study were to determine (i) the change in SOC and SIC concentrations, and (ii) the effects of different irrigated cropping systems on soil C and N stocks. Total C (SOC and SIC), total N and SOC and N stocks were analyzed at 0-5, 5-10, 10-15, 15-20, 20-30, and 30-60 cm depth. The SOC was greater in the shallow depths of soil in irrigated cropping systems relative to dryland cultivated systems in both years but the different was not as expected. The SIC was greater in the deeper profile and contributed for TC by 48% in 2007 and by 42% in 2010. The SOC stocks increased and N stocks decreased by small amount during short term (2007-2010). More investigation is needed to illustrate the influence of irrigation and cropping systems on C and N storage deeper in soil profile particularly in arid regions.

INTRODUCTION

Competition for limited water supplies has the potential to alter irrigated cropping systems as water transfers from agriculture to municipalities occur. Fallowing of formerly irrigated land is anticipated, but conversion to dryland cropping or limited irrigation is being explored as alternative water conserving approaches. There are concerns about the potential economic and ecological effects of dewatering irrigated farmland. One concern is the potential loss of soil carbon from de-watered irrigated crop land. Soil carbon levels may decline with reduced irrigation because of decreased biomass production and return to the soil.

Irrigation has an important impact on the soil C balance in several ways. It increases crop productivity and plant residue inputs. The plant net primary productivity NPP is important for the soil organic C accumulation rate (Jobbagy and Jackson, 2000), High levels of crop residue under irrigated systems may be sufficient to increase SOC storage relative to rain fed systems. For example, irrigated corn produces a large quantity of above and below ground residue and when returned to the soil, can increase C storage (Varvel et al., 2008). Also, Varvel et al. (2008) stated that the amount of residue produced from irrigated continuous corn was greater than either irrigated soybean-corn or irrigated continuous soybean. These studies support the hypothesis that soil carbon levels will decline when irrigated land is converted to limited irrigation or dryland production. Other studies, however, have shown that SOC may decline under irrigation due to direct enhancement of microbial activity that speeds SOM decomposition (Shrestha et al. 2004) or indirectly through aggregate disruption or clay dispersion (Shrestha et al. 2004). Many studies have indicated that irrigation had a negative impact on physical properties of the soil such as bulk density, porosity, and hydraulic conductivity (Shrestha et al. 2004). These studies make the prediction of how reduced irrigation levels will affect soil carbon less clear.

Most studies have focused on the impact of agricultural practices on soil organic C stocks in the surface soil profile and ignored the soil inorganic carbon (SIC) pool which is generally the most abundant C form (carbonates) in arid and semi-arid soils (Eswaran et al. 2000). The SIC pool is less susceptible to loss by agricultural practices compared to SOC because of its presence deeper in the profile which may in turn have potential as a long-term sink for atmospheric CO_2 (Lal, 2004). Paustian et al. (2008) found that SIC occurred deeper in the soil profile in cultivated sites, and was greater in dryland compared with irrigated sites to a depth of 0-75 cm. Therefore, significant changes in irrigation practices may affect the SIC by altering the dissolution of carbonates (Eswaran et al. 2000).

Previous studies have evaluated the impact of tillage, cropping system and nitrogen fertilization on soil C stocks. Little is known about the effect on soil C stocks of converting irrigated farmland to limited irrigation or dryland cropping systems. Therefore, this project focused on the effect of irrigation regimes under different cropping systems on C stocks in a semi-arid area over a 3-yr period. The specific objectives were to determine (i) the change in SOC and SIC concentrations, and (ii) the effects of different irrigated cropping systems on soil C and N stocks.

MATERIALS AND METHODS

The study is located at Colorado State University's Agricultural Research Development, and Education Center (ARDEC), located 8 km north of Fort Collins. The site is approximately 1 hectare under a linear-move sprinkler irrigation system. The soil is a Fort Collins Loam (fine-loamy, mixed, superactive, mesic Aridic Haplustalfs). The climate of this study location is semi-arid with average annual precipitation of 26.4 cm and mean annual temperature from 8.4 to 9.1^0C. Prior to the experiment, the location was used for irrigated crop production of crops including wheat, corn, and beans using an annual plow-based tillage approach, providing a setting to evaluate the effects of converting irrigated land to limited irrigation or dryland crop production.

The experiment was initiated in 2005 with the establishment of four different cropping systems, fully irrigated alfalfa-corn (Full AC), limited irrigation alfalfa-corn (Ltd AC), limited irrigation wheat-corn-forage sorghum (Ltd WCFs), dryland wheat-corn (Dry WC). All of these cropping systems are managed with no-till. The tillage system change was integrated to improve water capture and use in the limited irrigation and dryland systems and also to offset the potential for soil carbon loss. The irrigated corn-alfalfa system is used as the fully irrigated reference system. The alfalfa stands was maintained for 5 years (2005-2010) and then rotated with the corresponding block of continuous corn. The experimental design was a randomized complete block, with four replications. In addition, every phase of each crop rotation was present every year, making for a total of 36 individual plots. The irrigation system allowed for a maximum of 1 irrigation event per week and was controlled on an individual plot level by manually controlling drop nozzles.

Soil samples were collected at six different depths (0-5, 5-10, 10-15, 15-20, 20-30, and 30-60 cm). Twelve soil cores were taken from each plot at points randomly selected within a design stratified by position and composited by depth within each plot. Soil samples were taken at the end of the third (October, 2007) and sixth (October, 2010) cropping seasons and again in.

Variation in bulk density is due to the relative proportion and specific gravity of solid organic and inorganic particles and soil porosity. Bulk density was measured in soil cores taken from each plot after harvest by using a sampling cylinder (5 cm diameter x 5cm high). Soils were dried and weighed then weight was divided by core volume (Denef et al., 2008).

Total C (SOC+SIC) and N content was measured using a Carlo Erba NA 1500 CN analyzer. Soil inorganic C was determined by a modified pressure transducer method (Denef et al., 2008), and SOC was calculated by difference (total soil C - SIC). The C stocks were calculated using the following equation (Shrestha et al., 2004):

Carbon stock (kg/m^2) = d (m) × BD (kg/m^3) × % SOC-content

Analysis of variance was completed using PROC GLM procedure in SAS 9.1 (SAS Institute, 2009). Treatment means were compared using least significant difference (LSD) with 95% confidence in accordance with a randomized complete block experimental design to ascertain the effects of four different irrigated cropping systems on SOC and SIC within depth, and C and N stocks over the entire depth.

RESULTS AND DISCUSSION

Differences in SOC were identified among cropping systems in 2007. The Full AC had a higher level of SOC than the Dry WC rotation at most of the sampled depths (Figure 1c). In 2010, SOC had appeared to have increased relative to the 2007 levels over all cropping systems (Figure 1d). This increase may be due to the conversion of the entire experimental location from a tilled to a no-till system. In 2010, both Full AC and Ltd AC had higher levels of SOC than the Ltd WCFs or Dry WC. The results suggest that SOC loss may not be a large risk with conversion of fully irrigated cropland to limited irrigation or dryland, especially when the conversion included the application of conservation tillage. However, there is a reduced potential for carbon sequestration as irrigation is reduced.

Total C concentration in the soil tended to be higher in Ltd WCFS compared with other treatments in both years (Figure 1AB). The differences in total C among the other three treatments were not statistically significant in either year. Blanco-Canqui et al. (2010) reported that the differences in cropping systems among irrigation levels have differently influenced Soil C accumulation due to differences in residue production.

Even though, there were differences in the amount of irrigation in treatments with the same crops system (Full AC, Ltd AC), the differences were not significant among all depths in both years. It suggested that there were factors other than irrigation and crop rotation controlling the processes of SOC accumulation. Blanco-Canqui et al. (2010) indicated that, the accumulation of SOC does not only depend on the amount of plant residue but there are other dynamic factors controlling the processes. For example: rewetting of the soil enhanced the decomposition of SOM and reduced gains in residue-derived SOC.

The SOC concentration decreased with depth (Figure 1CD) and the SIC increased with depth in all treatments and years (Figure 1EF). The SOC concentration in Full AC tended to be greater than those under other treatments in all depth except in 15-20 cm depth in 2007 (Figure 1CD). However, SIC values were greater under limited irrigation (specifically, Ltd CFS) compared to those under other treatments in all depths and years, with the exception of the 30-60 cm depth in 2007. In year 2007, the SIC values appeared to be different among treatments at the 30-60 cm soil depth however; there were no significant differences (Figure 1EF). The increase in SOC with increased water applied may be due to the greater productivity and plant residue C inputs on soil surface as a result of availability of water under full irrigation. In arid or semiarid regions, soil is predicted to contain more SIC as a result of the reaction of dissolved CO_3^{2-} and HCO_3^- with Ca and Mg, resulting in precipitation of carbonates (Blanco-Canqui et al., 2010). The results show a greater concentration of SIC even though the quality of the irrigation water is good, this may be due to the organic matter being exposed directly by high solar radiation. Therefore, elevated temperatures with low irrigation increased the reaction of carbonate formation (Denef et al., 2008).

SOC stocks were significantly greater in Full AC and Ltd AC compared to the other treatments for the entire 0-60 cm depth in both years (Table 1). In addition, SOC stocks were higher in 2010 than in 2007 among all treatments. The moisture content under irrigation may enhance C stabilization in soil (Wang at el., 2010). They found that under center pivot irrigation, the C storage was higher by 25% compared with dryland cultivation. In this study, the possibility is that the C input by biomass during period of three years may enhance the physical protection of SOM through improved soil aggregation which in turn increases the SOC stock.

In 2007, N stocks were the highest in Ltd WCFs (table 1), in which Dry WC (18.35 kg/ha N) <Full AC (25.7 kg/ha N) <Ltd AC (11.014 kg/ha N) <Ltd WCFs (33.04 kg/ha N), but in 2010 almost there was no significant difference among these treatments. N stocks were higher in year 2007 compared to 2010. This may due to the differences in C:N ratio of the biomass between both years because the availability of N in the soil depends on the C:N ratio in SOM. The high ratio enhances the immobilization process which increases the N in soil however; the low ratio increases the nitrification and denitrification processes that decrease the N in the soil. Also water may negatively impact the N concentration by leaching or gas emission.

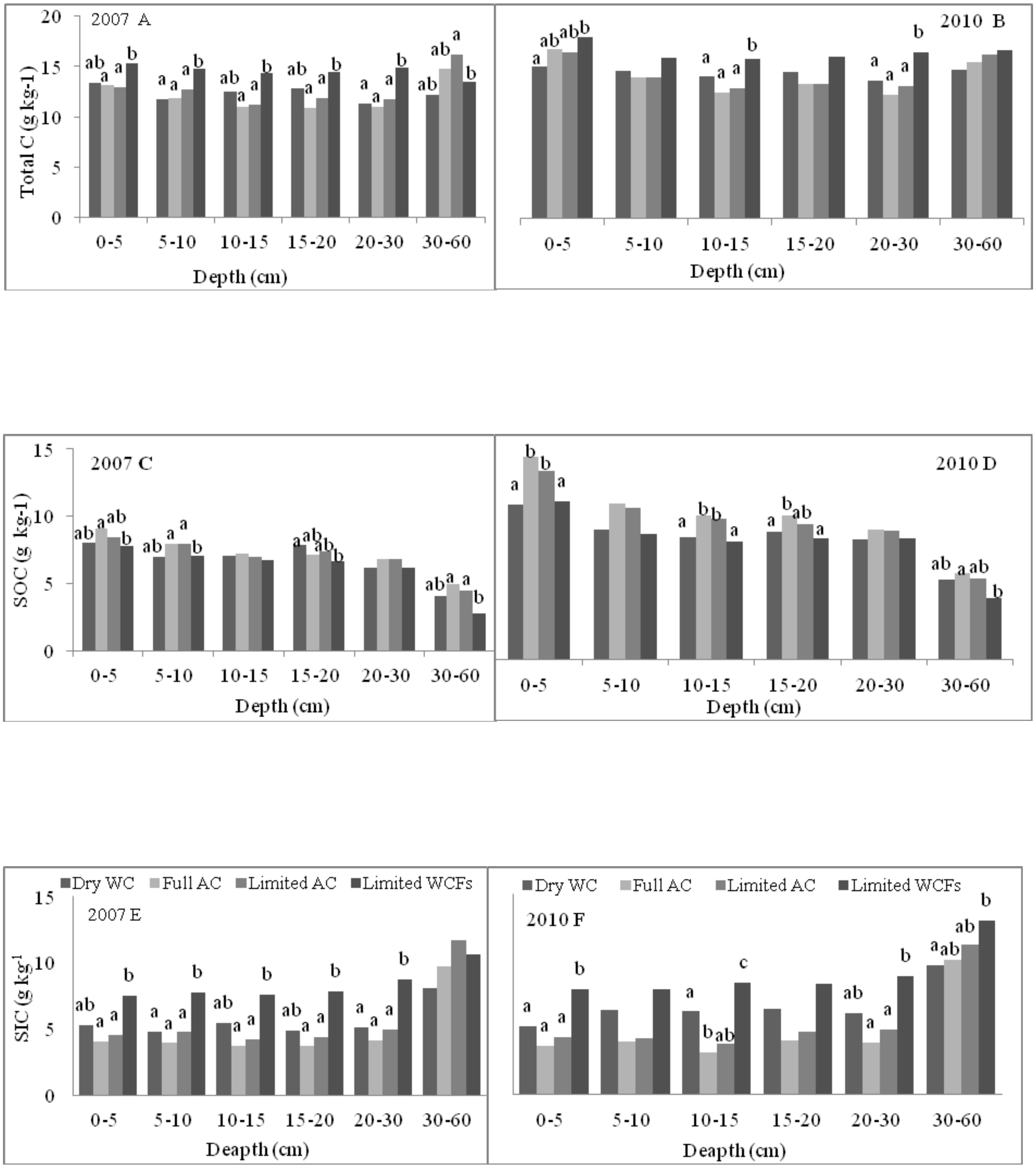

Figure.1 Concentration of Total C (A and B), SOC (C and D), and SIC (E and F) in the soil, in 2007 and 2010 at six soil depths under different systems in a semi-arid climate.

Table1. Mean soil C and N stocks (0-60 cm), under four different cropping systems in a semi-arid region during a three-year period (2007-2010). Define abbreviations of cropping systems in the table title. Define meaning of letters (abcd).

Treatments	SOC Stocks		N Stocks	
	g/m^2			
	2007	2010	2007	2010
Dry WC	4100 b	5330 b	820 d	740 a
Full AC	4500 a	5620 a	1100 c	770 a
Limited AC	4500 a	5550 a	1320 b	772 a
Limited WCFs	3420 c	4670 c	1430 a	650 b

CONCLUSIONS

We found an increased storage of SOC in the shallow depths of soil in irrigated cropping systems relative to dryland systems in both years. The anticipated loss of SOC due to reduced irrigation was not observed. The conversion to a no-till system appears to have offset the potential loss of SOC due to reduced irrigation levels. The SIC contributed only by 48% of total C in 2007 and by 42% in 2010. We observed that SOC stocks increased and N stocks decreased by small amount during short term (2007-2010). Based on the results of this study, SOC loss and the potential for increased carbon emissions to the atmosphere are not a major concern associated with reduced irrigation levels or conversion to dryland cropping.

REFERENCES

Blanco-Canqui, H. K., N. Schlegel, A. Stone and C. LR Rice. 2010. Impacts of deficit irrigation on carbon sequestration and soil physical properties under no-till. Soil Science Society of America Journal Vol. 74:1301-1309.

Denef, K., C. Stewart, J. Brenner and K. Paustian. 2008. Does long-term center-pivot irrigation increase soil carbon stocks in semi-arid agro-ecosystems? Geoderma. 145:121-129.

Eswaran, H., Reich, P.F., Kimble, J.M., Beinroth, F.H., Padmanabhan, E. and Moncharoen, P. 2000. Global carbon stocks. In: Global climate change and pedogenic carbonates (eds R. Lal, J.M. Kimble, H. Eswaran & B.A. Stewart). pp. 15–26. Lewis Publishers, Boca Raton.

Guzman, J. G. and M. M. Al-Kaisi. 2010. Soil carbon dynamics and carbon budget of newly reconstructed tall-grass prairies in south central Iowa. Journal of environmental quality. 39:136-146.

Jobbágy, E. G. and R. B. Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological applications. 10:423-436.

Knops, J. M. H. and D. Tilman. 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. Ecology. 81:88-98.

Lal, R., M. Griffin, J. Apt, L. Lave and M. G. Morgan. 2004. Managing soil carbon. Science. 304-393.

Lal, R., R. F. Follett, B. Stewart and J. M. Kimble. 2007. Soil carbon sequestration to mitigate climate change and advance food security. Soil Science. 172-943.

Lee, J., J. W. Hopmans, D. E. Rolston, S. G. Baer and J. Six. 2009 Determining soil carbon stock changes: Simple bulk density corrections fail. Agriculture, Ecosystems and Environment. 134:251-256.

Paustian, K., O. Andren, H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Noordwijk and P. Woomer. 1997. Agricultural soils as a sink to mitigate CO2 emissions. Soil use and management. 13:230-244.

Saha, S., R. Nair, V. Nair and B. Kumar. 2009. Soil carbon stock in relation to plant diversity of homegardens in Kerala, India. Agroforestry systems. 76:53-65.

Shrestha, B., B. Sitaula, B. Singh and R. Bajracharya. 2004. Soil organic carbon stocks in soil aggregates under different land use systems in Nepal. Nutrient Cycling in Agroecosystems. 70:201-213.

Townsend, A. R., P. M. Vitousek, D. J. Desmarais and A. Tharpe. 1997 Soil carbon pool structure and temperature sensitivity inferred using CO 2 and 13 CO 2 incubation fluxes from five Hawaiian soils. Biogeochemistry. 38:1-17.

Varvel, G. E. and W. Wilhelm. 2008. Soil Carbon Levels in Irrigated Western Corn Belt Rotations. Agronomy journal. 100:1180-1184.

Vesterdal, L., I. K. Schmidt, I. Callesen, L. O. Nilsson and P. Gundersen. 2008. Carbon and nitrogen in forest floor and mineral soil under six common European tree species. Forest Ecology and Management. 255:35-48.

Vitousek, P. M. and R. W. Howarth. 1991. Nitrogen limitation on land and in the sea: how can it occur? Biogeochemistry. 13:87-115.

Wang, Y., F. Liu, M. N. Andersen and C. R. Jensen. 2010. Carbon retention in the soil-plant system under different irrigation regimes. Agricultural Water Management. 98**:** 419-424.