Monitoring Carbon Sequestration and Greenhouse Gas Emissions from Irrigated AgroEcosystems

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Introduction

Conventional field cropping systems have been criticized as being unsustainable because they contribute to on-farm and off-farm environmental degradation, and are often economically uncertain. Methods to increase environmental and economic sustainability are needed. There is a critical need to develop management technologies to maximize yield and crop quality yet improve environmental impacts on soil and water resources. A long-term cropping system experiment has been established to evaluate the sustainability of reduced-till, and conventional till cropping systems in irrigated rotations. The major focus of this research is to evaluate the sustainability of the irrigated production systems by measuring agronomic performance, soil quality, nutrient dynamics, soil biological activity and trace gas fluxes (CO_2, N_2O, CH_4). One objective is to determine the mechanisms controlling carbon and nitrogen cycling and trace gas fluxes under reduced tillage in irrigated cropping systems.

Overview of Literature

Soils are the largest pool of carbon (C) in the terrestrial environment (Jobbagy and Jackson, 2000; Schlesinger, 1990, 1995). The amount of C stored in soils is twice the amount of C in the atmosphere and three times the amount of C stored in living plants (Schlesinger, 1990, 1995; Kimble and Stewart, 1995). Therefore, a change in the size of the soil C pool could significantly alter current increasing atmospheric CO_2 concentrations (Wang et al. 1999).

Carbon stored in soils is derived from litter and root inputs, while losses result from microbial degradation of organic matter (OM), eluviation, and erosion (Entry and Emmingham, 1998). As an ecosystem approaches maturity, maximum carbon sequestration potential is controlled by climate, topography, soil type, and vegetation (Van Cleve et al., 1993; Dewar, 1991; Harmom et al., 1990). At equilibrium the rate and amount of C added to the soil via vegetation are equal to the rate and amount of C lost through OM degradation and other pathways (Henderson, 1995).

Within limits, soil C increases with increasing soil water and decreases with increasing temperature (Wang et al., 1999). The effect of soil water is much greater than the effect of soil temperature (Hontoria et al., 1999; Liski et al., 1999). Increasing water within temperature zones can increase plant production and, thus, C input to soils via increased plant litter and root production (Liski et al., 1999). Land-use changes can impact the amount of C stored in the soil by altering C inputs and losses. Conversion of native vegetation to agricultural cropping systems has resulted in substantial C transfer to the atmosphere and loss of native vegetation to lower the equilibrium levels of C in soil (Lal et al.,1999; Wang et al.,1999; Cambardella and Elliot,1992; Johnson 1992).

Irrigation can increase plant production and economic viability of agriculture in arid and semi-arid environments where plant growth is limited by available water. Irrigation also increases C input to soils via increased litter and root production. However the potential of irrigation to cause a net increase of C storage is tempered by C loss as CO_2 emitted to the atmosphere as a result of (i) fertilizer manufacture, storage, transport, and application, (ii) pumping irrigation water, (iii) farm operations such as tillage and planting, and (iv) dissolved carbonate in irrigation water (West and Marland, 2002; Schlesinger, 1999). The CO_2 released during fertilizer production of 336 kg N ha^{-1} yr^{-1} is approximately 167 kg C ha^{-1} yr^{-1} (Schlesinger, 1999). Carbon dioxide released from pumping irrigation water in the U.S. ranges from 126 kg C ha^{-1} yr^{-1}, when using fossil fuels to 266 kg C ha^{-1} yr^{-1} when using electricity (West and Marland, 2002). In addition, C may be lost as CO_2 from irrigation water itself. Irrigation water in arid and semi-arid regions often contains as much as 1% dissolved Ca and CO_2. When water is applied to basic soil, $CaCO_3$ can precipitate, depositing some C into the soil but causing a net release of CO_2. If irrigation water containing 0.05 g L^{-1} dissolved Ca is used to irrigate crops enough to increase plant C by 2000 g C m^{-2} yr^{-1}, the net CO_2 released was calculated to be on the order of 8.4 g C m^{-2} yr^{-1} (Schlesinger, 1999).

However, with more sustainable farm management practices, it is possible to reduce the amount of CO_2 emitted to the atmosphere or even sequester substantial amounts of C from the atmosphere for the next 30 to 50 years (Entry et al., 2002). Farm management practices such as conservation tillage and erosion control have reduced the amount of CO_2 emitted to the atmosphere in studies in both Canada and the U.S. (West and Marland, 2002; Janzen et al., 1997; Paustian et al., 1997; Rasmussen and Collins, 1991). Intensively managed irrigated crop or pasture lands have potential for C gain through the use of improved grazing regimes, improved fertilization practices and irrigation management (Follett, 2001; Bruce et al., 1999). Figure 18.1 shows increases in soil C resulting from conversion of native shrub-steppe to irrigated agricultural production in the Columbia Basin of Eastern Washington.

The impact of land use changes on C sequestration were studied in southern Idaho on soils similar to those found in Eastern Washington. Four sites with long term cropping histories were identified: Native sagebrush vegetation (NSB), irrigated moldboard plowed crops (IMP), irrigated conservation-chisel-tilled crops (ICT), and irrigated pasture systems (IP). Using the C loss from CO_2 emitted as a result of fertilizer production, farm operations, and CO_2 lost via dissolved carbonate in irrigation water over a thirty years period, the potential of irrigation of arid and semi-arid land to increase C storage in soils was assessed (Entry et al., 2002). Total ecosystem C was greater in the order of IP>ICT>IMP>NSB before adjustment for input-related CO_2 emissions (Table 18.1), however after this adjustment, C in ecosystems was greatest to least in the order IP > ICT > NSB > IMP. This is due to IMP managed crops requiring more farm operations than NSB. Entry et al. (2002) estimated that converting NSB to IMP would cause a net loss of 0.15 kg C m^{-2} over a 30 yr period, but converting NSB to ICT or IP over the same period would produce a net gain of 0.80 kg C m^{-2} or 3.56 kg C m^{-2} respectively (Table 18.1).

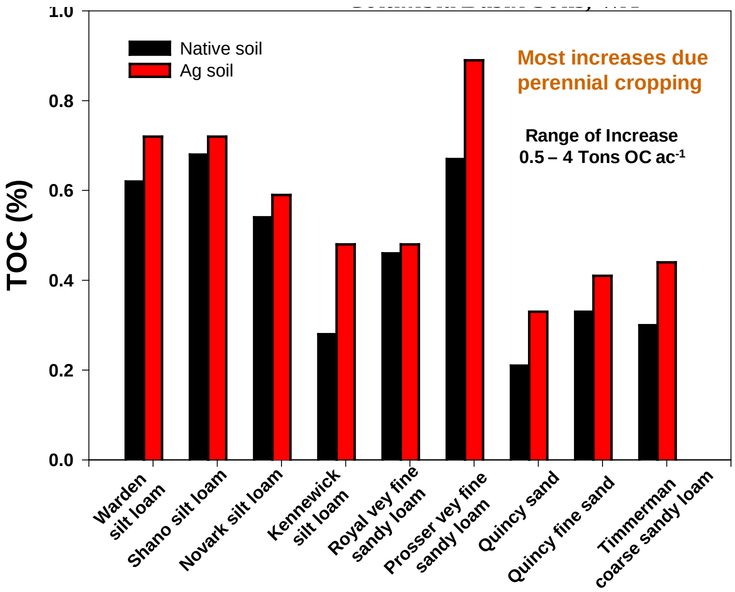

Figure 18.1. Impact of irrigated agriculture on percent organic carbon in soils of the Columbia Basin, WA.

Table 18.1. Organic C in soils, aboveground biomass and C emitted during agricultural operations. ***From*** Entry et al., 2002.

	Carbon present				Net carbon gain	
Vegetation	Soil‡	Aboveground §	Site	Carbon emitted¶	Soil‡	Site
	------------------------------- kg C m^{-2} -------------------------------					
Native sagebrush	5.91c	0.42a	6.34c	0.00d	5.91c	6.34c
Irrigated moldboard plow crops	7.29b	0.00c	7.29b	1.10a	6.19b	6.19c
Irrigated conservation till crops	8.01b	0.00c	8.01b	0.87b	7.14b	7.14b
Irrigated pasture	10.14a	0.05b	10.19a	0.29b	9.85a	9.90a

†In each column, values followed by the same letter are not significantly different as determined by the least square means test ($P \leq 0.05$), n = 30. ‡ Values of organic C stored in soils are based on the Walkley–Black procedure. § Carbon in soils, aboveground vegetation, and on the sites at the present

time. ¶ Estimated C emitted in production of fertilizer, fuel consumption in farm operations, and via irrigation water over a 30-yr period.

Converting IMP managed land to ICT or IP would increase the potential for C sequestration and simultaneously would reduce erosion, water pollution, and air pollution, while causing only modest economic impact to landowners and few socioeconomic issues (Entry et al., 2002).

The amount of C stored in native arid shrub-steppe vegetation (NSB) and irrigated agricultural systems are similar throughout the USA as well as worldwide (Entry et al., 2002; Bowman et al., 1999; Collins et al., 1999; Amthor et al., 1998; Potter et al., 1998; Rasmussen and Parton, 1994; Schlesinger, 1997). The data obtained from these studies were used to calculate potential C storage for irrigated agriculture in the Pacific Northwestern USA, the Western USA, and worldwide over a 30-yr period. Entry et al. (2002) estimated a gain over 30 yr of 1.5 Mg C ha^{-1} if IMP managed land was converted to NSB or 9.5 Mg C ha^{-1} if converted to ICT. Using this value they calculated that 8.6×10^7 Mg C, which is 0.15% of the total C emitted in the next 30 yr, could potentially be sequestered in irrigated agricultural soils in the Pacific Northwestern U.S. Irrigated lands produce approximately twice as much plant biomass as rain-fed agricultural production systems (Bucks et al., 1990; Howell, 2000). Using this assumption, the conversion of 1 ha rainfed crop land to irrigated crop land could allow the retirement of 1 additional ha of rainfed crop land back to native vegetation.

A substantial reduction of atmospheric CO_2 could be attained if policy makers and agricultural experts recognize the potential benefit of land and water management strategies. Lands could be more purposely used for their greatest good, be that food production, carbon storage, native habitat, or other uses.

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