# Climate Friendly Farming™: Irrigated Component

## Monitoring Carbon Sequestration and Greenhouse Gas Emissions from Irrigated AgroEcosystems

## Year One Report

**Project Lead: Harold P. Collins**
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## Introduction

Conventional field cropping systems have been criticized as being unsustainable because they contribute to environmental degradation (on-farm and off-farm), and are often economically uncertain. Reducing production costs, through the use of conservation tillage and reducing inputs as a means of increasing environmental and economic sustainability of cropping systems are needed. There is a critical need to develop management technologies to improve soil quality with adaptation of suitable cover crops for off season soil management, and reduced tillage for carbon sequestration and control of green house gas emissions. Cropping systems which optimize rotational crops in irrigated light texture soils are needed to maximize yield, crop quality and minimize potential adverse impacts on soil and water resources. Two long-term cropping systems experiments have been established to evaluate the sustainability of reduced-till, and conventional till cropping systems and the use of fall-planted cover crops 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 determine and understand the mechanisms controlling carbon and nitrogen cycling and trace gas ($CO_2$, $N_2O$, $CH_4$) fluxes under reduced tillage in irrigated cropping systems. This research will provide a greater understanding of the relative sustainability of conventional and alternative cropping systems, identify key challenges to increased sustainability, and develop a better understanding of mechanisms controlling ecological processes.

The current personnel of the Irrigated cropping systems team includes Dr. Dr. Harold P. Collins and Dr. Shawel Haile-Mariam. Dr. Collins provides overall leadership for this component, with significant cooperation from Dr. David Huggins, Dryland Systems; Dr. Shulin Chen, Dairy Systems; and Dr. Claudio Stockle, Systems Modeling.

## Overall goal

Establish long-term equilibrium values and rate changes of soil carbon storage and $N_2O$, $CH_4$ and $CO_2$ emissions of current/conventional and future/improved irrigated farming systems.

## Specific Objectives

1. Design and establish field-scale experimental and demonstration sites that facilitate long-term assessment of environmental and socioeconomic factors that impact greenhouse gas emissions, environmental health, resource efficiency, and agricultural sustainability.
2. Characterize and model fluxes of nitrogen, carbon, water, and energy under current and "climate friendly farming" systems in irrigated situations.

3. Use field research, biophysical modeling and socioeconomic assessments to identify practical and adoptable systems that will improve performance and maximize mitigation of global greenhouse gas emissions, resource use efficiency and water quality protection.

4. Provide education and outreach through tours, presentations, publications, and media.

Research objectives for the irrigated agroecosystem component are closely aligned with sampling protocols of both the dairy (Shulin Chang) and dryland (Dave Huggins) systems and dependent on the socioeconomic analysis of the two modeling groups (Dr. Claudio Stcckle and Phil Wandschneider).

## Progress by Objective and Task

1. Design and establish field-scale experimental and demonstration sites that facilitate long-term assessment of environmental and socioeconomic factors that impact greenhouse gas emissions, environmental health, resource efficiency, and agricultural sustainability.

*Task 1. Establish field-scale experiments that allows long-term comparative assessment of irrigated agroecosystem performance.* ***Completed.***

2. Characterize and model fluxes of nitrogen, carbon, water, and energy under current and "climate friendly farming" systems in irrigated situations.

*Task 1. Complete literature review on experimental methodologies for characterizing nitrogen, carbon, water, and energy flux.* ***Completed.***

*Task 2. Install monitoring equipment to evaluate irrigated agroecosystems.* ***Completed.***

*Task 3. Identify key scientific unknowns regarding greenhouse gas flux, formulate research hypotheses and design and implement experiments to test hypotheses.*

- A significant development related to monitoring of greenhouse gas emissions from irrigated agricultural systems was discovered during first year monitoring efforts and has contributed to the development and refinement of trace gas monitoring protocols. Preliminary measurements from the sampling stations indicated noisy data resulting from the timing of chamber deployment and sample collection interval. The original sampling intervals used were based on values derived from the current literature on trace gas flux measurements and was found to be inappropriate for the irrigated soils of the Columbia Basin. There fore, we developed new methodologies to identify sampling intervals of the gas flux measurement and also timing of chamber deployment after irrigation. This could prove to be a key 'scientific' contribution for measuring nitrous oxide emissions from irrigated, sandy soils.

*Task 4. Integrate experiments to characterize and model fluxes.*

3. Use field research, biophysical modeling and socioeconomic assessments to identify practical and adoptable systems that will improve performance and maximize mitigation of global greenhouse gas emissions, resource use efficiency and water quality protection. ***See Modeling and Economic Section Reports.***

4. Provide education and outreach through tours, presentations, publications, and media.

*Task 1. Establish a field day, presentations and informational publications.* ***Completed***

## Milestones

- Dr. Shawel Haile-Mariam joined the irrigated systems team February 2004. Responsible for conducting field and laboratory analyses.
- Established field-scale experiments for long-term comparative assessment of agroecosystem performance.
- Samples were collected for measuring soil bulk density and developing soil water-retention curves to parameterize trace gas flux measurements.
- Soil moisture and rain gauge monitoring systems were calibrated and installed at the Patterson field site.
- Trace gas chambers and anchors have been constructed and installed.
- Gas Chromatograph (GC) configured for analysis of $CO_2$, $N_2O$, and $CH_4$.
- Baseline trace gas flux measurements in the field were begun, as well as, laboratory experiments conducted to determine intervals for field sampling.
- ***Out Reach:***
  - **Field day** at Paterson, WA was sponsored on July 8th, 2004. The field day was attended by farmers, processors, consultants, and researchers from throughout the Columbia Basin. Approximately 110 attended.
  - **Pacific Northwest Vegetable Association**, Annual Conference and Trade Show. Nov. 17-18, 2004. Pasco, WA. "*Crop rotations for natural soil fumigation and biodiesel production*".
  - **Hermiston Farm Fair and Trade Show**. Dec 1-3, 2004. Hermiston, OR. *"Cover crops for soil fumigation and biodiesel production".*
  - **Extension Educators Update**. Dec. 14, 2004. Prosser, WA. *"Reduced tillage".*
  - **Columbia Basin Potato Work shop**. Jan 11-12, 2005. Pasco, WA. *"Crop rotations in potato production cropping systems".*
  - **Columbia Basin Crops Consultants**. Jan. 14, 2005. Moses Lake, WA. *"Reduced tillage in potato production systems".*

## Corollary Studies

In the spring of the 2004 growing season a trial (***not CFF funded***) was established to assess the inclusion of oil seed and biomass crops in irrigated cropping systems of the Pacific Northwest. The objective is to identify potential benefits of increased soil carbon sequestration, under conservation tillage systems, and to evaluate the potential for biodiesel and ethanol production. These tests were conducted on the USDA Paterson experimental farm and involve soil carbon and emissions monitoring of biofuel based cropping systems. Field data, along with biofuel emission statistics, will allow assessment of greenhouse gas emission reduction, the potential of a bioenergy industry in the PNW and determine the economic value of these crops.

The last decade has been characterized by huge U.S. trade deficits. Petroleum imports account for much of the trade imbalance. In fact, petroleum imports for transportation purposes alone were $50 billion in 1996. America's dependency on foreign oil (now over 60 percent and rising) is not only an economic issue, but is one of national security--particularly in times of global unrest. These factors, coupled with environmental concerns regarding the use of fossil fuels and production of excess $CO_2$, fostered with the expansion of the fuel ethanol industry, make biofuel production a high priority issue for USDA. The capacity of the U.S. for such fuels as ethanol exceeds 2.1 billion gallons per year. Similarly, a nascent biodiesel industry has been developing in recent years. The industry has become an important partner with American agriculture, and the USDA estimates that 17,000 jobs are created for every billion gallons of biofuel produced.

A likely market for alternative energies is within agriculture itself. Low-cost alternative fuels can be used to power farm tractors and small agricultural production and processing facilities within rural communities. Pacific Northwest biodiesel production has the potential for assisting rural and farm development and aid our national security through increased reliance on domestic renewable energy, It also has the potential to improve upon existing environmental concerns such as greenhouse gas emissions. Biodiesel is an EPA approved renewable fuel that can be produced either from regionally farmed oil seed crops or from recycled vegetable and animal fats. Development of biodiesel crushing and processing plants within the region could effectively add to state and, in particular, rural and farm economies by utilizing area commodities through the creation of a new job related infrastructure.

Biodiesel includes fuels derived from corn, soybeans, sunflower, cottonseed, canola and rape seed, crambe, safflower, flaxseed, and mustard seed. Currently, soybeans are the most commonly used fuel feedstock in the US, where rapeseed is the primary feedstock in Europe. Table 1 provides a list of crops and their vegetable oil production potential under rain-fed conditions. Those crops highlighted were included in the trials at the Paterson field site. Yields are anticipated to double under irrigation. Results of our first years' study are provided in Table 2.

Table 1. Oil producing crops, percent oil and kg vegetable oil ha$^{-1}$.

| Crop | % oil | kg oil/ hectare* | Crop | % oil | kg oil/ hectare* |
|---|---|---|---|---|---|
| Corn | 3-4 | 145 | **Safflower** | **42-48** | **655** |
| Cotton | 22-25 | 273 | Sunflower | 40-42 | 800 |
| **Soybean** | **20-22** | **403** | Peanut | 40-43 | 890 |
| **Mustard** | **25-27** | **481** | **W. Rapeseed** | **40-45** | **1000** |
| Camelina | 25-27 | 490 | <u>Tropical</u> | | |
| **Crambe** | **28-30** | **495** | Coconut | | 2260 |
| **S. Rapeseed** | **40-45** | **550** | Oil palm | | 5000 |

Production potential under rain-fed conditions. *Efficiency of crusher operations are not included in estimates of oil yields.

Table 2. Oilseed, oil and biodiesel yields at the irrigated USDA-ARS Paterson, WA field site in 2004.

| Crop | Variety | Seed Yield (kg/ha) | Oil yield* (kg/ha) | Biodiesel Yield• (L/ha) |
|---|---|---|---|---|
| Crambe† | Belann | 930 | 279 | 273 |
| | Meyer | 1183 | 355 | 348 |
| Spring Mustard | Idagold | 1462 | 395 | 387 |
| | Pacific Gold | 2457 | 664 | 651 |
| Soybeans | S2788 | 3700 | 740 | 725 |
| | S2100-2 | 3931 | 786 | 771 |
| | S1918-4 | 4346 | 869 | 852 |
| | S2422-2 | 4364 | 873 | 855 |
| Spring Rapeseed | Garnet | 2101 | 946 | 927 |
| | Sterling | 1982 | 892 | 873 |
| Safflower‡ | Montola | 2031 | 914 | 896 |

† Crambe will be removed from further considerations because of high weed pressures. ‡The safflower varieties selected did not reach the expected yield potential of 3572 kg ha$^{-1}$. Varieties used in subsequent

studies will be selected to better fit environmental conditions of Eastern WA. *Efficiency of crusher operations not included in estimates of oil or biodiesel yields. •Assumes 98% conversion of vegetable oil to biodiesel.

## Climate Friendly Farming™: Irrigated Component Annual Report: Year One

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### 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 OM, eluviation, and erosion (Entry & Emmingham, 1998). 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 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 & 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 has resulted in substantial C transfer to the atmosphere and has resulted in the 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).

In arid and semi arid environments plant survival & growth is limited by available water and irrigation is required to increase plant production to the point where crops become economically viable. Irrigation also increases C input to soils via increased litter and root production. When assessing the potential of irrigation of arid or semiarid land to increase C storage in soils, one needs to assess C loss from $CO_2$ emitted to the atmosphere as a result of (i) fertilizer manufacture, storage, transport, & application, (ii) fossil-fuel $CO_2$ emitted from pumping irrigation water, (iii) farm operations such as tillage & planting, & (iv) $CO_2$ lost via 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 16.7 g C $m^{-2}$ $yr^{-1}$(Schlesinger, 1999). Carbon dioxide released from pumping irrigation water in the USA, 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 semiarid regions often contains as much as 1% dissolved $CO_2$. When water is applied to basic soil, $CaCO_3$ can precipitate, depositing C into the soil. If irrigation water containing 0.05 g L-3 dissolved Ca is used to irrigate crops in semiarid climates, the calculated increase in plant C is 2000 g C $m^{-2}$ $yr^{-1}$ over C contained in native soils and vegetation. The net $CO_2$ released via irrigation water is calculated to be on the order of 8.4 g c $m^{-2}$ $yr^{-1}$ (Schlesinger, 1999). 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 amount of C added to the soil via vegetation is equal to the amount of OM degraded and other losses of C. Irrigated agricultural systems cannot accumulate C forever. However, with sustainable farm management practices, it is possible to sequester substantial amounts of C from the atmosphere for the next 30 to 50 yr (Entry et al., 2002) and also it is possible to reduce the amount of $CO_2$ emitted to the atmosphere by utilizing conservation tillage and erosion control practices (West and Marland, 2002; Janzen et al., 1997; Paustian et al., 1997; Rasmussen and Collins, 1991).

Farm management practices that have included conservation tillage and erosion control have reduced the amount of $CO_2$ emitted to the atmosphere in both Canada and the USA (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). Figure1 shows increases in soil C resulting from conversion of native shrub-steppe to irrigated pasture and alfalfa 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 semiarid land to increase C storage in soils was assessed (Entry et al., 2002).

Total soil C was greater in the order of IP>ICT>IMP>NSB before adjustment for agricultural $CO_2$ emissions (Table 1), however, after adjustment for agricultural $CO_2$ emissions, (net), C in soils 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 if NSB sites were converted to IMP a net loss of 0.15 kg C $m^{-2}$ over 30 yr period and they also estimated a net gain of 0.80 Kg C $m^{-2}$ and 3.56 kg C $m^{-2}$ over the same period if NSB sites were converted to ICT and IP respectively. If IMP sites were converted to ICT and IP, one would expect net gain of 0.95 kg C $m^{-2}$ and 3.56 kg C $m^{-2}$ respectively over 30 yr period (Table 1).

### *Regional and global Implications*

Changes in land use and agricultural practices have shown greater potential to sequester C in the soil. For instance, converting IMP managed land to ICT or IP would increase the potential for C sequestration and simultaneously these practice shifts would also reduce erosion and water or air pollution with modest economic impact to landowners and create relatively few socioeconomic issues (Entry et al., 2002). Due to a poor understanding of the dynamics that control C flow among plants, soils and the atmosphere, it is difficult to estimate the potential for C sequestration in terrestrial ecosystems. Estimated C storage in soils locally, regionally, and globally, using the values obtained in southern Idaho, in soils if: (i) 10% of irrigated land now in IMP agriculture was converted back to NSB, (ii) all land presently in IMP was converted to ICT, and (iii) 10% of land in irrigated IMP was converted to IP. Considering an increasing population growth that has to be fed, it is feasible to suggest a 10% conversion of IMP land to IP (Entry et al., 2002).

The amounts 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). Entry et al., (2002) estimated a gain of 1.5 Mg C $ha^{-1}$ if IMP managed land is converted to NSB (Table 2). They also estimated a gain of 9.5 Mg C $ha^{-1}$ over 30 yr if the land currently managed with IMP was converted to ICT. Using this value they calculated that $8.6 \times 10^7$ 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 USA (Table 2). Using these values to represent C gains for all irrigated crop land (worldwide) and if current land in IMP were converted to ICT, a possible $2.3 \times 10^8$ Mg C (0.40% of the total C emitted in the next 30 yr) and $2.5 \times 10^9$ Mg C (4.38% of the total C emitted in the next 30 yr) could be sequestered in irrigated agricultural soils of the western USA and worldwide respectively. A shift of 10% of current IMP land to IP will potentially sequester an estimated $3.4 \times 10^7$ Mg C in Pacific Northwestern USA soils (Table 2) based on 37.1 Mg C $ha^{-1}$ storage prediction by Entry et al., (2002). Land use change from crop land to irrigated pasture could also ease the burden on public rangelands grazing which is a big environmental issue between environmentalists and ranchers.

Carbon sequestration is expected to increase if efficient water use allows the expansion of irrigated agriculture. Land use shifts from NSB to ICT could sequester 8.0 Mg C $ha^{-1}$ (Table 4) and assuming 10% expansion of irrigated agriculture, ICT, $7.2 \times 10^6$ Mg C (0.01% of the total C emitted in the next 30 yr) could potentially be sequestered in pacific Northwestern USA soils.

The earth releases $1.9 \times 10^9$ Mg C $yr^{-1}$ (Schlesinger,1995; Amthor et al.,1998) and the conversion of 10% IMP to IP will result in a possible sequestration of $9.6 \times 10^8$ Mg C over 30 yr which may be insignificant. Yet, if crops were produced using well managed irrigated agriculture and at the same time less productive rain-fed agriculture land were returned native grassland-shrub, an increase of 5.6 and 13 mg C $ha^{-1}$, respectively could be gained over 30 yr for each unit of rain-fed land converted to native vegetation (Table 3). Howell, (2000) suggested an expansion of irrigated agriculture by 10% through efficient use of irrigation water and recycle of waste water could increase C sequestration.

Irrigated lands produce twice as much plant biomass as rain-fed agricultural production systems (Bucks et al., 1990; Howell, 2000). Using this assumption, the conversion of irrigated land to native forest could potentially sequester $1.1 \times 10^{8}$ Mg C in PNW, $2.8 \times 10^{8}$ Mg C in the western USA and $3.0 \times 10^{9}$ Mg C worldwide (Table 3). Converting IMP land back to desert or semi-desert could result in a relatively small soil C gain of 0.15 kg C $m^{-2}$ ($1.90 \times 10^{6}$ Mg C 30 $yr^{-1}$ in the PNW) because arid land's relatively little ecosystem C compared to forest and grassland ecosystems (Houghton et al., 1999; Amthor et al., 1998; Schlesinger, 1977). In the same manner of land use change could result in a soil C gain of $5.10 \times 10^{6}$ Mg C 30 $yr^{-1}$ in the western USA, and $5.46 \times 10^{7}$ Mg C 30 $yr^{-1}$ worldwide. However, more C can be sequestered by selectively returning less productive rain-fed agricultural lands back to native vegetation (Entry et al., 2002) and at the same time expanding irrigated agriculture for both crop production and C sequestration. This suggestion is based on the fact that nearly a third of the yield and almost half of the value of crops in the USA are produced on irrigated lands specifically in arid and semiarid regions (Bucks et al., 1990; Tribe, 1994; Howell, 2000) and also with renewed efforts of water development. 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.

### *Trace Gas Fluxes from irrigated Lands*

Nitrous Oxide is an important greenhouse gas with a lifetime of 166 years (Prinn et al., 1990). The atmospheric concentration of $N_2O$ (310 ppbv) is increasing, at a rate of 0.6-0.9 ppbv $year^{-1}$, as a result of biotic factors and anthropogenic activities (Prinn et al., 1990) and this increase accounts for approximately 5% of the global warming (Houghton et al., 1992). Based on Crutzen and Ehhalt (1977) estimate, doubling the $N_2O$ concentration in the atmosphere would result in a 10% decrease in the level of stratospheric ozone ($O_3$) which in return would cause in a 20% increase in the amount of ultraviolet radiation reaching the earth surface. Soils are the major source of $N_2O$ and contributes about 90% of the $N_2O$ emitted from the biosphere into the atmosphere (Bowman,1990). Fertilizer application to agricultural ecosystems is estimated to contribute about $1.5\times10^{6}$ t of $N_2O$-N $year^{-1}$ (CAST 1992), representing about 44% of the annual anthropogenic input of $N_2O$-N and 13% of the total annual input of $N_2O$-N to the atmosphere.

Nitrous oxide emission from soil has important implications for both agricultural production and environmental quality. From agricultural perspective, $N_2O$ emission from agricultural field represents a loss of soil nitrogen in terms of its availability to plants. Nitrous oxide is naturally produced from natural and cultivated soils through microbial processes during nitrification and denitrification reactions (Bowden, 1986;Tiedje, 1988) and the amount of gases produced depend on agricultural management practices, climatic conditions and soil properties (Aulakh et al., 1992). With low N utilization efficiency in agricultural system, the potential of agricultural soils to form and emit $N_2O$ is expected to increase due to worldwide increasing usage of fertilizer. Thus, the pattern of increase in $N_2O$ emission to the atmosphere is alarming and need quantification.

Emissions of $N_2O$ from N-fertilized agricultural fields vary considerably and have been found to range between 0.001% and 6.8% of the applied N fertilizer (Bowman, 1990; Eichner, 1990). Nitrous oxide emissions have been extensively studied from different agroecosystems (Eichner, 1990), however only limited data is available on irrigated systems (Ryden et al., 1979; Rolston et al., 1982; Hallmark and Terry, 1985; Mosier et al., 1986; Bronson et al., 1992; Bronson and Mosier, 1993; Delgado and Mosier 1996; Delgado et al, 1996).

The IPCC methodology for estimating direct $N_2O$ emissions from fertilized agricultural soils assumes an $N_2O$ emission factor of 1.25% ±1 of the fertilizer N applied (IPCC, 1997). However emission from potato fields were higher and do not fit the relation between N fertilization and $N_2O$ emission adopted by International Panel on Climate Change (IPCC) based on the study of Bowman(1994). Bowman has indicated that the emission factor of 1.25±1% is not applicable to estimate emissions from specific crops or local climate conditions. Bowman regression analysis is based on $N_2O$ emissions mainly from corn and grassland soils. In Spain, the measured $N_2O$ emission fluxes range from -40 to 389 g of $N_2O$-N $ha^{-1}$ $d^{-1}$ that has been irrigated by flooding (Teira-Esmatges et al., 1998). Ruser et al. (1996) reported 209 g of $N_2O$-N $ha^{-1}$ $d^{-1}$ during spring after fertilization and heavy rainfall events. Relatively high emissions of $N_2O$-N was also reported in Iowa soils fertilized with anhydrous ammonia (250 kg ha-1) that ranged from 87 to 141 g of $N_2O$-N $ha^{-1}$ $d^{-1}$ and in irrigated mountain meadows of Colorado and Wyoming. After the first irrigation of this sandy loam meadow soil, the $N_2O$ emission increased from unfertilized 0.4 g of $N_2O$-N $ha^{-1}$ $d^{-1}$ to 2000 g of $N_2O$-N $ha^{1}$ $d^{-1}$ in the spring fertilized soil. In semiarid region of Kenya, emission rates (4 to 8 g $N_2O$-N $ha^{-1}$ $d^{-1}$) were low, however considering the low C and N contents of the soil and the large area covered by semiarid lands these could be of some importance to global $N_2O$ budgets (Wulf et al., 1999).

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Table 1. Organic C in soils, aboveground biomass and C emitted during agricultural operations.

| | 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.

Table 2. Potential organic C gain by conversion of irrigated lands currently in moldboard plowing systems to conservation tillage, conversion of native sagebrush to irrigated conservation tillage, conversion of native sagebrush to irrigated pasture and conversion of 10% of irrigated lands currently in moldboard plowing systems to irrigated pasture over the next 30 yr.

| Vegetation conversion | C gained from a 10% conversion | Pacific Northwest United States† | | Western United States† | | Worldwide† | |
|---|---|---|---|---|---|---|---|
| | Mg C $ha^{-1}$ | Mg C | $\%C_S/C_{EW}$‡ | Mg C | $\%C_S/C_{EW}$‡ | Mg C | $\%C_S/C_{EW}$‡ |
| Irrigated moldboard plow to irrigated conservation tillage§ | 9.5 | 8.5 x $10^{7}$ | 0.15 | 2.3 x $10^{8}$ | 0.40 | 2.5 x $10^{9}$ | 4.38 |
| Native sagebrush to irrigated conservation tillage | 8.0 | 7.2 x $10^{6}$ | 0.01 | 1.9 x $10^{7}$ | 0.03 | 2.1 x $10^{8}$ | 0.37 |
| Native sagebrush to irrigated pasture | 35.6 | 3.2 x $10^{8}$ | 0.56 | 8.7 x $10^{8}$ | 1.53 | 9.3 x $10^{9}$ | 16.32 |
| 10% of irrigated moldboard plow to irrigated pasture§ | 37.1 | 3.4 x $10^{7}$ | 0.06 | 9.0 x $10^{7}$ | 0.16 | 9.6 x $10^{8}$ | 1.68 |

†Land area in irrigated cropland in Pacific Northwest - 9 055 979 ha, Western United States 24 322 029 ha, worldwide 260 000 000 ha. ‡$\%C_S/C_{EW}$ = C sequestered ($C_S$) divided by the amount of C projected to be emitted worldwide during the next 30 yr, which is 5.7 x $10^{10}$ Mg C ($C_{EW}$) multiplied by 100. §Estimated C gain from 100% conversion of moldboard plow to conservation tillage and 10% conversion of moldboard plow agriculture to irrigated pasture.

Table 3. Potential C transfer by converting an equal amount (10%) of rainfed moldboard plow land back to native forest or grassland on a basis of 1 unit of irrigated rainfed agricultural land to 1 unit of native forest or grassland and conversion of equal amount (10%) of rainfed moldboard plow land back to native forest or grassland on the basis of 1 unit of irrigated rainfed agricultural land to 2 units of native forest or grassland.

† $\%C_S/C_{EW}$ = C sequestered ($C_S$) divided by the amount of C projected to be emitted worldwide during the next 30 yr, which is 5.7 x $10^{10}$ Mg C ($C_{EW}$) multiplied by 100.

| Conversion of vegetation | C stored from conversion | Pacific Northwest United States | | Western United States | | Worldwide | |
|---|---|---|---|---|---|---|---|
| | Mg C ha$^{-1}$ | Mg C | $\%C_S/C_{EW}$† | Mg C | $\%C_S/C_{EW}$† | Mg C | $\%C_S/C_{EW}$† |
| Rainfed moldboard plow to native forest on a 1 unit/1 unit basis | 5.6 | 5.1 x $10^7$ | 0.09 | 1.4 x $10^8$ | 0.24 | 1.5 x $10^9$ | 2.63 |
| Rainfed moldboard plow to native grassland on a 1 unit/1 unit basis | 13.0 | 1.2 x $10^8$ | 0.21 | 3.2 x $10^8$ | 0.56 | 3.4 x $10^9$ | 5.96 |
| Rainfed moldboard plow to native forest on a 2 unit/1 unit basis | 5.6 | 1.1 x $10^8$ | 0.18 | 2.8 x $10^8$ | 0.49 | 3.0 x $10^9$ | 5.26 |
| Rainfed moldboard plow to native grassland on a 2 unit/1 unit basis | 13.0 | 2.4 x $10^8$ | 0.42 | 6.4 x $10^8$ | 1.20 | 6.8 x $10^9$ | 11.93 |