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# EVALUATING ECONOMICS OF GREENHOUSE GAS EMISSION UNDER HIGH AND LOW INPUTS FARMING SYSTEM

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## **ABSTRACT**

A serious concern about the sustainability of existing production systems has resulted from the low profitability of agriculture and the deterioration of the natural resource base. As a result of these concerns, increased attention has been given to alternative farming practices in order to decrease the use of fossil fuels, to enhance the efficiency of nitrogen fertilization, and to increase the implementation of conservation tillage practices. Farmers are recommended to include pulse crop into their rotation since legumes form symbiotic associations with bacteria that can fix atmospheric N<sub>2</sub> reducing the need of nitrogen fertilizer application and the emission of greenhouse gas (GHG) production. The objective of this study was to evaluate the economics of greenhouse gas mitigation for different cropping systems and management practices. Data from a 5-year study of a wheat-pea rotation, under different seeding systems and fertilizer and herbicide rates, was used to examine economic and greenhouse gas performance. Based on IPCC estimations of nitrous oxide (N<sub>2</sub>O) emissions, comparisons were made to measured N<sub>2</sub>O rates to determine if the difference between these figures were significant. Comparison of actual measured N<sub>2</sub>O emissions to estimations based on IPCC indicated that the measure emission rate was significantly lower than estimated values for the site. Results for low-fertilizer rates, under a low-disturbance system, suggests there is greater net carbon fixed as compared to the high-disturbance practices in both wheat and pea. Overall, the decreased use of fertilizer (50% to 75% of recommended rates) under a low-disturbance seeding-system was preferable, based upon environmental-economic indicators.

## **1. INTRODUCTION**

Growing concern about sustainability of current production systems has resulted due to the deterioration of natural resource base and the low profitability of farming. Low profitability of present farming can be attributed primarily to the use of more expensive inputs (chemical, fertilizer) and increasing total costs of production. The sustainability of farming systems depends on its cultural practices that produce economically-viable, socially-acceptable and environmentally-friendly farming systems (Acton and Gregorich 1995; Janzen et al. 1999; Zentner et al. 1996; Zentner and Campbell 1988a; Campbell et al. 1986, 1988, 1991, 1995, 1996). Research shows that when fertilizers are used properly and placed in the soil at, or near, the time of seeding, enhanced crop production and grain quality, without increasing nutrients losses to the air or

groundwater, will be observed (Rennie et al. 1993; Janzen et al. 1999). Other research has shown that including a pulse crop in rotation has positive influence on crop production N fertility (Campbell et al. 1992; Dekson et al. 2001), soil organic C and N (Campbell and Zentner 1993), mineralizable C and N (Biederbeck et al. 1994), energy use efficiency (Zentner et al. 1989), economic return and risk (Zentner et al. 1988b, 2002a) and long term sustainable production systems (Zentner et al. 2001). Producers have shown great interest in reduced-tillage management because of its potential to improve energy use efficiency and its positive contribution to soil conservation and the environment. Cropping systems have also been extended and diversified by adopting more pulse crops in crop rotations, not only to gain economic benefits but to reduce fertilizers in the subsequent crop (Zentner et al. 2002b). The objectives of this study were to evaluate: (i) the effects of reduced fertilizer and pesticides rates under high- and low-disturbance seeding-systems for a wheat and pea rotation; (ii) the economics of such rotation; (iii) the net greenhouse gas emission of fossil fuel inputs used in this production system including the production of biological soil greenhouse gases; (iv) the economic value of net greenhouse gases fixed; and (v) the relative comparison of N<sub>2</sub>O emission based on IPCC estimation with actual N<sub>2</sub>O measurement for this system.

## **2. MATERIALS AND METHODS**

### **2.1 EXPERIMENTAL DATA**

Five years of experimental data were used to accomplish the objectives (1997-2001). Data from the start up year were not included since the rotational effects of treatments had not occurred. The experiments were located in Brandon Research Centre (BRC) (with Clay loam texture) and Lowes farm (with Sandy loam texture) in Brandon, Manitoba, Canada. Soil in both locations is an Orthic Black Chernozemic soil. At each site, the experiments were set up for both wheat and pea in split plot designs with four replications. Wheat (cv. AC Barrie) rotated with pea (cv. Carnival) every year for five years (two cycles of wheat and peas plus start up year). The pea crop was treated uniformly (re: seeding and weed control) to provide rotational information for wheat. All treatments were implemented in low-disturbance (LD) seeding-system (zero tillage) and in high-disturbance (HD) seeding-system (seeded with sweeps followed by packing and harrowing). Wheat was seeded at a rate of 120 kg ha<sup>-1</sup> and pea was seeded at a rate of 198 kg ha<sup>-1</sup> plus granular inoculant at 5 kg ha<sup>-1</sup>. Seeding was performed by zero and minimum air seeder (sweeps 40-41 ft with 300 HP tractor). Both crops and tillage systems were seeded on the same day. Herbicide rates are 100% and 66% of recommended rates for Horizon plus Target at each of the fertilizer rates. Herbicides used consisted of burn-off for both wheat and peas, Round Up (35g/L formulation) at 0.5 L/ac for low-disturbance only and in-crop for wheat (Horizon plus Target) and for pea (Odyssey). Fungicide applied as required at each site. Fertilizer treatments in wheat are 25%, 50%, 75%, and 100% of recommended rates or 25, 50, 75, and 100 kg ha<sup>-1</sup> of actual nitrogen, respectively. Nitrogen (46-0-0) was applied at different rates and phosphorus (11-52-0) at 40 kg ha<sup>-1</sup>. Peas were seeded in both seeding systems but fertilizer and herbicide rates are not varied. Peas were swathed at desired maturity and harvested with a pick-up header. Wheat was harvested at maturity with a straight cut header.

## 2.2 ECONOMIC ANALYSIS

Our economic model is a standard budgeting analysis which provides net economic value of each cropping system under different tillage systems with different fertilizer and herbicide rates. For this purpose, we first developed a database using Econometric View (E-view) software and, then, an appropriate program in E-view syntax command file was written to do the analysis. All the inputs used in each phase of production including pre-plant activities, tillage, fertilization, planting, insects and pests control, harvesting, storage, and transportation were included in the analysis. The number of hours used in each machinery and equipment were recorded and evaluated together with fixed costs (depreciation, insurance, interest), and variable costs (fuel, lubricant, and repair costs). The program was written in such a way that provided a comprehensive analysis of the economic and energy use efficiency, and net GHG emission of inputs used in the production process.

## 2.3 ENERGY USE AND GREENHOUSE GAS EMISSIONS

### 2.3.1 ENERGY INPUT AND OUTPUT

Total energy inputs expended for growing a specific crop including all direct and indirect non-renewable energy going into manufacturing, packaging formulation, transportation, maintenance and application of all purchased inputs used in each production system were included. Direct energy and CO<sub>2</sub> emissions, related to diesel-fuel, lubricants and electricity, are the inputs that can be directly converted into energy and CO<sub>2</sub> units. Indirect energy and CO<sub>2</sub> emissions, related to machinery, fertilizers, and pesticides on the other hand, are the inputs that cannot be converted directly into energy and CO<sub>2</sub> emission units. The physical quantities of inputs used in production were converted to energy and CO<sub>2</sub> values using appropriate coefficients. Energy associated with the human labour input was not included in this analysis. Total energy output was defined as:

$$\text{Gross energy output} = (\text{yield} - \text{seed rate}) * \text{grain energy} \quad (1)$$

Finally, energy use efficiency was calculated as: i) net energy produced (energy output minus energy input), and ii) ratio of energy output to energy input. Environmental impacts of each production system were examined by computing net greenhouse gases content of total inputs used.

### 2.3.2 MODELLING OF THE NET CO<sub>2</sub> EQUIVALENT

The estimation of intake was divided into two parts: CO<sub>2</sub> intake for crop residues that remain in the field and CO<sub>2</sub> intake for the seed (grain) that are removed (C.E.E.M.A. Model, Agriculture and Agri-Food Canada, 1999). The first one was estimated using the following equation:

$$\text{ECC}_i = [\text{Yield}_i * (1 - W_i) * \text{BM}_i] * C * 3.667 \quad (2)$$

where ECC<sub>i</sub> is intake for carbon dioxide by i<sup>th</sup> crop plant in kg (or tonne) of CO<sub>2</sub> per ha; Yield<sub>i</sub> is yield of i<sup>th</sup> crop in kg (or tonne) per ha; W<sub>i</sub> is water content expressed as a proportion of plant biomass. We assumed 14% and 12% moisture content for wheat and

pea, respectively.  $BM_i$  is biomass factor for  $i^{th}$  crop; C is carbon content of dry matter. On a dry matter equivalent, 0.45 gram of carbon per gram of dry matter is used by plants through carbon fixation. The last coefficient (3.667) was the conversion factor from carbon to carbon dioxide. The second part of intake, the one for grain, was also estimated using the same equation, except that the BM for wheat and pea was set equal to one. Total  $CO_2$  intake of wheat or pea plant is obtained by adding the  $CO_2$  intake of residue and grain parts. Finally, the following equation was used to compute total  $CO_{2(equivalent)}$  fixed (or released if negative) for each treatment.

$$\text{Net } CO_{2(equivalent)} = \text{Total plant } CO_2 - \text{Actual (measured) soil } CO_{2(equivalent)} - CO_2 \text{ of input used} \quad (3)$$

The physical quantities of inputs used in production were converted to  $CO_2$  values using appropriate coefficients which are found in Table 1. Most of these coefficients were published by Nagy (2000), while the others were developed through personal communications with Nagy. Once the net  $CO_{2(equivalent)}$  was calculated for each treatment, the following two indicators have been developed to evaluate GHG performance of each treatment: a) Cost/Carbon Indicator (\$/kg) defined as total cost per hectare divided by total carbon fixed per hectare. This ratio provides intuition as to which treatment is economically more efficient. The smaller is the ratio, the more efficient is the system. b) Value of carbon fixed defined as the net carbon fixed times price of carbon per hectare. We assumed \$10 (Cdn) per tonne of carbon.

**Table 1. Greenhouse Gas Coefficients in Wheat-Pea Study**

Machinery and Equipments	kg C (embodied)		kg C (repair)	Embodied +Repair	kg C for fuel used
	fuel use (L/hr)	Per hour	Per hour	Per hour	kg C E /L
Tractor 300 HP 4 WD.	46	0.659	0.322	0.981	0.928
Tractor 130 HP 2 WD	28	0.293	0.143	0.436	0.928
Tractor 85 HP 2 WD	18	0.167	0.082	0.249	0.928
Sprayer 91-105 ft (700-800 GAL)		2.243	1.346	3.588	
Air Seeder, zero till 40-41 ft		2.081	1.249	3.330	
Air Seeder, minimum till 40-41 ft		2.216	1.330	3.546	
Harrow Packers, 50 ft		1.120	0.672	1.793	
Swather PTO, Standard, 36 ft		0.677	0.406	1.083	
Combine SP, medium rotary w/pick up, 250 HP	35	1.775	0.455	2.230	0.928
Combine PU Header 14 foot, 1996		0.192	0.049	0.241	
Combine Flex Header 20 foot, 1996		0.321	0.082	0.403	
Combine Ridged Header 24 foot, 1990		0.320	0.082	0.402	
Grain Auger PTO, 10 IN 50-60 ft		0.541	0.325	0.866	
Grain Auger SP, 7 IN 38-45 ft (w/18 HP)	1.4	0.237	0.142	0.379	0.883
1/2 ton pick up truck (G)	14	2.139	1.176	3.316	0.960
3 ton truck (G)	23	3.579	1.968	5.548	0.811

**Storage**

<u>Grain Storage</u>	Kg C /ha
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Airation Bins (cement floor)	0.411
Hopper Bottom	0.489
Granary wood floor	0.326
Granary cement floor	0.326
<b>Machine Shop and Machine Storage*</b>	<b>kg C /ha</b>
Shop	0.0874
Shed	0.0591

\*Based on 1800 cultivated hectares

<b>Fertilizer and Chemical GHG Emissions Coefficients</b>	
<b>Fertilizer:</b>	<b>kg C E/kg N</b>
Urea (46% N)	1.118
Phosphorus (52% P2O5)	0.155
Nitrogen (11% N)	0.852
<b>Chemical:</b>	<b>kg C E/kg a.i.</b>
ROUNDUP .356G/L GLYPHOSATE	0.356*6.4
TARGET 275 G/L MCPA 62.5 G/L MECOPROP 62.5 G/L	0.4*3
HORIZON 240 G/L CLODINAFOP-PROPARGYL	0.24*3.7
SCORE ADUVANT FOR HORIZON INCLUDED IN ABOVE	0
ODYSSEY 35% IMAZAMOX 35% IMAZETHAPYR	0.7*2.601
MERGE ADJUVANT FOR ODYSSEY INCLUDED IN ABOVE	0
BENLATE FUNGICIDE 50% BENOMYL	0.5*2.5
BRAVO FUNGICIDE 500 G/L CHLOROTHALONILN	0.5*2.5
INNOCULANT FOR PEAS	0.095/22.5*0.25
MCPA NA 300 G/L	0.3*3.6
LORSBAN 480 G/L CHLORPYRIFOS	0.48*2.5

### 2.3.3 NITROUS OXIDE EMISSION

Soil GHG fluxes (CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>) were determined throughout the growing season at each sampling grid in year 2000 and year 2001 using a vented chamber method (Hutchinson and Mosier, 1981). Soil temperature was also recorded and soil moisture was determined. The data were analyzed to calculate the actual nitrous oxide emission per hectare for the growing season for both crops in both locations. Total CO<sub>2</sub> equivalent emissions were calculated by multiplying CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O, by factors of 1, 21 and 310, respectively and then summing them. These are the conversion values according to the global warming potential (GWP) for each molecule. This means that N<sub>2</sub>O is 310 times more effective in its GWP (IPCC, 1996). Actual measurement of N<sub>2</sub>O was compared with estimated N<sub>2</sub>O based on IPCC methodology to examine the differences.

IPCC estimates of nitrous oxide emissions, excluding N leaching, are based upon contributions from fertilizer, crop residues and nitrogen fixing crops, defined as follows:

$$\text{Direct N}_2\text{O (kg N}_2\text{O/yr)} = \text{N}_2\text{O}_{(\text{fertilizers})} + \text{N}_2\text{O}_{(\text{crop residues})} + \text{N}_2\text{O}_{(\text{N-fixing crops})} \quad (4)$$

The fertilizer contribution to nitrous oxide emissions is defined as:

$$N_2O_{\text{fertilizer}} \text{ (kg } N_2O) = NfC * (1 - \text{Frac}_{\text{GASF}}) * EF_{\text{urea}} * 44/28 \quad (5)$$

where NfC is N fertilizer consumption in kg N/yr;  $EF_{\text{urea}}$  is the emission factor for urea, assumed to be 0.3% (Bouwman, 1996); the factor 44/28 is the conversion from  $N_2$  to  $N_2O$ ;  $\text{Frac}_{\text{GASF}}$  is the fraction of total synthetic fertilizer nitrogen that is emitted as  $NO_x + NH_3$  (kg N/kg N) and is assumed to be 0.1 kg  $NH_3-N + NO_x-N$ /kg of synthetic fertilizer nitrogen applied.

Nitrous oxide emissions from crop residues are estimated by assuming that crop production is about twice of the mass of the edible crop. A default factor of 0.015 kg N/kg of dry biomass is used for pea to convert units of kg dry biomass/yr to kg N/yr. This factor is assumed to be 0.03 for pea. The moisture content of the wheat crop is assumed to be close to 14%.

For wheat:

$$N_2O_{\text{crop res}} \text{ (kg } N_2O) = 2 * [(\text{TWCP} * \text{Frac}_{\text{(NCRO)}})] * (1 - \text{Frac}_{\text{(R)}}) * 0.0125 * 44/28 \quad (6)$$

For pea:

$$N_2O_{\text{crop res}} \text{ (kg } N_2O) = 2 * [(\text{TSY}_{\text{(pea)}} * \text{Frac}_{\text{(NCRBF)}})] * (1 - \text{Frac}_{\text{(R)}}) * 0.0125 * 44/28 \quad (7)$$

where TWCP is Total Wheat Crop Production; TSY is Total Seed Yield for pea;  $\text{Frac}_{\text{(NCRO)}}$  is the fraction of N in non-N-fixing wheat crop (kg N/kg of dry biomass) and is equal to 0.015 kg N/kg of dry biomass;  $\text{Frac}_{\text{(NCRBF)}}$  is the fraction of nitrogen in N-fixing pea crop (kg N/kg of dry biomass), and is equal to 0.03 kg N/kg of dry biomass;  $\text{Frac}_{\text{(R)}}$  is the fraction of crop residue that is removed from the field as crop (kg N/kg of dry biomass) and is equal to 0.45 kg N/kg crop-N; an emission factor of 0.0125 (1.25%) (IPCC, 1996b) is used to calculate the  $N_2O$  emissions (kg  $N_2O$  N/kg N).

The  $N_2O$  emissions from N-fixing crop are calculated by multiplying the %N in the specific crop (pea in our study) by an emission factor to give the amount  $N_2O$  emitted.  $N_2O$  emissions from N-fixing crops are calculated by assuming that the total biomass production of pea is about twice of the mass of edible crop. A default factor of 0.03 kg N/kg of dry biomass is used to convert from units of kg dry biomass/yr to kg N/yr in crops. The moisture content of the pea crop is assumed to be close to 12%.

$$N_2O_{\text{N-fixing-pea}} \text{ (kg } N_2O) = 2 * [\text{TP}_{\text{(kg dry biomass)}} * \text{Frac}_{\text{NCRBF}}] * EF_1 * 44/28 \quad (8)$$

where TP is total production;  $\text{Frac}_{\text{NCRBF}}$  is the fraction of nitrogen in N-fixing pea and is equal to 0.03 kg N/kg dry biomass;  $EF_1 = 0.0125$  kg  $N_2O-N$ /kg nitrogen input.

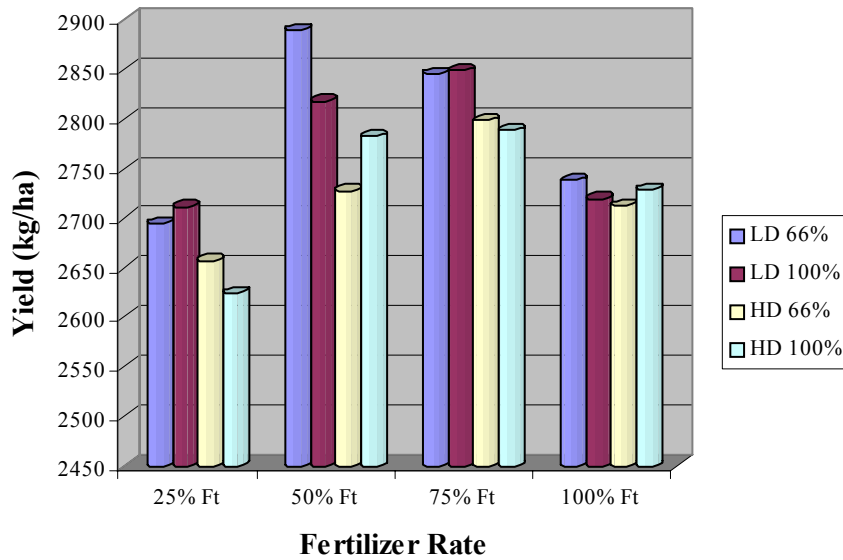
### **3. RESULTS AND DISCUSSION**

#### **3.1 ECONOMIC ANALYSIS: BRANDON SITE (CLAY LOAM)**

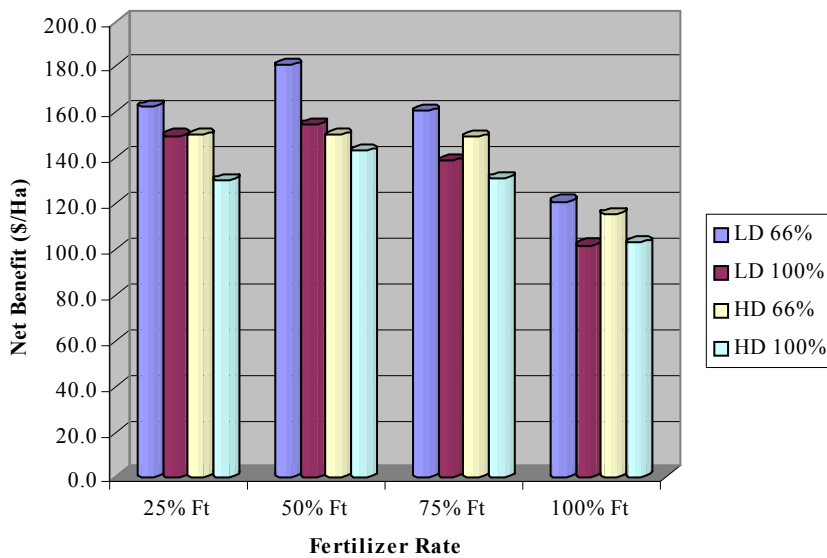
Wheat yield averages from 1998 to 2001 at the Brandon site (clay loam) were greater than the Lowes site (sandy loam). Average four-year yields differed by seeding system and fertilizer rate, but not with a change in recommended herbicide rate (Figure 1).



Results indicated that the recommended rate of fertilizer and herbicide (100%) in terms of yield response and net return was not preferred regardless of which seeding system was practiced. Both wheat yield and net benefit (Figure 2) reveal that, overall, 50% to 75% application of fertilizer with low-disturbance seeding-system is economically preferable treatments.



**Figure 1. Wheat Yield Brandon Site (Clay Loam): Average 1998-2001**



**Figure 2. Wheat Net Benefit Brandon Site (Clay Loam): Average 1998-2001**

The combined wheat/pea yield at the Brandon site was also greater than at the Lowes site. The average 1998-2001 wheat/pea yield and the economic results indicated that the recommended rate of fertilizer and herbicides (100%) is not preferred no matter

what tillage system is applied. In general, a low-disturbance seeding system with 50% to 75% application of recommended fertilizer was economically preferred.

### 3.2 ECONOMIC ANALYSIS: LOWES SITE (SANDY LOAM)

The wheat yield average from 1998 to 2001 at the Lowes site (Sandy loam) differed by tillage system (Figure 3). The low-disturbance system provided higher yield regardless of which fertilizer rate was applied, though the 25% rate provided higher yield relative to other fertilizer treatments. The net benefit results also revealed that 25% fertilizer treatment with low-disturbance seeding-system was economically preferred (Figure 4). The rate of recommended herbicide made no difference in yield response.

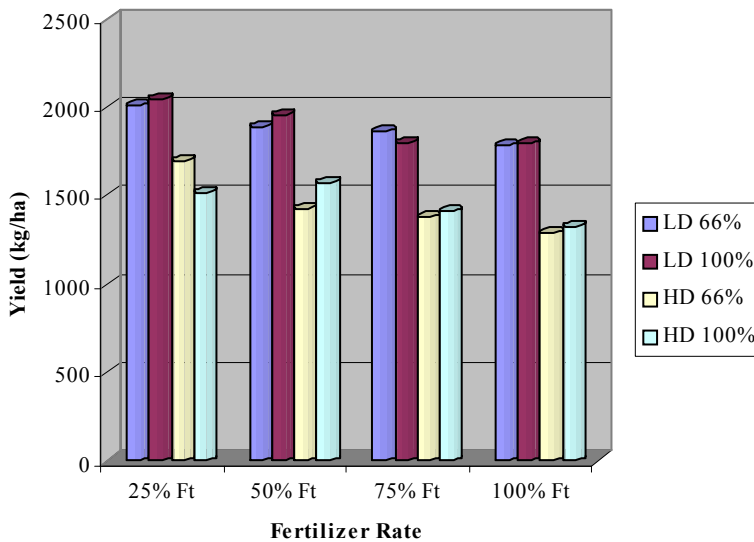


Figure 3. Wheat Yield Lowes Site (Sandy Loam): Average 1998-2001

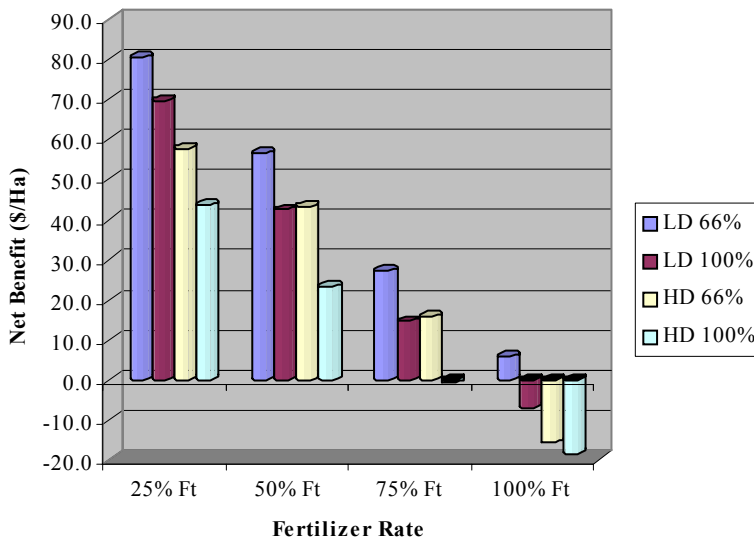


Figure 4. Wheat Net Benefit Lowes Site (Sandy Loam): Average 1998-2001

The combined wheat and pea yield and net benefit data at the Lowes site indicate that full application of recommended fertilizer and herbicide rate (100%) was not the economically preferred choice. Averaged four-year wheat and pea yield data differed by tillage system. Yields were greater for the low-disturbance seeding-system. The net return results revealed that 25% fertilizer rate treatment with low-disturbance system was economically preferred to other treatments and generated higher net return.

### **3.3 DISTRIBUTION OF TOTAL INPUT COSTS**

Distribution of total input costs indicates that machinery (34%) is the highest costs in the production of wheat/pea crops, followed by chemical (28%) and fertilizer costs (12%). This distribution slightly changes from site to site, with Brandon site having slightly higher machinery costs while slightly higher chemical costs were found in Lowes site.

### **3.4 ENERGY INPUTS**

Total energy input increased as the rate of fertilizer increased. The energy unit<sup>-1</sup> requirements of land in both locations increased an average of 61.7% to 64% as fertilizer rates increased from 25% to 100%. As expected, total energy input is lowest for 25% application of recommended fertilizer and highest for 100% application of recommended fertilizer. Results also show that herbicide rates or seeding systems do not play a significant role in variation of total energy requirements in wheat/pea production, though total energy consumption is slightly higher (1.5%) for high disturbance seeding system in Brandon site which was expected. Total energy input with 25% of fertilizer and with 66% of herbicide and under low-disturbance seeding-system was 3,710 MJ/ha. With the same rate of fertilizer but with 100% of herbicide use and high-disturbance seeding-system the total energy inputs increased to 3,795 MJ/ha only, indicating herbicide rates and seeding system are not significant in total energy input requirements in wheat/pea rotation. For Dark Brown soil zone of Alberta, Boerma et al. (1980) reported energy inputs of 3,100 MJ/ha for fallow-wheat and 9,300 MJ/ha for continuous wheat. The overall conclusion is, though the application of fertilizer from 25% to the recommended rate (100%) increases total energy requirements by about 63%, the increase in fertilizer to the full recommended rate won't generate an economically optimal option. In fact, the results indicate that the recommended rate of fertilizer can not be advised and application of 50% to 75% of recommended fertilizer is economically preferred.

As expected, the majority of the energy inputs used consisted of fuel and fertilizer as they are the two main carbon emitters among all the inputs consumed. Fertilizers accounted for 50% and liquid fuels used in the field operations and for product transport accounted for 35% of the total energy input of the rotation. Since the main CO<sub>2</sub> emitter is fuel and fertilizer, the CO<sub>2</sub> emission increases as fertilizer consumption increases. For example, at the clay loam site, CO<sub>2</sub> emission of fertilizer used increased from about 100 kg per hectare for 25% fertilizer use to about 360 kg per hectare for 100% fertilizer application. Finally, the proportion of fuel and fertilizer energy inputs change slightly as we move from one seeding system to another.

### **3.5 ENERGY OUTPUT AND EFFICIENCY**

Total gross energy output was higher in low-disturbance seeding-system (48,833 MJ/ha average of both sites) compare to high-disturbance seeding-system (45,874 MJ/ha average of both sites) irregardless of which fertilizer rates were used in both locations. Net energy production displays similar patterns as compared to gross energy output. Gross energy output in the low-disturbance seeding-system for fertilizer rates of 50% to 75% (49,214 MJ/ha average of both sites) is higher than the same category with 25% and 100% fertilizer rates (45,646 MJ/ha average of both sites). The same conclusion can be drawn from the net energy production except 25% fertilizer rate illustrates somewhat similar patterns. Energy output/input ratios were highest for 25% fertilizer rate and lowest for 100% fertilizer rate and were higher for the low-disturbance seeding-system (12.23) than the high-disturbance seeding-system (11.49) regardless of what fertilizer rates were used.

### **3.6 GREENHOUSE GAS EMISSION ANALYSIS**

Using IPCC methodology, the estimated nitrous oxide emissions were contrasted with the actual measurement of soil N<sub>2</sub>O emission. Comparison of N<sub>2</sub>O emission based on IPCC method with actual measurement of N<sub>2</sub>O emission indicated that IPCC estimates were significantly higher than the actual figures for both wheat and pea crops. From Table 2, IPCC estimate of N<sub>2</sub>O emission for wheat crop in Brandon site under low-disturbance seeding system, when N leaching was excluded, was 0.958 kg/ha at 25% of fertilizer application and 1.330 kg/ha with 100% of fertilizer application while the actual N<sub>2</sub>O emission was 0.052 kg/ha and 0.100 kg/ha, respectively. These figures for the same wheat crop and the same site but under high-disturbance seeding system was 0.960 kg/ha and 1.320 kg/ha for 25% and 100% of IPCC estimation and 0.103 kg/ha and 0.180 kg/ha for actual N<sub>2</sub>O emission, respectively. Figures in Lowes site generally displayed similar pattern. The IPCC estimates of N<sub>2</sub>O emission for pea include emissions from N fixing crop (ie: pea) which have caused the total soil nitrous oxide to become overwhelmingly higher than the actual N<sub>2</sub>O. For example, IPCC estimate of N<sub>2</sub>O emission for pea crop in Lowes site under low-disturbance seeding system when N leaching was excluded was 5.340 kg/ha at 25% of fertilizer application on previous crop and 5.320 kg/ha with 100% of fertilizer application on previous crop while the actual N<sub>2</sub>O was 0.407 kg/ha and 0.678 kg/ha, respectively. These figures for the same pea crop and the same site but under high-disturbance seeding system was 5 kg/ha and 5.130 kg/ha for 25% and 100% of IPCC estimation and 0.550 kg/ha and 0.753 kg/ha for actual N<sub>2</sub>O emission, respectively. Figures in Brandon site generally displayed similar pattern.

**Table 2. Comparison of IPCC Estimated Nitrous Oxide Emission to Measured Values, Average of 2000&2001 (Excluding N Leaching)**

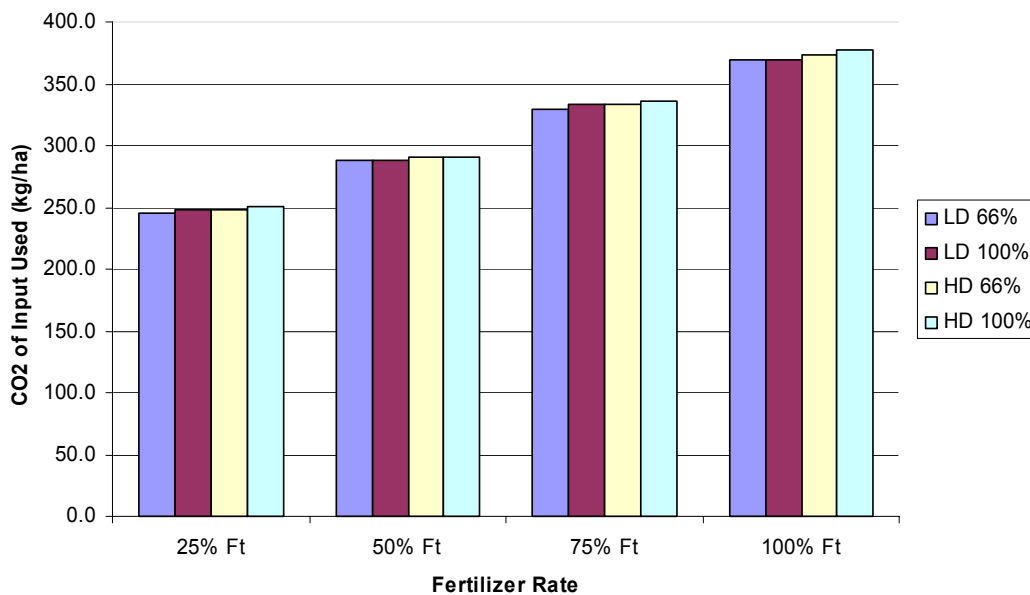
Site	Crop	Fertilizer Rate	LD 66% kg/ha	LD 100% kg/ha	HD 66% kg/ha	HD 100% kg/ha
BRC	Wheat	25%	0.952	0.964	0.961	0.957
		50%	1.156	1.127	1.108	1.123
		75%	1.254	1.238	1.243	1.237
		100%	1.352	1.291	1.316	1.325
		Measured 25%	0.036 <sup>§</sup>	0.068	0.106 <sup>§</sup>	0.099
	Measured 100%	0.142 <sup>§</sup>	0.058	0.202 <sup>§</sup>	0.155	
	Pea	25%	5.755	5.959	6.008	6.079
		50%	5.731	5.688	5.708	5.811
		75%	5.784	6.221	6.064	6.242
		100%	5.97	5.836	6.167	6.444
Measured 25%		0.091 <sup>§</sup>	0.057	0.014 <sup>§</sup>	0.073	
Measured 100%	0.091 <sup>§</sup>	0.065	0.112 <sup>§</sup>	0.105		
LOWES	Wheat	25%	0.654	0.652	0.493	0.406
		50%	0.728	0.74	0.463	0.534
		75%	0.825	0.787	0.577	0.604
		100%	0.946	0.943	0.686	0.688
		Measured 25%	0.941 <sup>§</sup>	0.55	0.917 <sup>§</sup>	0.533
	Measured 100%	0.516 <sup>§</sup>	0.784	2.008 <sup>§</sup>	0.992	
	Pea	25%	5.088	5.594	5.223	4.768
		50%	5.397	5.244	5.589	5.253
		75%	5.459	5.408	5.104	5.149
		100%	5.348	5.289	4.994	5.269
Measured 25%		0.440 <sup>§</sup>	0.374	0.676 <sup>§</sup>	0.414	
Measured 100%	0.911 <sup>§</sup>	0.444	0.587 <sup>§</sup>	0.918		

<sup>§</sup> These values in this column represent year 2001 only.

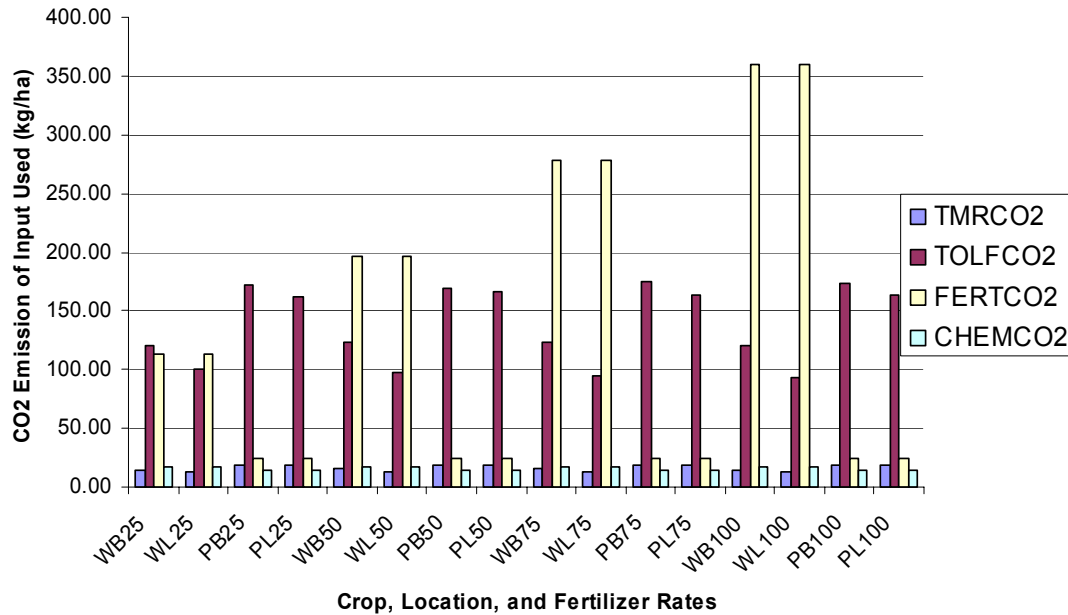
We measured net value of carbon fixed defined earlier as net carbon fixed per hectare multiplied by price of carbon, assuming \$10 per tonne of carbon. We measured this only for 25% and 100% recommended fertilizer rate because the protocol for this project was defined in such that measurement of greenhouse gases (ie: N<sub>2</sub>O, CO<sub>2</sub>, CH<sub>4</sub>) were conducted only for 25% and 100% of recommended rates of fertilizer due to the high cost of measurement. Therefore, because of this limitation we were not able to provide net carbon value for 50% and 75% of recommended fertilizer rates which were economically preferred rates. Generally, net carbon fixed and therefore net carbon value index was higher under low-disturbance seeding system compare to high-disturbance seeding system except for pea in Brandon site. For example, net carbon fixed (released, equation 3) per hectare ranged from a negative value of 1,086 kg/ha (or

about \$10 net carbon value (cost)) for wheat under high-disturbance system with 100% fertilizer rate in Lowes site to a positive value of about 3,967 kg/ha (or about \$40 net carbon value) for pea under high-disturbance system with 100% fertilizer rate on previous crop in Brandon site. The ratio of total cost to total carbon fixed per hectare displayed similar pattern. This ratio, for example, was about 0.12 for wheat under low-disturbance seeding system with 25% fertilizer use in Brandon site and about 0.17 for the same crop but under high-disturbance seeding system and with 100% fertilizer application.

Differences in CO<sub>2</sub> input use between cropping systems and herbicide rates under similar fertilizer rates were insignificant in both sites (Figure 5 shows the relation for the BRC site). As shown in Figure 6 (W = wheat, P = pea, B = BRC, L = Lowes, TMR = total machinery and repair emission, TOLF = Total oil and fuel consumption, FERT = fertilizer application, CHEM = chemical application), total oil and fuel consumption and fertilizer application contributed the most to CO<sub>2</sub> emissions in wheat, as compared to emissions related to chemical application and total machinery and repair. For pea, the largest contributor to CO<sub>2</sub> emissions was total oil and fuel consumption, as fertilizer was not applied.



**Figure 5. GHG Emission of Input Used: W-P Study at BRC**



**Figure 6. Distribution of CO<sub>2</sub> Emission of Input Used**

#### **4. CONCLUSION**

We examined the economic, energy and GHG performance of a wheat and pea rotation with variable rates of fertilizer and herbicide in high- and low-disturbance seeding-systems. The results indicated that the recommended rate of fertilizer and herbicide (100%) in terms of yield response, net return, and GHG mitigation was not economically superior no matter what tillage system was practiced. The increase application of fertilizer from 25% to the recommended rate of 100% increased total energy requirements by about 63%, but this increase did not lead to economically optimal scenario. This increase in fertilizer caused increase in total CO<sub>2</sub> emission. Environmental-economic indicators revealed that, overall, decreased use of fertilizer (50% to 75% of recommended rates) with the low-disturbance seeding-system was preferable. This range may slightly differ from site to site but lower than recommended fertilizer rates provided higher yields, net returns, and gas mitigation. These findings strongly encourage us to revisit the recommended rates of fertilizer and herbicides and determine more accurately estimated fertilizer requirements. Finally, comparison of IPCC estimation of agricultural soil emission with actual measurement indicated that N<sub>2</sub>O emission computed from IPCC was significantly higher than actual soil N<sub>2</sub>O emission measured in the sites.

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