THE ECONOMICS, ENERGY USE EFFICIENCY, AND GREENHOUSE GAS EMISSIONS OF HIGH AND LOW INPUTS USED IN AGRICULTURE: A WHEAT-PEA ROTATION STUDY

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ABSTRACT

In recent years, alternative farming practices have received considerable attention to reduce use of fossil fuels, enhance efficiency of nitrogen fertilizer, improve pest managements, and adopt conservation tillage practices. The objective of this study was to determine energy efficient cropping systems and management methods, which provide economic benefits, lower fossil fuel consumption, and reduce emissions of greenhouse gases. Data collected during a 5-year study were used to examine the economic, energy and GHG performance of a wheat and pea rotation with variable rates of fertilizer and herbicide in a high- and low-disturbance seeding-system. We also compared actual measurement of N_2O with the estimates of soil nitrous oxide emission based on IPCC approach to examine if the differences between these two figures are significant. Results suggest that lower application of fertilizer under the low-disturbance seeding-system provides better yields, net benefits, and net carbon fixed than the high-disturbance system for both crops. Environmental-economic indicators revealed that, overall, lesser use of fertilizer (50% to 75% of recommended rates) with the low-disturbance seeding-system was preferable. Results also indicated that N_2O emission computed from IPCC was significantly higher than actual soil N_2O emission measured in the sites.

1. INTRODUCTION

The deterioration of natural resource base and low profitability of farming have caused growing concern about sustainability of current production systems. Low profitability of present farming can be attributed primarily to the use of more expensive inputs (chemical, fertilizer) and increasing total costs of production, negative impacts on the natural resource base and the environment. It is well documented that the sustainability of farming systems depends on its cultural practices that produces 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 shown that when fertilizers used properly and placed in the soil at or near the time of seeding it will enhance crop production and grain quality without increasing nutrients losses to the air or groundwater (Rennie et al. 1993; Janzen et al. 1999). Other research has shown that including 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 riskiness (Zentner et al. 1988b, 2002a) and long term sustainable production system (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. They have also extended and diversified their cropping systems by adopting more pulse crops in their crop rotations not only to gain economic benefits but also to reduce fertilizers in subsequent crop (Zentner et al. 2002b). In the present study, our main objectives 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_2O emission based on IPCC estimation with actual N_2O measurement for this system.

2. MATERIALS AND METHODS

2.1 EXPERIMENTAL DATA

Five years 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 (with Clay loam texture) and Lowes farm (with Sandy loam texture) in Brandon Manitoba, Canada. Soil in both locations is a 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. CD Barry) 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 seeding-system (LD ie: zero tillage) and in high-disturbance seeding-system (HD ie: seeded with sweeps followed by packing and harrowing). Wheat was seeded at a rate of 120 kg ha^{-1} and pea was seeded at a rate of 198 kg ha^{-1} plus granular inoculant at 5 kg ha^{-1}. 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^{-1} of actual nitrogen, respectively. Nitrogen (46-0-0) was applied at different rates and phosphorus (11-52-0) at 40 kg ha^{-1}. Peas were seeded in both seeding systems but fertilizer and herbicide rates are not varied. Peas were swathed at desired maturity and harvested with 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 syntex 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_2 emission is the inputs that can be directly converted into energy and CO_2 units, i.e., diesel-fuel, lubricants and electricity. Indirect energy and CO_2 emission, on the other hand, is the inputs that cannot be converted directly into energy and CO_2 emission units, i.e., machinery, fertilizers, pesticides. The physical quantities of inputs used in production were converted to energy and CO_2 values using appropriate coefficients. Energy associated with the human labor input was not included in this analysis. Total energy output was defined as:

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

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_2 EQUIVALENT

The estimation of intake was divided into two parts: CO_2 intake for crop residues that remain in the field, and CO_2 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:

$$ECC_i = [Yield_i * (1-W_i) * BM_i] * C * 3.667 \qquad (2)$$

Where, ECC_i is intake for carbon dioxide by i^{th} crop plants, in kg (or tonne) of CO_2 per ha; $Yield_i$ is yield of i^{th} crop in kg (or tonne) per ha; W_i is water contents, 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, 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.

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

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.

2.3.3 NITROUS OXIDE EMISSION

Soil GHG,s fluxes (CO_2, N_2O and CH_4) 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_2 equivalent emissions were calculated by multiplying CO_2, CH_4 and N_2O, 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_2O is 310 times more effective in its GWP (IPCC, 1996). Actual measurement of N_2O was compared with estimated N_2O based on IPCC methodology to examine the differences.

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 years 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 no matter what seeding system was practiced. Both wheat yield and net benefit (Figure 2) reveal that, in overall, 50% to 75% application of fertilizer with low-disturbance seeding-system is economically preferable treatments.

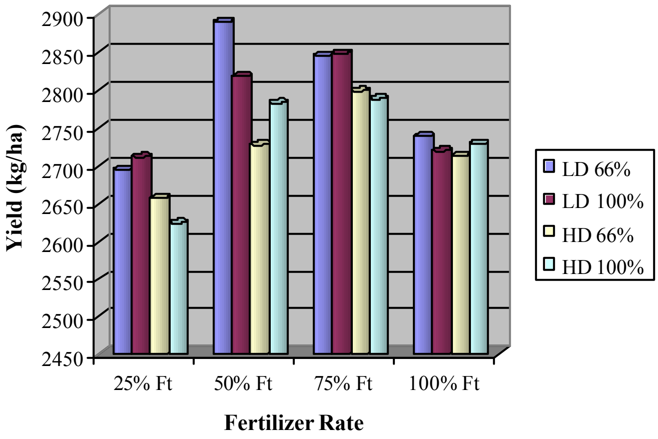

Figure 1. Wheat Yield Brandon Site (Clay Loam): Average 1998-2001

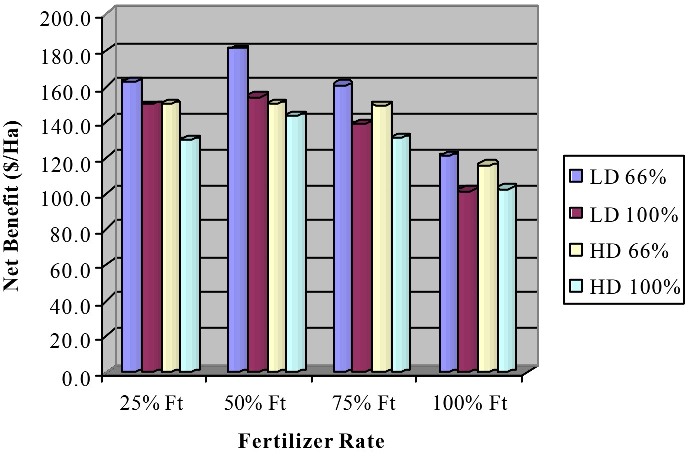

Figure 2. Wheat Net Benefit Brandon Site (Clay Loam): Average 1998-2001

The combined wheat and pea yield at the Brandon site were also greater than 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, 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 no matter what fertilizer rate was applied, though 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.

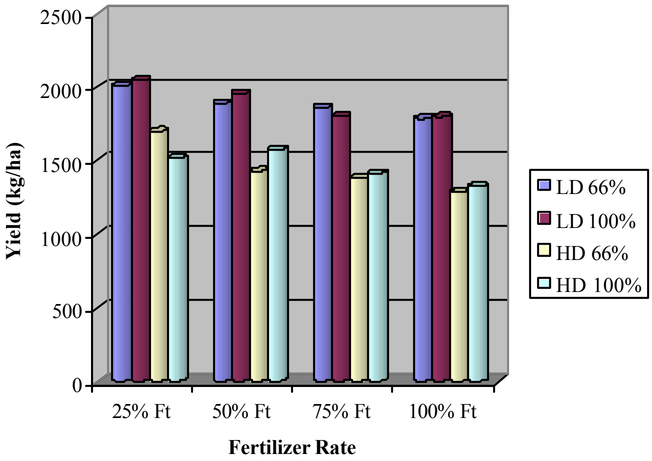

Figure 3. Wheat Yield Lowes Site (Sandy Loam): Average 1998-2001

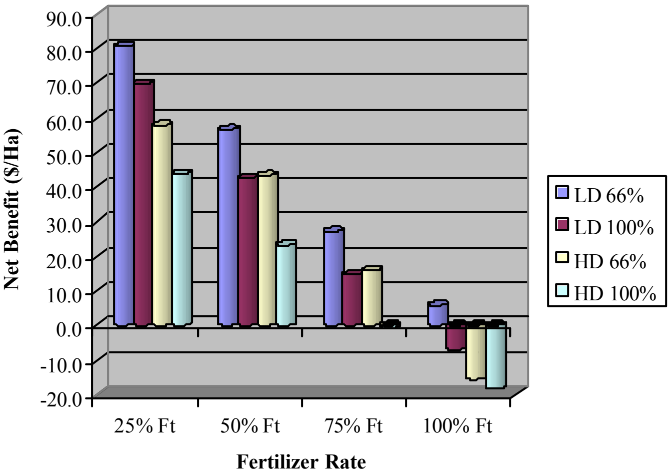

Figure 4. Wheat Net Benefit Lowes Site (Sandy Loam): Average 1998-2001

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 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 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 and slightly higher chemical costs in Lowes site.

3.4 ENERGY INPUTS

Total energy input increased as the rate of fertilizer increased. The energy unit^{-1} 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 (1.5%) higher for high disturbance seeding system in Brandon site (as expected). Total energy input with 25% of fertilizers and with 66% of herbicides and under low-disturbance seeding-system was 3710 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 3795 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 3100 MJ/ha for fallow-wheat and 9300 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_2 emitter is fuel and fertilizer, the CO_2 emission increases as fertilizer consumption increases. For example, at clay loam site, CO_2 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 (48833 MJ/ha average of both sites) compare to high-disturbance seeding-system (45874 MJ/ha average of both sites) no matter what fertilizer rates were used in both locations. Net energy production displays similar patterns as for gross energy output. Gross energy output in the low-disturbance seeding-system for fertilizer rates of 50% to 75% (49214 MJ/ha average of both sites) is higher than the same category with 25% and 100% fertilizer rates (45646 MJ/ha average of both sites). The same conclusion can be drawn from the net energy production except 25% fertilizer rate illustrates somehow 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_2O emission. Comparison of N_2O emission based on IPCC method with actual measurement of N_2O emission indicated that IPCC estimates were significantly higher than the actual figures for both wheat and pea crops. For example, IPCC estimate of N_2O 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_2O 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_2O emission, respectively. Figures in Lowes site generally displayed similar pattern. The IPCC estimates of N_2O emission for pea include emissions from N fixing crop (ie: pea) which have caused the total soil nitrous oxide become overwhelmingly higher than the actual N_2O. For example, IPCC estimate of N_2O 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_2O 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_2O emission, respectively. Figures in Brandon site generally displayed similar pattern.

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_2O, CO_2, CH_4) 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 1086 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 3967 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.

4. CONCLUSION

We examined the economic, energy and GHG performance of a wheat and pea rotation with variable rates of fertilizer and herbicide in a high- and low-disturbance seeding-system. 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_2 emission. Environmental-economic indicators revealed that, overall, lesser 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 rate 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 accurate estimate of fertilizer requirements. Finally, comparison of IPCC estimation of agricultural soil emission with actual measurement indicated that N_2O emission computed from IPCC was significantly higher than actual soil N_2O emission measured in the sites.

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