**Cost efficient Tillage and Rotation options for Mitigating GHG Emissions from Agriculture in Eastern Canada**

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*Abstract*

*The economic efficiency of cropping options to mitigate GHG emissions with agriculture in Eastern Canada was analyzed. Data on yield response to tillage (moldboard plow and chisel plow) and six corn based rotations were obtained from a 20-year field experiment in Ontario. Budgets were constructed for each cropping system while GHG emissions were measured for soil carbon and were estimated for nitrous oxide according to IPCC methodology. Complex crop rotations with legumes, such as corn-corn-soybeans-wheat with red clover underseeded, have higher net returns and substantially (more than 1 Mg ha$^{-1}$ year$^{-1}$) lower GHG emissions than continuous corn. Reduced tillage reduces GHG emissions due to lower input use but no sequestration effect could be found in the soil from tillage. Rotation had a much bigger effect on the mitigation potential of GHG emissions than tillage. However, opportunity costs of more than \$200 per Mg $CO_2$ eq ha$^{-1}$ year$^{-1}$ indicate the limits to increase the mitigation potential beyond the level of the economic best cropping system.*

## 1. Introduction

The integration of legumes into cropping systems can reduce the reliance of cropping systems on non-renewable resources and therefore potentially reduce the use of such inputs along with GHG-emissions. Increasing energy prices may increase the competitiveness of legumes compared to other crops, which rely more on nitrogen fertilizer and energy inputs. However, the integration of legumes has complex effects on cropping systems in terms of carbon sequestration in the soil (Yang and Kay, 2001), yield of following crops (Raimbault and Vyn, 1991), and fluxes of C and N in the soil (Drinkwater et al., 1998). The aim of this paper is to analyze the profitability and GHG mitigation potential of integrating legumes into corn-based rotations for conditions in Eastern Canada. The legumes considered are soybeans, alfalfa and red clover underseeded into wheat or barley.

## 2. Material and Methods

The data for this study were taken from an experiment established in 1980 at the University of Guelph. Average annual rainfall for the region is 800mm with rainfall distribution approximately uniform over the year. Average monthly temperatures for January, April and July are –4.7, 8.3 and 22.2C, respectively.

The experiment provides data on crop and soil response to two levels of tillage and seven different corn-based crop rotations. An eighth rotation consisted of continuous alfalfa. Aside from continuous corn, the other corn-based rotations consisted of two years of corn, followed by either soybeans, alfalfa, barley or soybeans with winter wheat. The rotations involving barley or wheat were implemented with and without red clover underseeded into the cereal. Each rotation plot of the field experiment was split into two levels of tillage alternatively with a moldboard plow or a chisel plow. Plots were uniformly maintained such that fertility, weeds, insects etc. were not limiting. N-fertilization was oriented at the general recommendations for fertilizer applications for Ontario (OMAF, 2002) without considering rotation specific fertilizer saving potentials (N-credits). The experiment was designed in a split plot design with four replications for each tillage-rotation combination.

*2.1 Net GHG emissions of the cropping systems*

The carbon sequestration potential of the tillage-rotation combinations was based on measurement of organic matter content in the soil of each experimental plots in 1999 and 2000. Five soil cores were taken prior to tillage operations in the fall from each plot at depths of 0-5, 5-10, 10-20, 20-40, and 40-60 cm. The composite depth samples for each plot were analyzed for bulk density and organic carbon. Soil carbon storage on an equivalent soil mass basis was calculated as per Yang and Wander (1999). Organic carbon was calculated as the difference between total carbon content and inorganic carbon determined by a Leco SC-444 method. Carbon sequestration rates of all management options were compared to the continuous corn rotation with conventional tillage, since this was the management prior to the experiment on the field and a common practice at that time. The difference was divided by the number of years of the experiment to arrive at annual sequestration rates of carbon.

The $N_2O$ emissions from crop production were calculated based on biological nitrogen fixation, crop residues, synthetic fertilizer inputs and indirect emissions, according to IPCC methodology (IPCC, 1997) with some adjustments as proposed for the GHG inventory in Canada (Matin et al., 2004). The GHG-relevant emission coefficients due to fuel consumption, machinery repair, and the manufacturing of fertilizer were taken from the assumptions of Canada's Greenhouse Gas Inventory (Matin et al., 2004) and Kulshreshtha and MacDonald (2000). GHG emissions from pesticide manufacturing and from seed production were ignored as were other on-farm energy uses and induced energy use which are marginally affected by the choice of cropping system.

## *2.2. Profitability analysis*

Net returns for each cropping system were obtained by subtracting the costs of production from gross revenue, which was obtained by multiplying observed yields by the 1999 to 2003 average crop prices. Prices were \$130 $Mg^{-1}$ for corn, \$277 $Mg^{-1}$ for soybeans, \$127 $Mg^{-1}$ for soft white wheat, \$119 $Mg^{-1}$ for barley and \$85 $Mg^{-1}$ for alfalfa hay (OMAFRA, 2005a). Costs of production were based on the 2005 Field Crop Budgets for Ontario (OMAFRA, 2005b) with some adjustments for the cover crop and additional pesticide applications which were necessary in some of the rotations (Table 1). Assumed annual fertilizer N rates were 160 kg N $ha^{-1}$ for corn, 8 kg N $ha^{-1}$ for soybeans, 110 kg N $ha^{-1}$ for winter wheat, 60 kg N $ha^{-1}$ for barley, and 10 kg N $ha^{-1}$ for alfalfa in the first year. The fertilizer rates to corn after a crop other than corn were adjusted according to N-credits as suggested by Janovicek and Stewart (2004). Fuel expenses for the different tillage systems were estimated according to the work rates of the implements and the fuel consumption of the tractor. Chisel plowing was assumed to need 6 l $ha^{-1}$ less fuel for the tillage operation than moldboard plow, with a fuel price of \$0.69 $l^{-1}$. Drying charges were assumed to be \$16 $Mg^{-1}$ for corn and \$8 $Mg^{-1}$ for soybeans. Further yield dependent costs such as storage, trucking and marketing fees were calculated according to values from the Crop Budgets (OMAFRA, 2005b). The estimated costs were subtracted from the calculated revenue to obtain net returns to land, labour and management for an individual crop in a given tillage system. The net returns for each crop were averaged over each four-year rotation period in order to obtain the yearly net revenue associated with each rotation-tillage combination.

## 3 Results

### *3.1 Net GHG emissions*

The calculated $N_2O$-emissions expressed in $CO_2$ equivalents of the crops planted in the experiment are presented in Figure 1. The estimated emission values are highest for corn, when planted after a red clover cover crop. Even though the red-clover cover crop lowers the fertilization requirement of the following corn crop and thus reduces the emissions from fertilization by more than 200 kg $CO_2$ eq. $ha^{-1}$, these gains are more than offset by the emissions from N-fixation of the legumes and crop residues of the cover crop. The lowest $N_2O$ emissions are from barley because the fertilizer input is moderate and no N-fixation contributes to high N-inputs into the system. For wheat, soybeans and alfalfa, the estimated $N_2O$ emissions are approximately the same even though the source of emissions differs between the legumes and wheat.

GHG-emissions from on-farm fuel use and induced emissions due to the manufacturing of fertilizers and the machinery for the considered crops are illustrated in Figure 2. For corn these emissions on average over all treatments sum up to 1200 kg $CO_2$ eq $ha^{-1}$ because of high energy requirements of fertilizer processing and high emissions due to crop drying. The lower fertilizer requirement of corn, when planted after red clover results in about 250 kg $CO_2$ eq $ha^{-1}$ lower emissions from this cropping option, which more than offsets the higher $N_2O$ emissions due to the legume cover crop (Figure 1). However, this very much depends on the N-fixation of the legume, which can substantially vary. The emissions from fuel use vary between the crops from 250 kg to 550 kg $CO_2$ eq $ha^{-1}$. The highest emissions from fuel use were in the alfalfa systems due to high-energy requirements during multiple harvests. Substitution of the moldboard plow with the chisel plow results in an additional 30 kg $ha^{-1}$ $CO_2$ eq for all crops.

While rotation had a significant impact on carbon sequestration at the 10% level of significance, no significant effect was found for tillage. Compared to continuous corn, the continuous alfalfa rotation had the highest sequestration rates of 513 kg C $yr^{-1}$. To a lesser extent, the integration of cereals and red clover underseeded into the cereals had some sequestration effect. The inclusion of soybeans into the rotation did not affect sequestration rates significantly.

The average annual GHG-emissions over the rotations of the analyzed cropping systems are compiled in Table 2. $N_2O$ emissions (1433 kg $CO_2$ eq $ha^{-1}$) are lowest for the corn-corn-barley-barley rotation with the chisel plow and highest for continuous corn under conventional tillage (2082 kg $CO_2$ eq $ha^{-1}$). Emissions from direct and indirect energy use vary from 509 kg $CO_2$ eq $ha^{-1}$ for continuous alfalfa to 1278 kg $CO_2$ eq $ha^{-1}$ for continuous corn. Sequestration only partially offset total GHG emissions from $N_2O$ and energy sources in contrast to agriculture in the Great Plains region of North America where sequestration potential is greater and other emission levels lower. In eastern Canada, GHG emissions can be reduced by more than one Mg $CO_2$ eq $ha^{-1}$ GHG compared to a continuous corn rotation through crop selection.

*3.2. Net return of cropping systems*

Net returns were affected by tillage and rotation as well as by interaction effects between tillage and rotation. Rotations containing wheat had the highest annual net returns. Compared to continuous corn, corn-based rotations with wheat were \$53 $ha^{-1}$ and \$82 $ha^{-1}$ more profitable under a moldboard system and \$110 $ha^{-1}$ and \$114 $ha^{-1}$ with a chisel plow tillage system (see Table 3). Including soybeans in the rotation increased profitability of the corn-based cropping systems in both tillage systems but the response was greater in the chisel system. Overall, net returns for rotations that included barley did not differ from continuous corn. Tillage differences for all rotations other that continuous corn were relatively small and did not differ by more than \$18 $ha^{-1}$.

### *3.3. Trade-offs between GHG emissions and farm returns*

Net GHG emissions and farm returns are illustrated together for all cropping systems in Figure 3. The highest net return is realized with a corn-corn-soybean-wheat rotation that is underseeded with red clover. Under conventional tillage, the net GHG emissions are 2428 kg $CO_2$ eq $ha^{-1}$, where 2597 kg $CO_2$ $ha^{-1}$ stem from the production process of which 169 kg $CO_2$ eq $ha^{-1}$ is sequestered in the soil. Compared to continuous corn with this management option more than one Mg $CO_2$ eq $ha^{-1}$ $year^{-1}$ of GHG emissions are mitigated and returns are approximately \$100 $ha^{-1}$ greater. The same corn-soy-wheat rotation without the cover crop is slightly less profitable and emits higher net GHG levels and is thus considered inefficient. GHG levels can be reduced by replacing wheat and soybeans with either alfalfa or barley. The steepness of the trade-off curve indicates that such mitigation will be costly as average abatement costs are \$200 to \$1000 per Mg of abated $CO_2$ eq GHGs.

## 4 Conclusions

The integration of legumes into corn based cropping systems provides multiple benefits, including higher yields, cost savings and the mitigation of GHGs. Diversifying a corn rotation with soybeans and wheat underseeded with red clover results in \$100 $ha^{-1}$ higher net returns and a mitigation of more than a ton of $CO_2$ eq GHG compared to continuous corn. Even though legumes contribute considerably to the emissions of GHG by fixing nitrogen in the soil, these emissions are offset by reduced emissions from less fertilizer use and the reduced induced emissions from manufacturing the fertilizer. However, a further mitigation of GHGs requires significant opportunity costs to the farmer.

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Table 1. Cost structure of corn, soybeans, wheat, barley and alfalfa production in the different tillage systems

| | Production costs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Corn | | Soybeans | | Wheat | | Barley | | Alfalfa | |
| Input | Moldboard | Chisel | Moldboard | Chisel | Moldboard | Chisel | Moldboard | Chisel | Moldboard | Chisel |
| | $\$$ ha$^{-1}$ | | | | | | | | | |
| Seed | 150 | | 93 | | 91 | | 80 | | 68 | |
| Fertilizer | 210 | | 66 | | 207 | | 135 | | 99 | |
| Herbicides | 86 | | 79 | | 15 | | 76 | | 24 | |
| Custom Work for fertilizer and pesticides | 44 | | 44 | | 44 | | 44 | | 66 | |
| Energy related yield variable costs [a] | 187 | | 39 | | 28 | | 22 | | - | |
| Fuel and lubricants | 31 | 27 | 20 | 16 | 26 | 21 | 26 | 21 | 56 | 54 |
| Variable machine costs and overhead expenses [b] | 264 | 262 | 210 | 208 | 249 | 248 | 236 | 235 | 279 | 278 |
| Sum | 972 | 966 | 551 | 545 | 660 | 654 | 619 | 613 | 593 | 589 |

[a] Drying and trucking costs assuming average yield for each crop (corn: 8.5 t ha$^{-1}$, soybeans: 2.7 t ha$^{-1}$, wheat: 5.1 t ha$^{-1}$, barley: 3.7 t ha$^{-1}$, alfalfa: 7 t ha$^{-1}$)

[b] Including costs on interest on operating capital, rent, marketing fees, storage and labour costs

Table 2. Average annual emissions from different crop rotations in $CO_2$ eq $ha^{-1}$ $year^{-1}$

| | CCCC | | CCBB | | CCBrcBrc | | CCSS | | CCSW | | CCSWrc | | CCAA | | AAAA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MP | CP | MP | CP | MP | CP | MP | CP | MP | CP | MP | CP | MP | CP | MP |
| $N_2O$ emissions from the soil | | | | | | | | | | | | | | | |
| Crop Residues | 718 | 677 | 517 | 508 | 618 | 608 | 564 | 553 | 573 | 576 | 681 | 673 | 368 | 367 | 0 |
| Fertilizer | 1364 | 1364 | 916 | 916 | 767 | 767 | 610 | 610 | 912 | 912 | 763 | 763 | 469 | 469 | 21 |
| N-Fixation | 0 | 0 | 0 | 0 | 91 | 91 | 441 | 437 | 232 | 241 | 333 | 340 | 647 | 634 | 1358 |
| Sum | 2082 | 2041 | 1433 | 1424 | 1476 | 1466 | 1615 | 1600 | 1717 | 1729 | 1777 | 1776 | 1484 | 1470 | 1379 |
| Emissions from direct and indirect energy use | | | | | | | | | | | | | | | |
| Crop Drying | 361 | 341 | 180 | 180 | 182 | 182 | 206 | 201 | 192 | 191 | 199 | 193 | 185 | 185 | 0 |
| Fuel use | 131 | 114 | 121 | 104 | 121 | 104 | 111 | 94 | 116 | 99 | 116 | 99 | 183 | 171 | 199 |
| Fuel manufacturing | 175 | 153 | 162 | 140 | 162 | 140 | 148 | 126 | 155 | 133 | 155 | 133 | 246 | 229 | 266 |
| Machine Manufacturing | 18 | 18 | 20 | 20 | 20 | 20 | 18 | 18 | 19 | 19 | 19 | 19 | 30 | 30 | 35 |
| Fertilizer Manufacturing | 592 | 592 | 398 | 398 | 333 | 333 | 265 | 265 | 396 | 396 | 331 | 331 | 204 | 204 | 9 |
| Sum | 1277 | 1218 | 881 | 842 | 818 | 779 | 748 | 704 | 878 | 838 | 820 | 775 | 848 | 819 | 509 |
| GHG Mitigation from C-Seq | 0 | 0 | 71 | 71 | 193 | 193 | -73 | -73 | 130 | 130 | 169 | 169 | 289 | 289 | 513 |
| Net GHG emission mitigation from all sources | 3359 | 3259 | 2243 | 2195 | 2101 | 2052 | 2436 | 2377 | 2465 | 2437 | 2428 | 2382 | 2043 | 2000 | 1375 |

Table 3. Rotation and tillage effects on yearly net revenue

| | Tillage | |
|---|---|---|
| Rotation | Moldboard Plow | Chisel Plow |
| | ----$ ha$^{-1}$ ---- | |
| C-C-C-C[a] | 70 | 24 |
| C-C-B-B | 53 | 48 |
| C-C-B(rc)-B(rc) | 63 | 45 |
| C-C-S-S | 113 | 103 |
| C-C-S-W | 123 | 134 |
| C-C-S-W(rc) | 152 | 138 |
| C-C-A-A | 87 | 84 |
| A-A-A-A | 88 | |
| SE | | |
| C-C-C-C and A-A-A-A (n = 20) | 14.5 | |
| Rotation (n = 40) | 11.8 | |
| LSD (Tillage x Rotation, 0.05) | | |
| C-C-C-C and A-A-A-A | 41 | |
| Rotations | 34 | |

[a] C = corn, B = barley, rc = underseeded red clover, S = soybean, W = winter wheat, A = alfalfa

Figures:

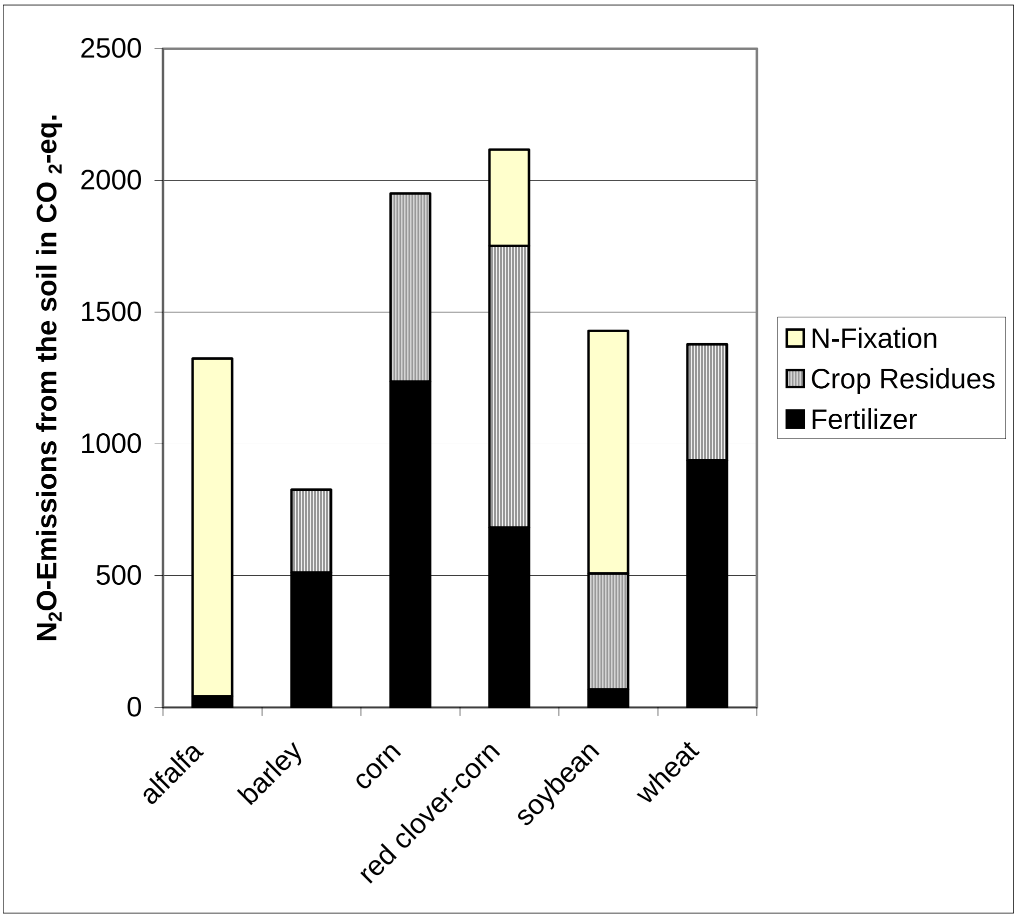


Fig. 1. Estimated 20 years average $N_2O$ emissions (direct and indirect) of the crops over all treatments from nitrous fertilizer, crop residues and nitrogen fixation according to IPCC accounting methodology

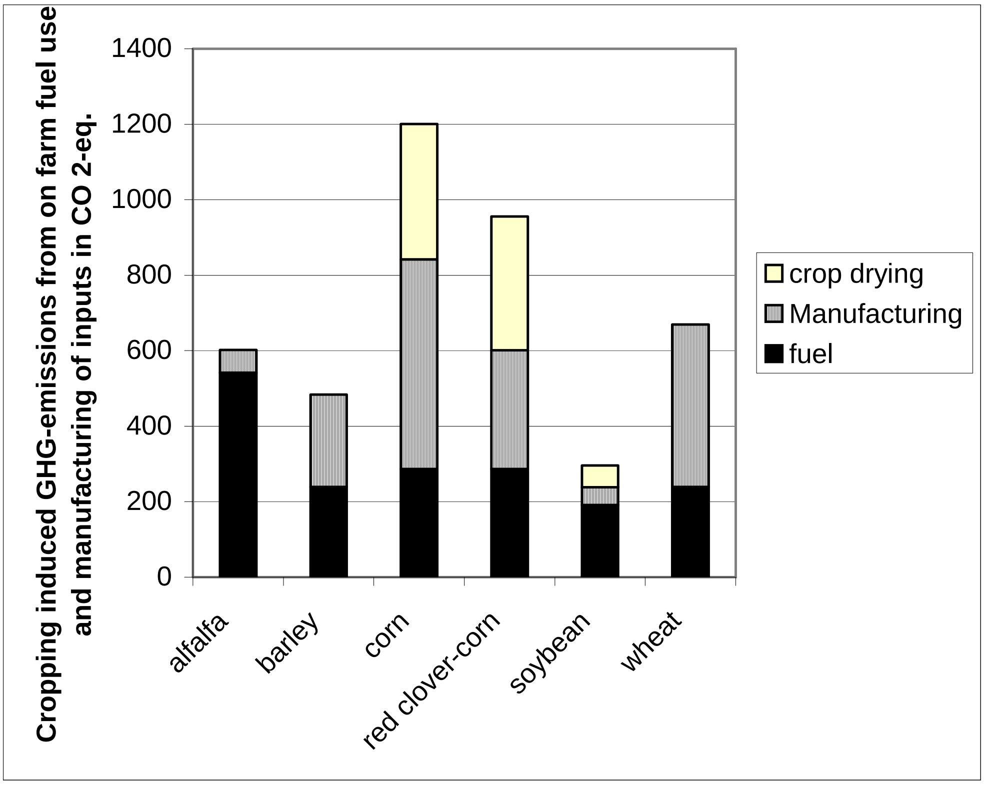


Fig.2. Contribution of cropping to GHG emissions in other sectors

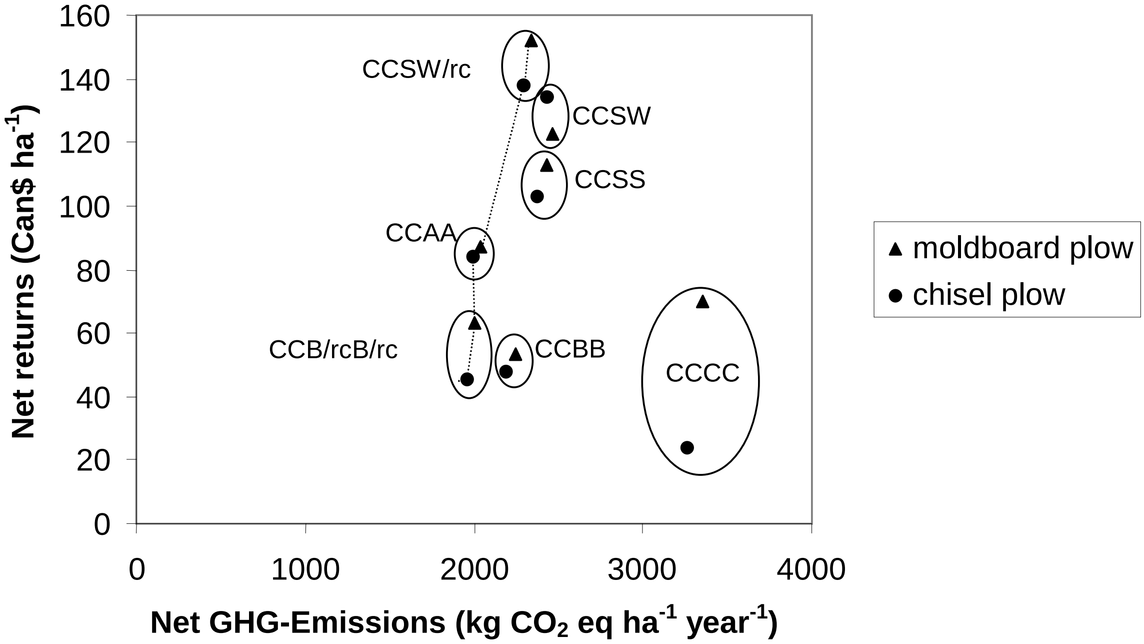


Fig 3. Trade off of GHG emissions versus Net return to the farmer