Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment

Project Summary

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ABSTRACT

This report describes an integrated agro-ecological modeling system that was developed to assess the potential economic and soil erosion impacts of different agricultural policies for the Canadian prairie provinces of Alberta, Saskatchewan, and Manitoba. The system was constructed by linking erosion metamodels (response functions), based on multiple simulations of the USDA Erosion Productivity Impact Calculator (EPIC), with a modified version of Agriculture Canada's Canadian Regional Agriculture Model (CRAM) denoted as RS-CRAM (resource sensitive CRAM). A summary of both the environmental and agricultural decision (RS-CRAM) components are presented, including a description of the modifications and enhancements that were made to CRAM.

Results of policy analyses are discussed for the following scenarios: (1) Gross Revenue Insurance Program (GRIP), (2) sensitivity of GRIP results to different risk levels, (3) tillage practice sensitivity, and (4) industrial crops sensitivity. Future recommendations are also presented, emphasizing how the current system can be improved and the potential to include additional regions, environmental indicators, and other environmental models within the system.

AGRICULTURAL POLICIES AND SOIL DEGRADATION IN WESTERN CANADA: AN AGRO-ECOLOGICAL ECONOMIC ASSESSMENT

Project Summary

Policymakers face increasing pressure to ensure that agricultural policies are environmentally sound as well as economically viable. In Canada, an environmental screening process must be performed for all new policy and program proposals brought before the Federal Cabinet. In addition, periodic postimplementation reviews must be carried out for all new farm income and stabilization programs, to ensure that farm programs adequately integrate environmental values with economic considerations under important farm programs. To perform these assessments, improved tools are required that can provide reliable estimates of economic and environmental indicators of proposed Canadian agricultural policies.

To help address this need, an integrated agro-ecological economic modeling system has been constructed around Agriculture Canada's Canadian Regional Agriculture Model (CRAM) (Webber et al. 1986; Horner et al. 1992) for Prairie provinces of Alberta, Saskatchewan, and Manitoba (Figure 1). This system incorporates a multidisciplinary approach that can be used to comprehensively assess the economic and soil degradation (wind and water erosion) impacts of proposed policies for the Prairies. It follows the emerging trend of integrated modeling systems that have been constructed for other applications at the farm level (Cole and English 1990; Taylor 1990; Wossink et al. 1992), watershed level (Milon 1987; Bouzaher et al. 1990; Lakshminarayan et al. 1991), and regional level (Bouzaher et al. 1994; Setia and Piper 1992).

The resource neutrality of the Gross Revenue Insurance Program (GRIP) in the Prairies was evaluated as an initial application to test the performance of the integrated system.[1] GRIP is a farm program that offers insurance against yield and price risks. Concern has been expressed that GRIP is not resource neutral and will encourage production on economically and environmentally marginal lands, leading to higher erosion rates and increased soil degradation. Additional simulations were performed to assess the sensitivity of the system to variations in tillage and crop mix distributions.

Detailed descriptions of the conceptual framework, environmental modeling system, integration of the environmental and economic components, and CRAM modifications and policy analysis results are given in Agriculture Canada (1993a, b; 1994; and 1995).

This report summarizes the major findings of the study in four sections: (1) the integrated modeling system, (2) policy analysis results, (3) future recommendations, and (4) summary.

The Integrated Modeling System

The integrated modeling system consists of two major components: (1) agricultural decision and (2) environmental (Figure 1). The agricultural decision component is a revised version of CRAM called RS-CRAM (denoting resource-sensitive CRAM) that incorporates new input substitution and producer risk modules. The environmental component consists of environmental metamodels (summary response functions) that were constructed on the basis of a statistically designed set of simulations performed with the Erosion Productivity Impact Calculator (EPIC), a model developed by the USDA-ARS to estimate the long-term impacts of erosion upon soil productivity (Williams et al. 1984; Williams 1990; Agriculture Canada 1993b). The metamodels allow for a consistent interface between the disparate spatial and temporal scales and the cropping systems scenarios that were simulated in the agricultural decision and environmental components.

The Environmental Component

The major soil degradation problems observed on the Prairies are wind and water erosion, salination, and organic matter depletion (PFRA 1990). Additional soil degradation and environmental concerns have been raised over soil compaction and surface and groundwater pollution from agricultural nonpoint sources of pesticides and nutrients. The environmental modeling system discussed here was configured to provide indicators of wind and water erosion for nine different crops grown in a suite of rotations.

The Environmental Database. An environmental database was constructed for the environmental component of the integrated modeling system that consisted of two main sub-databases: (1) soil layer and landform and (2) weather. A detailed description of the linking

processes used to create these databases is given in Agriculture Canada (1993b). Additional details are provided in Agriculture Canada (1994 and 1995).

Soil layer data were obtained separately for each of the three Prairies that is applicable at either the landscape polygon, Agroecological Resource Area (ARA), or CRAM production region level. Landform data were obtained from the Soil Landscapes of Canada database (Shields et al. 1991) that are identified by one dominant and one subdominant landscape, and associated soil series, that is applicable at the landscape polygon level. The landscape data were initially linked with the layer data on the basis of consistent matching between landscape polygon, Agroecological Resource Areas (ARAs), and soil series codes. Further links were made to spatially locate landscape polygons and ARAs that cross CRAM region boundaries. In all, three EPIC soil layer files and three landform databases were created, one for each province.

Three types of weather data sets were created for the weather database. Individual files were created for each province, resulting in nine total data sets. Daily EPIC weather data sets that contained precipitation and maximum and minimum temperature data were developed for each ARA by transforming 31-year ARA historical weather data sets (Kirkwood et al. 1993) into the proper EPIC format. EPIC weather generator tables were constructed for each ARA by linking available climate normal data with statistical data generated for each daily weather file, using a utility program provided with EPIC. Wind speed and direction files were also created for each ARA.

EPIC Testing and Regional Simulation Results. EPIC has been undergoing continuous development in the United States since its inception in the early 1980s. An initial foundation for testing the EPIC model under Prairie conditions was laid by Izaurralde et al. (1992), who tested different components of the model at various scales, ranging from field research plots to ARAs. Testing of the crop parameters for several crops was performed by comparing EPIC-predicted yields with measured yields available in the literature (Kiniry et al. 1995). Additional tests were performed with 25-year continuous wheat and wheat-fallow data sets obtained from the Agriculture Canada Research Station at Swift Current, Saskatchewan, and other site-specific data. These tests indicated that EPIC was accurately simulating the long-term average yields but was not capturing year-to-year yield variability (Agriculture Canada 1995).

Testing was conducted of a new wind erosion submodel that was inserted in EPIC 3090. It was concluded that this new model was performing better than the previous one, based on expert opinion provided by Tajek (1993). Further testing of the erosion submodels revealed that the model was overpredicting crop residue accumulations, because of the cooler and drier conditions in the region (Agriculture Canada 1995). To overcome this problem, adjustments were made to the crop residue decay and incorporation of standing dead residue functions in EPIC.

An experimentally designed set of EPIC simulations was performed for the entire study region. Yield responses were sensitive to regional productivity and climatic differences. Tillage had little impact on the estimated yields. The EPIC yield estimates were higher than the ten-year average census yields previously used in CRAM. Fallowing was predicted to be very beneficial for wheat and canola yields in the Brown soil zone, but not in the other soil zones. The weakest performance of the model was in the regions representative of the Dark Brown soil zone, where fallow is known to provide definite yield improvements over stubble cropping.

The greatest wind and water erosion rates were predicted for fallow conditions. The highest wind erosion rates were predicted to occur in southern Alberta and southern Saskatchewan. These results followed expected trends. Predicted EPIC water erosion rates compared favorably with previous USLE erosion rate estimates for Alberta. Reduced levels of tillage resulted in lower erosion rates for crops grown on stubble. However, tillage had little impact on predicted erosion rates for crops grown on fallow.

The Environmental Metamodels. An experimentally designed set of EPIC simulations was performed based on a stratified random sampling scheme, with a complete factorial design, of the soil series, slope gradient, and slope length combinations that exist in each of the three provinces. An automatic input file builder and control program was constructed to facilitate the execution of the experimentally designed EPIC simulation set and the development of the environmental metamodels. The total number of simulations performed were 7,734 for Alberta, 9,750 for Saskatchewan, and 4,455 for Manitoba.

Ordinary least squares regression models were used to construct the wind and water erosion metamodels for each crop and crop sequence (stubble or fallow). Fourth-root transformations of both the wind and water erosion data were performed to ensure normality. The wind and water erosion metamodels were very robust in replicating the EPIC model simulations, with the majority of the R-square values falling in the range of 0.8 to 0.95. The predictive power of the metamodels was confirmed in validation tests comparing metamodel output with the original simulation data. These validation tests included a comparison with the entire set of simulated data and two cross-validation tests.

The Agriculture Decision Component

Modifications to CRAM were confined to production regions within the provinces of Alberta, Manitoba, and Saskatchewan. The changes were made only to crop production activities for the major crops simulated in RS-CRAM, which includes the new crops of field peas and lentils in addition to the previous barley, canola, flax, and wheat crops simulated in CRAM. The major structural modifications were as follows: (1) Three alternative tillage practices, defined as conventional, reduced and no-till, are simulated for each crop production activity, rather than using the previous single representative tillage system. (2) Lentils and field peas were added to the list of crop production activities. (3) Returns to the crop production activities are modified to include expected returns to crop and/or revenue insurance programs. (4) Price and yield risk are explicitly incorporated into the model. (5) The execution of the environmental metamodels was incorporated as a fourth phase.

Tillage Specification. The tillage systems are defined in RS-CRAM on the basis of percent residue cover as: (1) less than 30 percent for conventional, (2) 30 to 70 percent for reduced, and (3) greater than 70 percent for no-till. Thus, crop production activities are defined in RS-CRAM by production region, crop, crop sequence (stubble/fallow), and tillage level. A major challenge was encountered in calibrating these tillage systems within the Positive Mathematical Programming (PMP) framework used in RS-CRAM. The PMP framework contains three phases: (1) a precalibration phase, (2) a calibration phase, and (3) an execution phase of the calibrated PMP model. In the first two phases, crop production aggregate activities are constrained to observed levels and fallowed area is allocated among crops in each region according to net returns. The resulting marginal values of production are used to derive coefficients for the PMP model executed in the third phase.

The introduction of tillage into RS-CRAM presents problems for the calibration process because observed data are unavailable for crop production by regions, crop, and tillage. Crop acreages by summer fallow and stubble were derived in the "precalibration" phase according to the relative returns of each crop on fallow and on stubble and the observed relative amounts of all crops grown on fallow and on stubble. Tillage was allocated to summer fallow and stubble in the same manner as to crops. However, the proportion of each crop by tillage was specified according to observed data on aggregate proportions in each region; i.e., all crops within a region have the same tillage patterns. Therefore, the model was used to allocate summer fallow and stubble across observed crop and tillage areas. The demand, transportation, and livestock sectors were unaffected by the tillage specification. Where linkages between these sectors and the crop production sector occurred, aggregated crop numbers were used.

Addition of Lentils and Field Peas. Crop production activities for lentils were added for summer fallow and stubble. Activities for field peas were added for stubble only. Historical acreages for the "other crops" activities were adjusted to account for this explicit inclusion of lentils and field peas. These crops are calibrated by PMP in the same manner as other crops. The demand for lentils and field peas is recorded at the national level and is completely disposed of in the national market. The prices for both crops are specified exogenously. Transportation from the region to the national level for both crops was included. There is no interaction of either lentils or field peas with the livestock sector in RS-CRAM, because neither crop is included in the list of commodities fed to livestock.

Besides the addition of lentils and field peas to RS-CRAM, other modifications were made to the cropping activities used in CRAM. Flax is simulated only for stubble cropping in RS-CRAM; previously it was simulated only for fallow cropping. The barley fallow crop activity was eliminated also, resulting in only stubble-cropped barley being simulated in RS-CRAM. The wheat, canola, and "other" crop activities are simulated for both stubble and fallow cropping in RS-CRAM, as before.

Incorporation of Revised Yields. The average census yields used in CRAM were modified in RS-CRAM to account for the impact of tillage, and of stubble versus fallow cropping, as predicted by EPIC. The EPIC yield estimates were generated from the experimentally designed simulation set that was used to construct the wind and water erosion metamodels. As previously discussed, the EPIC yield estimates were typically higher than the average census yields used in CRAM. This was especially true for the EPIC-simulated stubble cropped yields in the soil zones outside the Brown soil zone. Thus, the magnitudes of the EPIC yields were reduced as described in Agriculture Canada (1994 and 1995) to ensure that no distortions occurred in RS-CRAM.

Returns to Crop Production with Crop Insurance and GRIP. The 1992 baseline for the analysis performed by CARD assumes 100 percent participation in crop yield insurance. Indemnity payments and the producer share of premiums are calculated explicitly for the baseline in RS-CRAM. Previously, payments from crop yield insurance were summed with payouts from several other programs, including the Western Grain Stabilization Act, Agricultural Stabilization

Act, Federal and Provincial Red Meat Stabilization Program, and several others, into a single government payment (Horner et al. 1992). In Alberta, Saskatchewan, and Manitoba, these payments have been replaced by the net of expected crop insurance indemnity payments and premiums. In other provinces, the government payments used in the previous version of CRAM are left in the model (MacGregor 1993).

To evaluate GRIP, 100 percent participation was assumed and the 1991 program was modeled. Expected indemnity payments and premiums were calculated for each of the crop production activities. The discussion in the previous paragraph regarding government payments from other programs also applies for the GRIP policy run.

Risk. Because crop insurance and GRIP are policies that are designed to reduce the fluctuations in returns experienced by producers, risk is modeled in RS-CRAM. The methodology used was devised by Hazell and Scandizzo (1974 and 1977). It is the most practical method of including price and yield risks in the objective function of a sector model with endogenous commodity prices (Hazell and Noron 1986). The methodology closely followed that used by House (1989) in the USMP regional agricultural model.

Incorporation of the Environmental Metamodels. The interface between the agricultural decision and environmental components is accomplished by passing the mix of management practices and input use for every CRAM region predicted by RS-CRAM for a given policy scenario to the environmental metamodels to evaluate soil degradation impacts. This linkage is the fundamental relationship between producer responses to agricultural policies and their impacts on resource use. Aggregation of the metamodel output can then be performed at the soil, landscape polygon, ARA, CRAM region, or province level, depending on the type of analysis desired.

To compare environmental indicators with economic indicators consistently for each policy scenario, the environmental indicators must be aggregated from the landscape polygon level to the CRAM production region level. This is a multi-step process that begins with inputting predicted RS-CRAM cropping patterns and tillage distributions to the metamodels and then aggregating the environmental indicators back up to the production regions. Crop and tillage weighted erosion rates are estimated for each landscape polygon-soil type combination available in the total population of the environmental database for each scenario. The next step is to aggregate the indicators to ARA/CRAM production region level, using weights based on the total cropped acres of each soil type in each landscape polygon. Thus, greater weight is placed on those landscape polygon-soil combinations that occupy the most acres.

Policy Analysis Results

As a test of the integrated system, economic and environmental (erosion) indicators were evaluated for several different policy scenarios. Following an initial GRIP run, four sensitivity runs were performed, defined as: (1) GRIP without risk, (2) GRIP with "high" risk, (3) industrial crop, and (4) revised tillage distribution. The GRIP scenario is described first, followed by the sensitivity runs.

GRIP

The 1991 Gross Revenue Insurance Plan (GRIP) is modeled for Saskatchewan, Alberta, and Manitoba in the same manner as crop insurance in the baseline. Annual net returns for 1980-1992 are simulated assuming 100 percent participation in both GRIP and crop insurance. Mean indemnities and premiums are computed for each activity time series, and the variance-covariance matrix for the objective function is reestimated using these simulations.

The results of the simulation run indicated that GRIP has little overall impact on the share of aggregate seeded acres under each tillage system in the Prairies. The cropped acreage under conventional tillage increased by 145,000 hectares, while the acres planted with reduced-till systems increased by about a third of the conventional tillage change. The area under no-till systems increased by only 11,000 hectares. The percentage changes in areas under each tillage practice are about the same.

The GRIP results also indicate a shift in crop sequencing away from fallowing. The area planted on fallow under GRIP fell by 179,000 hectares from a baseline of 7.8 million. This implies an equal reduction in the area of cropland being fallowed. The area planted on stubble increased by 323,000 hectares from a baseline of 16 million. About 60 percent of the net shift toward stubble planting involved wheat, and the largest shifts occurred in Saskatchewan.

According to RS-CRAM, GRIP also favors barley, lentils, and flax relative to the baseline. Because (endogenous) crop prices are left relatively unchanged in the model by GRIP, almost all the increase in net income per hectare is due to increased returns from revenue insurance relative to yield insurance alone. The biggest increases in net income per hectare were for barley, lentils, and flax, the crops whose areas increased most under GRIP. Barley is a marginal crop in some regions, with a significantly declining market price in recent years. The

GRIP support prices (IMAP) in recent years thus tend to support barley net incomes significantly when the average indemnity payments are computed. Similarly, high IMAP prices for lentils and flax increase net activity returns per hectare for those crops. Areas planted to field peas also increase because of the relatively large increases in net returns per hectare. Although net returns per hectare also increase for wheat and canola, the increases are smaller than for the other crops. Thus, the model indicates that wheat and canola are relatively less attractive at the margin under GRIP than are the other crops competing for the same cropland. Accordingly, wheat and canola acreages decline slightly under GRIP.

The reduction price risk provided by GRIP significantly reduced the aggregate risk premium (value of the risk term of the objective function) relative to yield protection alone. A reduction of 43 percent was predicted, equivalent to 24 million dollars. Producers in Alberta tend to benefit relatively more than those in Saskatchewan and Manitoba in terms of risk reduction, although GRIP increased net incomes relatively more for Saskatchewan producers.

Slight reductions in water erosion of 1.4, 0.4, and 0.6 percent were predicted under GRIP for Alberta, Saskatchewan, and Manitoba. Similarly, minor reductions in wind erosion of 2.2, 1.0, and 0.3 percent were predicted for Alberta, Saskatchewan, and Manitoba. The shift away from fallow and toward stubble provides most of the decline in total erosion under GRIP relative to the baseline. The major finding here is that GRIP is not having a significant impact on soil degradation in the Prairies.

Sensitivity of GRIP Results to Risk Aversion. Two alternative baseline and GRIP runs were made to gauge the sensitivity of GRIP results to risk aversion. In scenario GRIPNR (GRIP with no risk aversion), the coefficient of absolute risk aversion is set at zero. Risk is thus completely removed from the model formulation in GRIPNR. In scenario GRIPHR (GRIP with high risk aversion), the estimated coefficient of absolute risk aversion is multiplied by 5, thus increasing the contribution of risk considerations to producers' decisions in the model. For each scenario, a new baseline was computed to reflect the changed risk coefficient. GRIP policy runs were then made.

Each GRIP policy run was compared with its corresponding baseline, which differed in some respects from the baseline used for comparison in the other sensitivity analyses presented here. The results indicate that large changes in the risk aversion coefficient do not alter the direction of impacts of GRIP relative to yield insurance alone, but do accentuate the magnitudes of these impacts. Changes in planted acreages and shifts away from fallowing are larger in

GRIPHR and smaller in GRIPNR compared to GRIP, as expected a priori. Changes in proportions of crops planted to stubble are not significantly affected. Net returns per hectare are also relatively unaffected. However, because of the larger planted acreage increase under GRIPHR the increase in aggregate net crop income is about $15 million higher under GRIPHR than under GRIP or GRIPNR. Changes in erosion indicators were somewhat higher under GRIPHR than under GRIP or GRIPNR.

Tillage Practice Sensitivity

The sensitivity of baseline calibration to tillage practice assumptions was gauged by switching the percentage of cropland under conventional till with the percentage under no-till in each CRAM region. For example, suppose that under the baseline, 60 percent of cropland in a CRAM region was under conventional tillage, 30 percent under reduced tillage, and 10 percent under no-till. Under the TILL scenario, 10 percent would be under conventional till, 30 percent under moderate tillage, and 60 percent under no-till.

The net result of this change is a 13.4 million hectare shift of land from conventional tillage to no-till. Under this set of tillage assumptions, a larger share of lentils is planted on stubble than in the baseline, but sequencing for wheat and canola is not affected. Barley yields are consistently higher on no-till than on conventional tillage, but other crop yields do not systematically vary to the degree barley yields do. Production of barley also increases more than production of other crops, solely because of the change in average yields. Similarly, net returns to barley production show the largest change, almost 10 percent compared to the baseline, because of the higher yields under no-till and the generally lower average costs for barley on on-till relative to conventional tillage. Aggregate net returns increase $53 million, but 85 percent of that increase is attributable to higher returns to barley production; the remainder comes almost entirely from wheat production. The aggregate risk premium falls negligibly overall, but increases slightly for Saskatchewan.

Dramatic declines in both water and wind erosion rates occurred for this scenario, demonstrating the sensitivity of the metamodels to tillage. The declines for water erosion were 27.2, 18.3, and 40.4 percent for Alberta, Saskatchewan, and Manitoba. The corresponding declines in wind erosion rates were 25.9, 15.7, and 25.3 percent.

Industrial Crop Sensitivity

In this scenario, the aggregate acreages of canola and flax were increased by 50 percent. The model was allowed to choose in which regions to increase production. Less than 2 percent of the increased production goes to areas outside the Prairies, to British Columbia. The acreages of both crops increased by about 49 percent in the Prairies. Net returns per hectare fell by 29 percent to canola and by 40 percent to flax. Net returns per hectare to all other crops increased by 5 to 10 percent. Net crop income for the Prairies fell by 2.2 percent as a whole. Saskatchewan had the largest absolute loss in net income ($52 million), followed by Alberta ($27 million), and Manitoba ($25 million).

Erosion rates increased under this scenario, revealing the more erosive nature of canola and lentils. The water erosion rate increases were 3.4, 0.1, and 0.5 percent for Alberta, Saskatchewan, and Manitoba. The total corresponding increases in wind erosion rate were 4.6, 1.6, and 5.8 percent.

Future Recommendations

Several recommendations were given in preceding reports for this project regarding continued testing, modification, and enhancements of different parts of the integrated modeling system that could lead to improvements in its overall performance. The major recommendations for continued testing and modification of the two major components of the system are given again here. Recommendations on expanded applications to other regions and for other environmental indicators are also discussed.

Recommendations for the Environmental Component

The statistical robustness of the wind and water erosion metamodels was very high. Thus, it would not be expected that major gains would be realized by attempting to improve the statistical procedures used to estimate the metamodels. However, the metamodels could be strengthened by improving the accuracy of the EPIC crop yield and erosion predictions for Prairie conditions (which would result in the need to re-estimate the metamodels). Three potential options exist to improve the EPIC estimates: (1) improved calibration of crop parameters and other inputs, (2) modifications of the code, and (3) improved estimates of some of the data incorporated within the environmental database. Based on these possibilities, there are some recommendations to improve future calculations:

1. A comprehensive review of the soil layer/landform and weather databases should be performed by a team of experts most familiar with the data. Particular attention should

be given to the estimation of slope lengths and hydrologic groups, and to the extrapolation of relative humidity and wind data to the ARA level. An additional layer should be built into the environmental database that allows for an overlay of the major soil zones on the landscape polygons, ARAs, and CRAM production regions.

2. In conjunction with (1), a review of the aggregation process of the environmental indicators is needed. This should begin with the crop acreages assumed in the environmental database, and then cover the techniques that are currently used to aggregate the indicators to the CRAM production region level. There are discrepancies in the total cropped acres assumed in the environmental database as compared with the census data used in RS-CRAM. The reasons for this, and the potential implications, need to be better understood.

3. Additional calibration of the EPIC crop growth model and yield estimates is necessary. Continued testing should be performed with long-term rotation data available for different sites in western Canada. Crop response to nitrogen and soil moisture should be examined closely for Prairie conditions. Regional variation in planting dates and management systems should be incorporated into the modeling system.

4. Continued testing of the erosion submodels is also required. To the extent possible, erosion estimates should be compared with measured data. Expert opinion should also be sought to confirm the accuracy of the erosion predictions. Improved estimates of the crop parameters used in the wind erosion submodel are needed.

5. Code modifications should be considered for those portions of the model that are revealed through testing to be performed inadequately for Prairie conditions. The modifications made to the residue decay and standing dead residue functions should be further tested.

6. An interdisciplinary team should be assembled to carry out the efforts to test and modify EPIC. The model developers at the USDA Grassland Research Laboratory in Temple, Texas, should be included as advisors to this team.

Recommendations for the Agricultural Decision Component

Recommendations to improve the agricultural decision component focus on data inputs and additional structural enhancements to RS-CRAM. The recommendations are:

1. Improve cost estimates. The survey data used in this study do not provide reasonable or consistent estimates with respect to tillage practices in many cases. Data were completely lacking for many crop-tillage combinations.

2. In conjunction with the cost data, improve the reliability of fertilizer use rates, to accurately account for nutrient loadings in different production regions. This would complement recommendation (2) for the environmental component, which proposed that regionally specific management systems be simulated in EPIC.

3. Improve reconciliation between EPIC-generated yields and the historical average yields used in CRAM, especially with respect to lentils. Reconciliation is critical for proper estimates of insurance premiums and payouts as well as net returns, as used in variance calculations.

4. Change the way hay acreages in RS-CRAM are presently determined, as a function of the demand from the livestock sector, to be like other cropping activities. Hay area can then respond to the export demand for dehydrated alfalfa.

5. Build sunflower and fall rye cropping activities into RS-CRAM. This will require reliable cost data presently not available to describe these activities.

6. Adjust the costs and yields for the "other crops" category in the Prairies for lentils and field peas.

7. Facilitate calibration by selectively omitting cropping activities with very small acreages. Primarily, these are cropping activities characterized as fallow and/or no-till cropping, which cover relatively small areas in certain production regions. These activities with small areas make PMP calibration difficult.

8. Use crop-specific estimates of tillage percentages to improve model response to policy shocks. Percentages are presently assumed to be the same for all crops in a given CRAM region.

9. Update data for demand and transportation, and all livestock data that were not updated for the 1992 base year.

Expanded Applications for Other Regions

The potential exists to expand the integrated modeling system to other agricultural regions of Canada. Seven other production regions are included in the original CRAM model, representing British Columbia, Ontario, Quebec, New Brunswick, Newfoundland, Nova Scotia, and Prince Edward Island. These regions are included in the RS-CRAM structure; currently, only economic analysis can be performed for these production regions within the integrated modeling system. The EPIC model has a flexible structure that permits configuration of a large number of management and cropping systems for virtually any combination of environmental (soil, landform, and climatic) conditions. Thus, it can also be adapted to Canadian agricultural regions outside the Prairies.

Several key factors must be considered before expanding the integrated modeling system to other regions. First, as noted, improvement of the EPIC estimates for crop growth and soil erosion in the Prairies is needed through additional calibration and validation exercises. Second, major data gaps exist in accurately configuring cost data by tillage system and other management criteria for the 22 production regions in RS-CRAM that represent the Prairies, requiring more testing of RS-CRAM under its current configuration. Finally, major data and testing efforts for both EPIC and RS-CRAM would have to be initiated for any new regions to which the models would be applied. Careful calculation must be made whether the resources exist to carry out these additional tasks successfully, while adequately updating and maintaining the current modeling system for Alberta, Saskatchewan, and Manitoba.

Expanded Applications for Other Environmental Indicators

Besides wind and water erosion, other potentially negative environmental impacts from current agricultural production practices have raised concerns. As noted, these impacts include organic carbon depletion, salinity, soil compaction, and pesticide and nutrient contamination of groundwater and surface water. Indicators of climate change are also important. EPIC can be configured to assess many of these concerns, at least in part, for different management systems and environmental conditions in western Canada. Potentially, other models could be linked into the integrated modeling system to expand its capabilities to address the environmental indicators.

According to PFRA (1990), the soil degradation problem with the most important economic impact in western Canada is organic matter depletion. Thus, it is logical to expand the system outputs to include indicators of this degradation problem. Organic carbon[2] changes were generated from EPIC over the 31-year simulation period used for this study. However, these data were output from EPIC by different rotations and thus could not be linked to specific crops (Agriculture Canada 1994), as is required to interface the indicators to RS-CRAM. Therefore, the EPIC output routine should be modified to allow construction of metamodels of organic carbon depletion that are a function of crop and crop sequence (stubble/fallow). These indicators can then be directly interfaced with RS-CRAM.

Soil salinity has also been identified by PFRA (1990) as having a major economic impact on production in western Canada. The current version of EPIC does not have a soil salinity submodel. A soil salinity routine was constructed from a previous version of EPIC but was never tested (Williams 1992). This routine could be incorporated into an operational version of EPIC and used within the integrated modeling system. Also, according to Williams (1992), a soil compaction equation currently exists in the ALMANAC (Kiniry et al. 1992) version of EPIC that is intended to simulate the increase in bulk density as a function of equipment weight and soil depth. This routine is also considered nonoperational at present but could potentially be linked into the overall system. Bulk density changes were output for the current study in the same manner as described for the organic matter changes.

Edge-of-field loadings of nutrients (nitrogen and phosphorous) and pesticides in runoff water, on eroded sediment, and in leachate can be simulated by EPIC. Output of nutrient loading indicators were generated for the current study on both a crop-specific and rotational basis. However, these indicators were of limited value because the ranges of application rates were not simulated for the different management systems. Metamodels of nutrient and pesticide losses could be constructed on a crop and crop sequence basis. Additional work would be necessary to develop data sets for pesticide application rates, costs, and so forth that would be required for the integrated modeling system.

Finally, the EPIC model can be applied to provide indicators of the effects of climate change on crop growth. This is accomplished by accounting for effects of CO_2 concentration upon crop growth processes and subsequent yields (Stockle et al. 1992a). Climate change scenarios with EPIC have been performed for specific sites or regions in the United States (Stockle et al. 1992b), England (Favis-Matlock et al. 1991), and Canada (Touré et al. 1994).

The Incorporation of Other Environmental Models. A plethora of environmental computer models that have been developed over the past two decades can be used to evaluate different agricultural management systems at the field, watershed, and/or river basin scales. These models vary in complexity and in the types of environmental indicators that they output. The field-scale models generate edge-of-field indicators in a manner similar to that described for EPIC. Watershed models such as the Agricultural Nonpoint Source Pollution (AGNPS) model (Young et al. 1989) and the Simulator for Water Resources in Rural Basins (SWRRB) model (Arnold et al. 1990) provide output of nonpoint source pollutants at the watershed outlets and at different points within watershed. River basin models such as the Hydrologic Simulation Program-Fortran (HSPF) (Johansen 1983) provide the ability to estimate runoff loadings of nonpoint source pollutants and to analyze in-stream indicators of pollutant impacts. Comparisons of some of the more widely used field-scale, watershed, and river basin models are provided by DeCoursey (1985), Crowder (1987), Devries and Hromadka (1993), and Ghadiri and Rose (1992).

A large number of groundwater models have also been developed that can potentially be used to evaluate the movement of agricultural chemical contaminants in aquifer systems. A review of 399 groundwater models is given in van der Heijde et al. (1985). Attempts have been made to link groundwater models with other models that output pesticide and nutrient loadings in leachate from the root zone. Examples of such linked modeling systems for agricultural chemicals are described in Jones (1986) and EC (1991). Applications of models for estimating water and salt movement in subsurface soils, such as those described by Stolte et al. (1992), have also been performed for soil salinity problems.

Besides water quality models, other models have been developed to assess the impacts of agricultural production upon soil nutrients (carbon, nitrogen, phosphorous, and sulfur) in agro-ecosystems. One of the most widely used of these models is the Century model (Parton et al. 1988). The Century model has been applied to the midwestern United States to determine if agricultural management systems can be managed to conserve and sequester carbon, reducing carbon dioxide (CO_2) accumulation in the atmosphere. Touré et al. (1994) have also applied the Century model to evaluate its usefulness in assessing climate change impacts in southern Alberta.

As with expansion to other regions there are important factors that should be considered before other environmental models are linked into the integrated modeling system. First, incorporating other models would require obtaining additional data and/or reformatting the current data sets. Also, additional resources would be required to train personnel to operate these models. The data gathering and training tasks would be considerable undertakings for many of these models. Such efforts could potentially detract from the more important goals of improving the accuracy of EPIC and RS-CRAM as emphasized here.

Second, it appears that several of the most important environmental problems that are in western Canada are confined to landscapes rather than having off-site impacts. Coote (1984) emphasized that erosion assessments and mitigation efforts in western Canada should focus on landscape productivity rather than on off-site sediment loss, because 95 percent of the eroded sediment stays within the original watersheds. This viewpoint was confirmed by de Jong (1993), who stated that very little eroded sediment leaves watersheds in Saskatchewan. Thus, linking watershed or river basin models to the system to study off-site erosion impacts would have limited value.

Evaluations of the mechanisms driving soil salinity by Stolte et al. (1992) indicate that this problem is also a function of landscape position. This could potentially be evaluated with a modified version of EPIC. Alternatively, an additional model could be linked into the system for the express purpose of simulating soil salinity impacts. Organic matter depletion and nutrient cycling can also be evaluated for specific landscapes; both of these evaluations can be performed in EPIC. It is possible that applying Century or a similar model may provide additional information on organic matter depletion and nutrient cycling indicators. Off-site movement of agricultural chemicals is a possibility in western Canada. However, at this time, agricultural chemical movement is best assessed using edge-of-field indicators provided by EPIC or a similar model.

Summary

The assessment of environmental as well as economic impacts of proposed agricultural policies is becoming more important. To meet this objective, an agro-ecological modeling system has been constructed for the Prairies around a modified version of Agriculture Canada's CRAM model. This modeling system provides the means to analyze the potential economic and soil degradation (wind and water erosion) impacts of proposed agricultural policies.

The system consists of two major components: (1) an agricultural decision component, which is RS-CRAM (Resource Sensitive CRAM); and (2) an environmental component that consists of an environmental database and environmental metamodels for wind and water erosion. Several additions and enhancements were made to the original CRAM model to develop RS-CRAM. The wind and water erosion metamodels were constructed from an experimentally designed set of EPIC simulations and proved to be statistically robust.

Evaluations of GRIP and four sensitivity scenarios were performed with the integrated system. Little overall impact was predicted under GRIP on the share of seeded acres under each tillage system in the Prairies. It was also indicated by RS-CRAM that GRIP would favor barley, lentils, and flax and that there would be a shift in crop sequencing away from fallow. An overall price risk reduction of 43 percent was estimated, reducing the aggregate risk premium by $24 million. Slight decreases in wind and water erosion were predicted for the GRIP scenario, indicating that GRIP would have negligible impact on soil degradation in the Prairies. Changes in the risk aversion coefficient in RS-CRAM (GRIPNR and GRIPHR scenarios) did not alter the direction of impacts of GRIP relative to yield insurance alone but did accentuate the magnitudes of those impacts.

Dramatic declines in wind and water erosion were predicted for the TILL scenario, demonstrating the sensitivity of the metamodels to tillage. Aggregate net returns relative to the baseline were predicted to increase by $53 million, 85 percent of which was due to higher returns to barley production. Per hectare returns to canola and flax dropped by 29 and 40 percent when the acreages of both were assumed to increase by 50 percent under the INDCROP scenario. Net income for the Prairies was predicted to fall 2.2 percent overall. Erosion rates were predicted to increase in response to the INDCROP scenario, showing the more erosive nature of canola and lentils.

The application of the integrated modeling system to these different scenarios shows its flexibility in analyzing both the economic and soil degradation impacts of proposed agricultural

policies for the Prairies. The current configuration of the system should be thought of as an initial phase. Several recommendations have been made that could improve the reliability of the system for future applications. The system could also be expanded to other environmental indicators and regions. This would enhance the ability of Agriculture Canada to fully assess the ramifications of different agriculture policies before they are implemented.

ENDNOTES

1. Originally, it was also intended to evaluate the Net Income Stabilization Account (NISA), which was designed to protect eligible producers against income volatility (especially during low-income years). However, a well-developed theoretical framework does not currently exist for NISA, so it cannot be evaluated with the integration system.

2. Organic carbon is equal to organic matter divided by 1.72.

REFERENCES

Agriculture Canada. 1993a. Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 1: Conceptual Framework). Technical Report 2/93, Policy Branch, Ottawa, Ontario.

_____________ 1993b. Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 2: The Environmental Modeling System). Technical Report 5/93, Policy Branch, Ottawa, Ontario.

_____________ 1994. Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 3: The Integration of the Environmental and Economic Components). Technical Report 1/94, Policy Branch, Ottawa, Ontario.

_____________ 1995. Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 4: Modification to CRAM and Policy Evaluation Results). Technical Report 1/95, Policy Branch, Ottawa, Ontario.

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. *SWRRB, A Basin Scale Simulation Model for Soil and Water Resources Management.* College Station, Texas: Texas A&M University Press.

Bouzaher, A., J.B. Braden, and G.V. Johnson. 1990. A Dynamic Programming Approach to a Class of Nonpoint Source Pollution Control Problems. *Management Science* 66(1):1-15.

Bouzaher, A., J.F. Shogren, P.W. Gassman, D. J. Holtkamp, and A. P. Manale. 1994. Use of a Linked Biophysical and Economic Modeling System to Evaluate Risk-Benefit Tradeoffs of Corn Herbicide Use in the Midwest. In *Proceedings of the ABCS Symposium: Regulation of Agrochemical Environmental Fate in the 1990s*. Chelsea, Michigan: Lewis Publishers.

Cole, G.V., and B.C. English. 1990. The Micro Oriented Agricultural Production System (MOAPS): A Documentation. Research Report, 90-03. Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville.

Coote, D.R. 1984. The Extent of Soil Erosion in Western Canada. *Proceedings of the Annual Western Provincial Conference on Rationalization of Water and Soil Research and Management*. Saskatoon, Saskatchewan.

Crowder, B.M 1987. Issues in Water Quality Modeling of Agricultural Management Practices: An Economic Perspective. In *Proceedings of the Symposium on Monitoring, Modeling, and Mediating Water Quality*, S.J. Nix and P.E. Black, ed. Technical Publication Series No. TPS87-2. Bethesda, Maryland: American Water Resources Association.

DeCoursey, D.G. 1985. Mathematical Models for Nonpoint Water Pollution Control. *J. Soil and Water Cons.* Sept.-Oct.:408-413.

de Jong, E. 1993. Personal Communication. Soil Science Department, University of Saskatchewan, Saskatoon, Saskatchewan.

Devries, J.J. and T.V. Hromadka. 1993. Computer Models for Surface Water. In: *Handbook of Hydrology,* D.R. Maidment, ed. McGraw-Hill, Inc., New York, New York. pp. 21.1-21.39.

E.C. 1991. Soil and Groundwater Research Report II, Nitrate in Soils: In the Framework of the Fourth Environmental Research Program (1988-90). EUR 13051. Environment and Quality of Life, Commission of the European Communities, Directorate-General Telecommunications, Information Industries and Innovation, Luxembourg.

Favis-Matlock, D.T., R. Evans, J.Boardman, and T.M. Harris. 1991. Climate Change, Winter Wheat Yield and Soil Erosion on the English South Downs. *Agrc. Systems* 37:415-433.

Ghadiri, H. and C.W. Rose. 1992. Sorbed Chemical Transport Modeling. In: *Modeling Chemical Transport in Soils: Natural and Applied Contaminants*. H. Ghadiri and C.W. Rose, ed. CRC Press, Inc., Boca Ratan, Florida, pp. 15-104.

Hazell, P.B.R. and R.D. Norton. 1986. *Mathematical Programming for Economic Analysis in Agriculture*. New York: Macmillan Publishing Co.

Hazell, P.B.R. and P.L. Scandizzo. 1974. Competitive Demand Structures under Risk in Agricultural Linear Programming Models. *American J. of Agric. Econ*. 56:235-44.

______________ 1977. Farmers' Expectations, Risk Aversion, and Market Equilibrium under Risk. *American J. of Agri. Econ.* 59:204-19.

House, Robert M. 1989. *Risk Analysis in the USMP Regional Agricultural Model*. Conference Proceedings. Southern Regional Research Project, S-232 1989 Annual Meeting, Sanibel Island, Florida.

Horner, G.L., J. Corman, R.E. Howitt, C.A. Carter, R.J. MacGregor. 1992. The Canadian Regional Agriculture Model Structure, Operation and Development. Ottawa: Agriculture Canada.

Izaurralde, R.C., F. Tajeck, F. Larney, and P. Dzikowski. 1992. Evaluation of the Suitability of the EPIC Model as a Tool to Estimate Erosion from Selected Landscapes in Alberta. Edmonton: Alberta Agriculture.

Johansen, R.C. 1983. A New Mathematical Modeling System. In *Fate of Chemicals in the Environment: Compartmental and Multimedia Models for Predictions*, R.L. Swann and

A. Eschenroeder, eds. ABCS Symposium Series. Washington, D.C.: American Chemical Society.

Jones, R.L. 1986. Field, Laboratory, and Modeling Studies on the Degradation and Transport of Aldicarb Residues in Soil and Ground Water. In *Evaluation of Pesticides in Ground Water*. W.Y.Garner, R.C. Honeycutt, H.N. Nigg, ed. ABCS Symposium Series No. 315. Washington, D.C.: American Chemical Society.

Kiniry, J.R., J.R. Williams, P.W. Gassmann, and P. Debaeke. 1992. A General, Process-Oriented Model for Two Competing Plant Species. *Transactions of the ASAE* 35:801-810.

Kiniry, J.R., D.J. Major, R.C. Izaurralde, J.R. Williams, P.W. Gassman, M. Morrison, R. Bergentine, and R.P. Zentner. 1995. EPIC Model Parameters for Cereal, Oilseed, and Forage Crops in the Northern Great Plains Region. *Can. J. Plant Sci.* 75:679-688.

Kirkwood, V., A. Bootsma, R. de Jong, J.Dumanski, J.C. Hiley, E.C. Huffman, A. Moore, C. Onofrei, W.W. Pettapiece, and B. Vigier. 1993. Documentation of the Database Files Associated with the Agroecological Resource Area Maps for Alberta, Saskatchewan, and Manitoba (Draft). Centre for Land and Biological Resources Research, Agriculture Canada, Ottawa, Ontario.

Lakshminarayan, P.G., J.D. Atwood, S.R. Johnson, and V.A. Sposito. 1991. Compromise Solution for Economic-Environmental Decisions in Agriculture. *Journal of Environmental Management* 33:51-64.

MacGregor, R.J. 1993. Personal Communication. Economic Analysis and Innovation Division, Industry Performance and Analysis Directorate, Agriculture Canada, Ottawa, Ontario.

Milon, J.W. 1987. Optimizing Nonpoint Source Controls in Water Quality Regulation. *Water Resources Bulletin* 23:387-396.

Parton, W.J., C.V. Cole, J.W.B. Stewart, D.S. Ojima, and D.S. Schimel. 1988. Simulating Regional Patterns of Soil C, N, P and S in Grassland Soils; A Model. Biogeochemistry 5:109-131.

Prairie Farm Rehabilitation Administration (PFRA). 1990. Prairie Soils: The Case for Conservation. PFRA Soil and Water Conservation Service. Regina, Saskatchewan.

Setia, P. and S. Piper. January 1992. Effects of Soil and Agricultural Chemicals Management on Farm Returns and Ground Water Quality. *Rev. of Agr. Econ.* 14:65-80.

Shields, J.A., C. Tarnocai, K.W.G. Valentine, and K.B. MacDonald. 1991. Soil Landscapes of Canada - Procedures Manual and User's Handbook. Agriculture Canada Publication 1868/E, Land Resource Research Centre, Ottawa, Ontario.

Stockle, C.O., J.R. Williams, N.J. Rosenberg, and C.A. Jones. 1992b. A Method for Estimating the Direct and Climatic Effects of Rising Atmospheric Carbon Dioxide on Growth and Yield of Crops: Part I—Modification of the EPIC Model for Climate Change Analysis. *Agricultural Systems*. 225-238.

Stockle, C.O., P.T. Dyke, J.R. Williams, C.A. Jones, and N.J. Rosenberg. 1992a. A Method for Estimating the Direct and Climatic Effects of Rising Atmospheric Carbon Dioxide on Growth and Yield of Crops: Part I - Sensitivity Analysis at Three Sites in the Midwestern USA. *Agricultural Systems*. 38:239-256.

Stotle, W.J., S.L. Barbour, and R.G. Eilers. 1992. Study of the Mechanisms Influencing Salinity Development around Prairie Sloughs. *Trans ASAE* 35(3):795-800.

Tajek, J. 1993. Personal communication. Centre for Land and Biological Resources Research. Agriculture Canada, Edmonton, Alberta.

Taylor, M.L. 1990. *Farm-level Response to Agricultural Effluent Control Strategies: The Case of the Willamette Valley*. Ph.D. dissertation. Corvallis: Oregon State University.

Touré, A., D.J. Major, and D.J. Lactin. 1994. Sensitivity Analysis of Spring Wheat Yields to Grasshopper Pest Damage. 24th Annual Workshop on Crop Simulation, March 15-18, Department of Crop Science, North Carolina State University, Raleigh, North Carolina.

Touré, A., D.J. Major, and C.W. Lindwall. 1995a. Comparison of Five Wheat Simulation Models in Southern Alberta. *Can. J. Plant Sci.* 75:61-68.

______________ 1995b. Sensitivity of Four Wheat Simulation Models to Climate Change. *Can. J. Plant Sci.* 75:69-74.

van der Heijde, P., Y. Bachmat, J. Bredehoeft, B. Andrews, D. Holtz, and S. Sebastian. 1985. *Groundwater Management: The Use of Numerical Models, Second Edition*. Monograph 5. Washington, D.C.: American Geophysical Union.

Webber, R.J., J. D. Graham, and K.K. Klein. 1986. The Structure of CRAM: A Canadian Regional Agricultural Model. Department of Agricultural Economics, University of British Columbia, Vancouver, British Columbia.

Williams, J.R. 1992. Personal communication. Grassland, Soil and Water Research Laboratory. U.S. Department of Agriculture, Temple, Texas.

Williams, J.R. 1990. The Erosion-Productivity Impact Calculator (EPIC) Model: A Case History. *Phil. Trans. R. Soc. Land B* 329:421-28.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. A Modeling Approach to Determining the Relationship Between Erosion and Soil Productivity. *Trans. ASAE* 27(1):129-144.

Wossink, G.A.A., T.J. de Koeijer, and J.A. Renkema. 1992. Environmental-Economic Policy Assessment: A Farm Economic Approach. *Agricultural Systems* 39:421-438.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS: A Nonpoint Source Pollution Model for Evaluating Agricultural Watersheds. *J. Soil and Water Cons.* 44(2):168-173.