AGRI-ENVIRONMENTAL INDICATOR PROJECT

Agriculture and Agri-Food Canada

REPORT NO. 11

INPUT USE EFFICIENCY INDICATOR: USE EFFICIENCY FOR FERTILIZERS, PESTICIDES AND ENERGY

DISCUSSION PAPER

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October 1995

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October 1995

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1. Introduction [1]

The Agri-Environmental indicator (AEI) project of Agriculture and Agri-Food Canada (AAFC) was initiated in 1993 in response to recommendations made by a number of agencies, organizations and special studies. The overall objective of this project is to develop and provide information to help integrate environmental considerations into decision-making processes at all levels of the agri-food sector.

The project aims to develop a core set of regionally-sensitive national indicators that build on and enhance the information base currently available on environmental conditions and trends related to primary agriculture in Canada. The indicator of input use efficiency is one such indicator. Other indicators are being developed in relation to issues of soil quality, water quality, biodiversity, farm resource management and climatic change.

Key clients for the information that will be developed and reported through the AEI project include decision-makers in government and industry and other interested stakeholders. The AEIs will facilitate the design, targeting and assessment of policies and programs and help assess the agri-food sector's progress in meeting environmental and resource sustainability objectives.

This paper documents the development of input use efficiency indicators for fertilizer (plant nutrient), pesticide (plant protection), and energy inputs. Discussion includes general aspects of inputs and environment, policy context, rationale for input use efficiency indicators, methodology, data, and analyses of results.

2. Farm Inputs and the Environment

Inputs of fertilizer, pesticides, and energy are used in agriculture to optimize yields and minimize the risk of crop failure due to disease and pest attack. There are, however, environmental risks associated with their excessive or otherwise inappropriate use. As with other economic activities, agricultural production interacts with environmental resources with a possibility of impacting adversely on the quality of environment. Trends in agriculture of environmental significance, tracked through appropriate indicators, offer the potential to

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[1] The author gratefully acknowledges Joseph Thomsen of Thomsen Corporation, Ottawa for constructing the indicators under contract with Agriculture and Agri-Food Canada; Dave Culver, Max Colwell, Brian Davey, Terry McRae and Mavis Wade of the Policy *Branch,* Agriculture and Agri-Food Canada, for providing comments and assisting with graph preparation; the participants of the second national consultation workshop on agri-environmental indicators held in Fredericton, New Brunswick on February 9 and 10 for their comments on a different version of this paper presented at the workshop; and the participants of the Agri-environmental Indicator project work planning workshop, May 11-12 1995, held in Ottawa, for their useful comments on a previous version of this paper.

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forewarn about the emergence of such adverse consequences. Environmental implications of fertilizers, pesticides and energy inputs in agriculture for which the indicators are presented in this paper are summarized below.

2.1. Fertilizer

Plant nutrients (fertilizers) are essential inputs which, when properly used, contribute to maintaining soil health and optimal yields. Detrimental environmental impacts stem from excessive (inefficient) levels of application over and above plant requirements leading to build-up of fertilizer nutrients in the soil and their eventual loss in the environment. Of particular concern are nitrogen and phosphorus, both of which can contaminate water, leading to eutrophication or other forms of pollution and impacts on aquatic life. Secondly, volatilization of excess fertilizers in the form of ammonia and nitrous oxide can lead to acid precipitation, which damages the ecosystem and plant growth. These gases also contribute to climate change. In addition, the presence of heavy metals in some chemical fertilizers can contribute to contamination of soil and water, hampering plant growth and poisoning food. Factors such as soil and weather conditions (eg. sandy soil, heavy rainfall), method and timing of application, and manure handling /storage can aggravate or ameliorate the severity of environmental impacts [OECD, 1994]. Conversely, under usage of fertilizers can also lead to a loss of residual soil fertility (i.e land degradation or mining the soil).

2.2. Pesticides

Pesticides, applied largely on cereal and horticulture crops, can be lost in the environment through evaporation and leaching. Pesticide residues can also remain on crop products. Once in the environment, accumulation of active pesticide ingredients in soil and water can contribute to toxic contamination, which may be detrimental to flora and fauna. Some pesticides ingredients, like bromide in its evaporated form, contribute to stratosphere ozone depletion. Here also, soil properties and temperature, drainage, weather, type of crop, application method, timing, and frequency influence the fate and effects of pesticides in the environment [OECD, 1994].

2.3. Energy

Energy inputs used in agriculture (eg. to power farm machinery), in particular fossil fuels (gasoline, diesel, natural gas) and electricity derived from fossil fuels, generate emissions contributing to atmospheric pollution and green house effects. Expenditures on energy inputs in Canadian agriculture are significantly higher than either for fertilizer or pesticide inputs. Increased efficiency in energy use leads to reductions in relative use of energy inputs which, in turn, cuts exhaust emissions (gases, carbon dioxide etc.). As with other inputs, obtaining increased energy efficiency is also a function of the type and condition of machinery and buildings, type of fuel, timing of operation etc. [OECD, 1994].

3. Rationale for Input Efficiency Indicators

Surveys of public perceptions about agriculture and the environment consistently rank chemical input use in agriculture among the highest agri-environmental issues of concern. Of the “environmentally-sensitive" inputs, pesticides are of greatest public concern, followed by drugs and hormones, chemicals in processed food and chemical fertilizer (The Environmental Monitor, 1995).

Efficient use of environmentally-sensitive inputs is part of a larger road map to achieving environmentally (and economically) sustainable agriculture. Greater efficiency of input use generally implies less relative environmental risk (from inputs) per unit of production, as well as conservation of non-renewable fossil fuels. Thus, from both an environmental as well as an economic perspective, an important objective is the enhancement of input use efficiency. An assessment of the change in the input use efficiency indicator will show whether progress toward this objective is being achieved. This can also help to identify areas of higher environmental risk due to declining efficiency. The concept of measuring input use efficiency was endorsed at the first national consultation workshop on environmental indicators for Canadian agriculture (McRae and Lombardi, 1994).

4. Definition and Measurement

Simply stated, the general definition of input use efficiency is, "Quantity of input used to produce a unit quantity of agriculture output". Depending upon data availability this measure can be derived over time and space (country/regions). In this analysis, the indicator is expressed as an index number with a base year equal to 100.

Quantities of input and output were derived implicitly from expenditures and receipts data by deflating with appropriate price indexes. This approach overcomes the lack of actual quantity data for many input and output items and facilitates aggregation of inputs and outputs measured in different units eg. kilograms, litres, bushels. Implicit quantity is also a legitimate measure as it is expressed in constant dollars, and is proportional to and closely tracks the trends in absolute quantities used. This approach is commonly used in productivity estimations [ERS, USDA.,1989, p3].

The construction of the indicators was done as follows. First the quantity indexes for inputs and related outputs were developed using the Tornqvist divisia indexing procedure available in Time Series Processor[2] (TSP) software [ERS, USDA, 1989, p25., Narayanan *et al.* 1993, TSP]. The indicator was then derived by dividing the input index by the output index. No models or industry coefficients are involved in this procedure. This indicator is similar to Transport Canada's rating of automobile fuel efficiency by litre of gasoline consumed per

[2] DIVIND procedure in TSP is used to compute Tornqvist indexes.

100 Km. A lower index number indicates a higher efficiency. A declining trend in this indicator (as in charts 2,4, and 6) is therefore environmentally desirable. Other relevant details of the indicators are:

a) Fertilizer input covers only chemical fertilizers providing the nitrogen (N) phosphorus (P), and potash (K) crop nutrients. Manure fertilizer is excluded. Efficiency is related only to crop production, where chemical fertilizer is mostly applied.

b) Pesticide input includes herbicide, insecticide and fungicide. Efficiency is related only to crop production to which pesticides are applied.

c) Energy input includes fuel and electricity. Efficiency is related to all output (crop and livestock) because energy is used in both livestock and crop operations.

5. Data Sources

All the data required to develop the input use efficiency indicators were obtained from the productivity data base maintained by the Policy Branch, Agriculture and Agri-Food Canada [Agriculture and Agri-Food Canada, 1994]. This data base includes detailed annual accounts of quantities, expenditures, price indexes and derived prices of about 200 input and output items for the 1961-1992 period by provinces, regions and Canada. This data base was developed from published and specially requested data on farm output quantities, market receipts, program payments, output inventories, input expenditures/quantities and inventory change, prices, and price indexes by items from Statistics Canada and Industry associations. This data base is used primarily to construct multi-factor productivity indexes for Canadian agriculture by provinces and regions and is updated annually.

6. Results and Analysis

Spatially, the indicators are calculated for the Prairie region, non-prairie region (Canada excluding Prairie provinces) and Canada and the results are presented graphically in charts 2,4 and 6 and numerically in the appendix tables 1-3. This type of regional differentiation, as opposed to traditional east and west regions, is purposely adopted because the prairie provinces account for majority of the inputs used - about 65 to 70 percent of fertilizer and pesticide inputs, and 60 percent of energy inputs. The charts and the tables show implicit quantities of inputs and outputs and input use efficiency indexes. The results were generated for the 1961 to 1992 period; but analyses of use efficiency of fertilizer and pesticide inputs were confined to the post 1980 period. In the 1960's and the 1970's, the input industries and the producers went through a phase of rationalization and gradual adoption showing unstable and erratic use trends. Only since the mid to late 70's have application levels stabilized. The situation was quite different for energy input where farm mechanization and energy use progressed uniformly across the industry after the second world war, spurred by low energy prices.

6.1. Fertilizer (Chemicals only)

6.1.1. Total Use and Related Crop Output

Chart 1 and Appendix table 1, which show fertilizer quantities used annually from 19611992, indicate that fertilizer use in the prairie region was generally higher (barring in the early to mid 1960's) and grew much faster relative to the non-prairie region. The use in the prairie region grew at an annual rate of 12.5% in the 1960's (1962-1971), 12.2% in the 1970's(1971-1980) and 3.0% in the 1980's (1980-1992), compared to only 4.9%, 5.9% and 1.7% respectively in the non-prairie region. This pattern of growth gradually levelling in the 1980's indicates convergence to a stable pattern in total use. For Canada as a whole, annual growth in total fertilizer use was 7.5% in the sixties, 9.0% in the seventies and 3.0% in the eighties. The intensity of fertilizer use (Kg/ha) always remained higher in the non-prairie region, with its crop area being 5 to 6 times lower and total use only two times lower, than in the prairie region. According to the 1991 census of agriculture, the fertilizer use intensity in the non-prairie region was 2.7 times higher than in the prairie region. The distribution of chemical fertilizer use by crop nutrients on the average was N =65%, P =30% and K= 5%. in the prairies, and N =40%, P= 25%, and K =35% in the non-prairie region.

Chart 7 and Appendix table 4 give the related crop output quantities. Crop output in the prairies was higher than in the non-prairie region (average by about one third) and grew at an annual rate of 3.2% in the 1960's (1962-1971),1.3% in the 1970's (1971-1980), rebounding to 3.3% in the 1980's (1980-1992). The non-prairie region crop output grew at annual rates of 1.7%, 3.3%, and 1.5% in the 1960's, 1970's and 1980's respectively. For Canada as a whole, the crop output growth pattern was similar to the prairies but the rates were lower. In the 1980's, the use efficiency analysis period, the crop output was relatively stable in the non-prairie region whereas in the prairie region, it grew faster with high year to year variability.

6.1.2. Use Efficiency

Chart 2 and Appendix table 1 present the Input use efficiency indexes (1991=100) by region. Only the indexes for the 1980-1992 period, to which analysis is confined, are shown in Chart 2. In both regions the pattern of change (peaks and valleys) in efficiency use is similar although in the non-prairie region the peaks are less pronounced. Efficiency levels were highest in the 1980-1982 period. A severe farm financial crisis that occurred in this period compelled farm producers to cut inputs to below normal levels, as a cost saving measure - a deviation from the normal situation. Therefore input efficiency trends over the subsequent (1983-1992) period were examined.

In the prairie region, the fertilizer use efficiency trend over the 1983-1992 period improved, with a high year to year variability (Chart 2). Over this period, fertilizer use efficiency increased at an annual rate of 2.3%, based on the index trend line. The peak indexes in 1984 and in 1988, denoting a strong decline in fertilizer use efficiency, are attributable to major droughts which kept the crop output down (chart 7) considerably, after most fertilizers were applied at planting.

The environmental significance of this trend is interpreted as follows. First, this trend in efficiency relates only to chemical fertilizer use. In this regard, the increasing trend in fertilizer use efficiency means that in the prairie region, increase in crop output had outpaced the increase in chemical fertilizer use. The trend is therefore, in the right direction, conducive to a reduction in the risks of water contamination from nutrients, although these risks are lower in the prairie region (than in the non-prairie region) due to dry climate and deeper soils. However, given the historical under fertilization of prairie soils and reliance on organic matter as a nutrient source, this trend could also mean a diminishing rate of increase in chemical fertilizer use at the expense of residual soil nutrients and organic matter (land degradation/soil mining), which is clearly undesirable from the soil health point of view. However, the prairie provinces account for about half of Canada's annual manure production (49.9 million tonnes) which is applied to farmland, although at a low rate (between 1 to 2 tonnes per ha), because of extensive grazing land for cattle (Dyer J.A, 1995). Therefore, the land degradation (i.e soil mining) interpretation would require further investigation in view of the possibility of soil nutrients being at least partially replenished by manure applications, which has been discounted by this indicator.

In the non-prairie region, efficiency index levels moved within a relatively shorter range (Chart 2) indicating relatively less variability in fertilizer use efficiency. Over the 1983-1992 period, the efficiency index trend line sloped slightly upward, meaning input use efficiency actually declined at about 0.5% per annum. Within this period, efficiency declined substantially until 1986, but subsequently improved by 1992 to near the 1980 level.

The environmental significance of these trends have to be interpreted carefully in conjunction with other background factors. First, the threat and potential for water contamination and leaching is greater in this region due mainly to the wetter climate (ecological difference). Second, manure production and application on a per hectare basis is several times higher in this region compared to the prairies, substantially elevating the manure nutrient concentration in the soils and its associated risks of water contamination (Dyer, J.A, 1995). Third, the intensity of fertilizer use is also relatively much higher in this region (observed earlier). Considering the above, the declining fertilizer use efficiency trend in this region could pose environmental risks, particularly to water quality, but these risks may have declined since 1986. Factors such as increases in legume (eg. soybean) acreage, soil testing, environmental auditing, environmental farm plans, and improved input management practices offer the potential to offset some of these risks and to continue the efficiency improvement trend which commenced after 1986.

Nationally, the trend in fertilizer use efficiency index (chart 2) appears very similar to Prairie region - downward sloping over 1983-1992 although the slope is less pronounced. This implies an increase in use efficiency estimated at rate of 1.1% per annum - less than half of the prairie rate. The non-prairie declining trend has been totally masked, therefore, the interpretations at the national level should be properly qualified.

Chart 1

Fertilizer Total Use

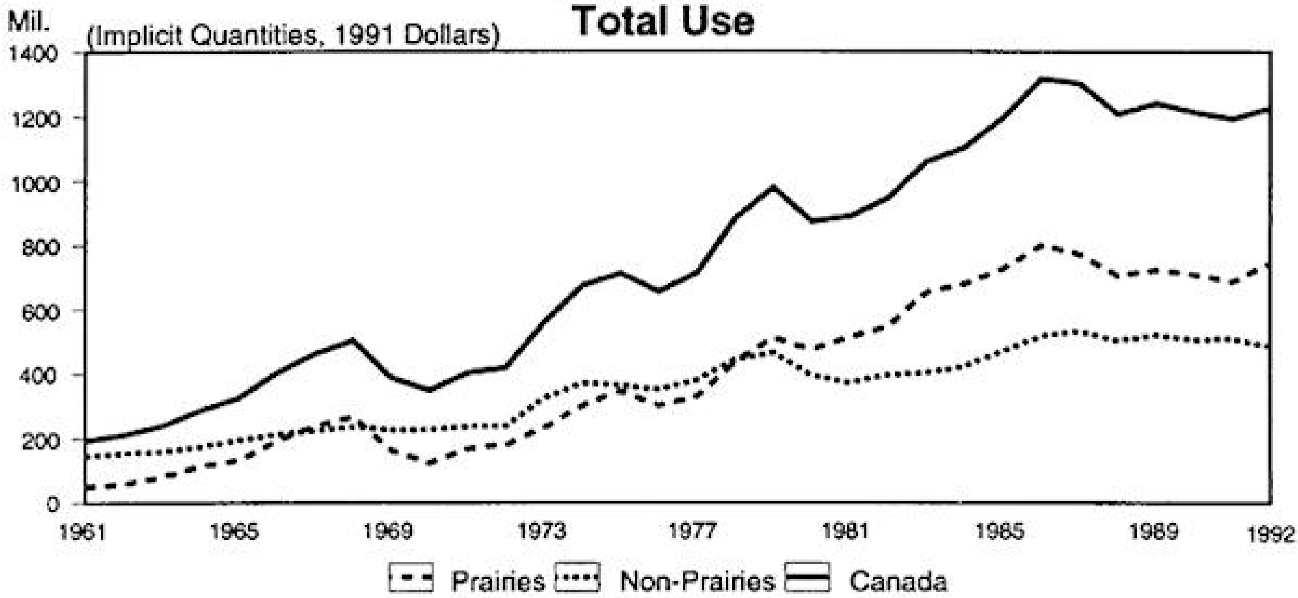
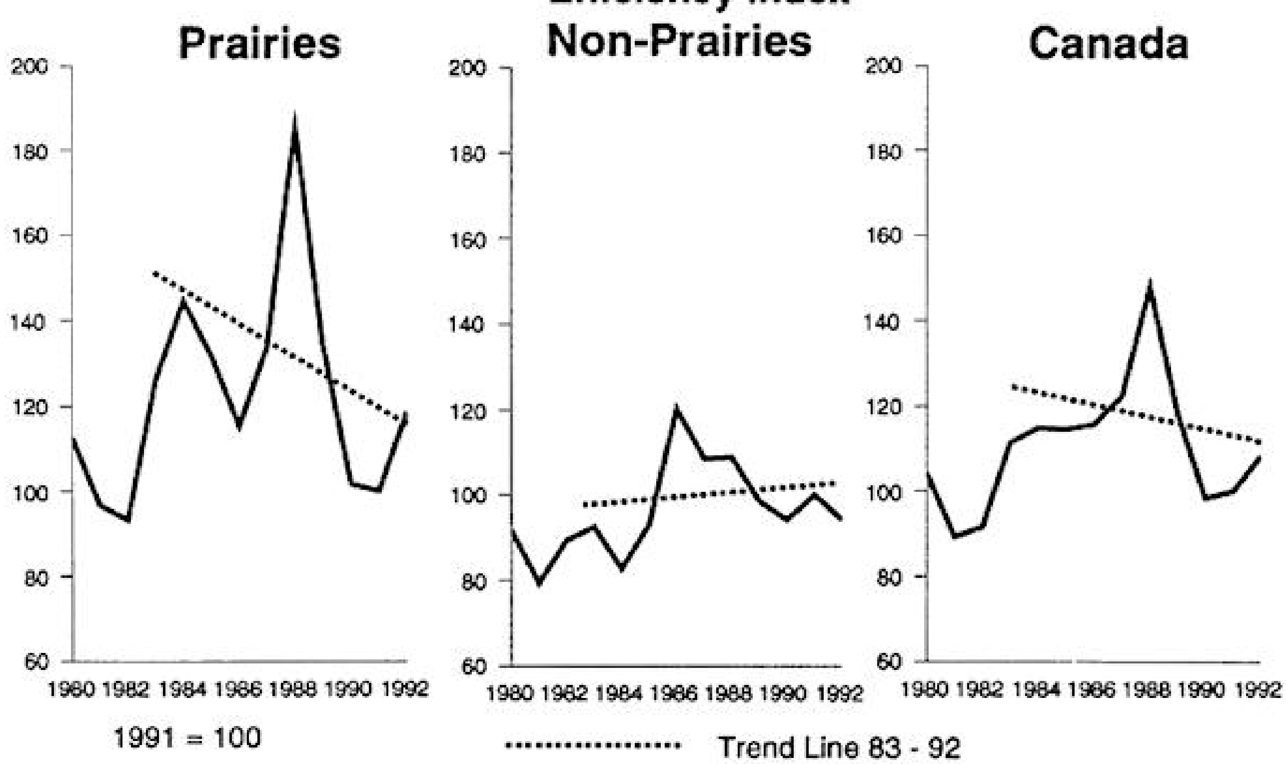


Chart 2

Fertilizer Efficiency Index



6.2. Pesticides

6.2.1. Total Use and Related Crop Output

The pesticide use pattern over 1961-1992 (chart 3 and Appendix table 2) is similar to fertilizers. In the Prairie region, pesticide use increased steadily and sharply over 19611992. In the non-prairie region pesticide use rose moderately until the early 1980's and fell sharply thereafter. Total pesticide use as a ratio of fertilizer use was lower in the non-prairie region (less cropped area) although intensity of use was much higher.

In the Prairie region annual growth in pesticide use was 2.9% in the 1960's (1962-1971), rising steeply to 18.1% in the 1970's (1971-1980) and falling to 9.3% in the 1980's (1980-1992). In the non-prairie region annual growth rate was 5.0% in the 1960's, rising to 8.2% in the 1970's and sliding to deep negative -9.0% in the 1980's. Nationally, total use increased steadily over 1961-1992. Annual growth rates were, 4.7% in the 1960's, rising to 10.8% in the 1970's, and falling to 1.8% in the 1980's. The crop output pattern remains the same as discussed before under fertilizers.

6.2.2. Use Efficiency

Chart 4 and Appendix table 2 show the pesticide use efficiency indexes by regions over 1980-1992. In the prairie region, the variability pattern in the index was similar to the pattern for fertilizer. The highest use efficiency occurred in the 1980-1982 period. As explained in the case of fertilizers, this also represented a deviation from normality, attributable to compulsory ad hoc adjustments in response to severe financial stress in this period. The peak levels in the index also occurred in 1984 and 1988, indicating lowest efficiency due to drought impact on the final crop output. But, unlike in the case of fertilizers, the use efficiency trend over 1983 and 1992 was negative (Chart 4). The decline translated to 1.6% per annum, which may have implications for bio-diversity and water quality concerns. However, this decline can be attributed, in part, to the rapid increase in the adoption of conservation and no-till farming in the prairie region since the 1980's, which requires chemical methods (herbicides) for weed control. Since conservation-till and no-till agriculture provide several important environmental benefits (eg. erosion control, carbon sequestering, improved soil structure) extraneous to this indicator, the implications of this trend should be interpreted with caution using information derived from other indicators.

In the non-prairie region, where the intensity of pesticide use is much higher, this indicator shows a continual and rapid increase in pesticide use efficiency between 1983 and 1992, estimated at 8.8% per annum. This achievement is very significant for this region where the risks of leaching and water contamination are greater, underscoring the potential for enhancing water quality.

Chart 3

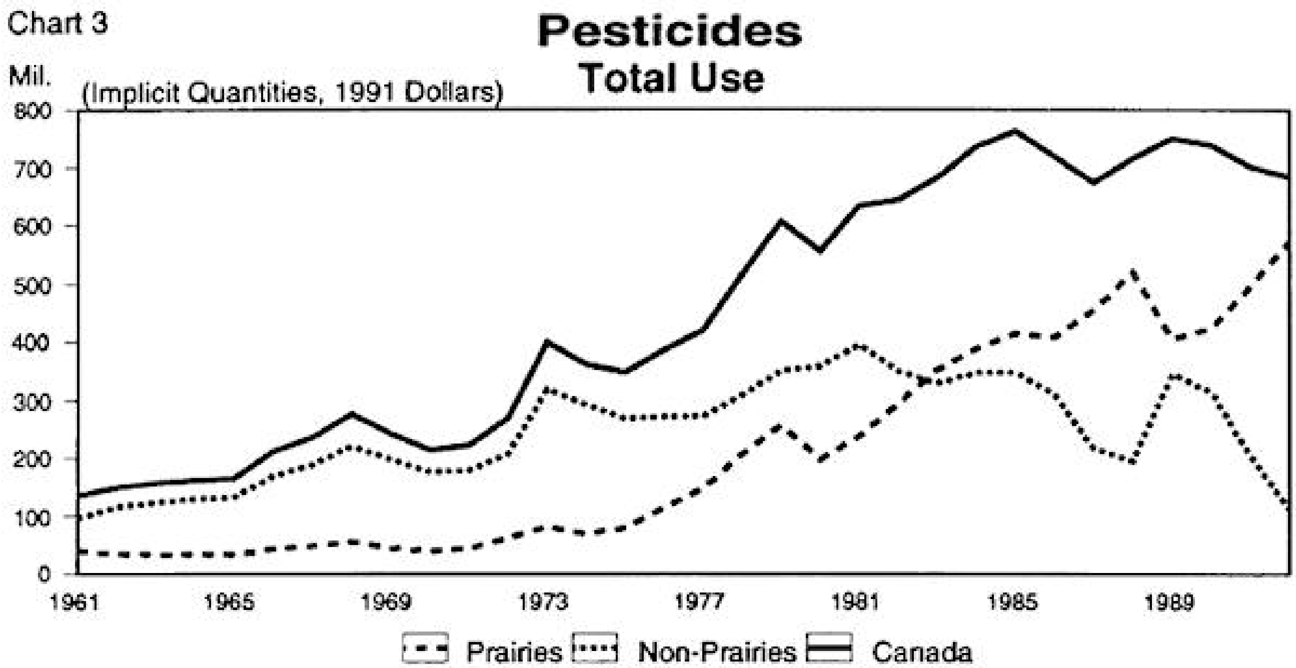
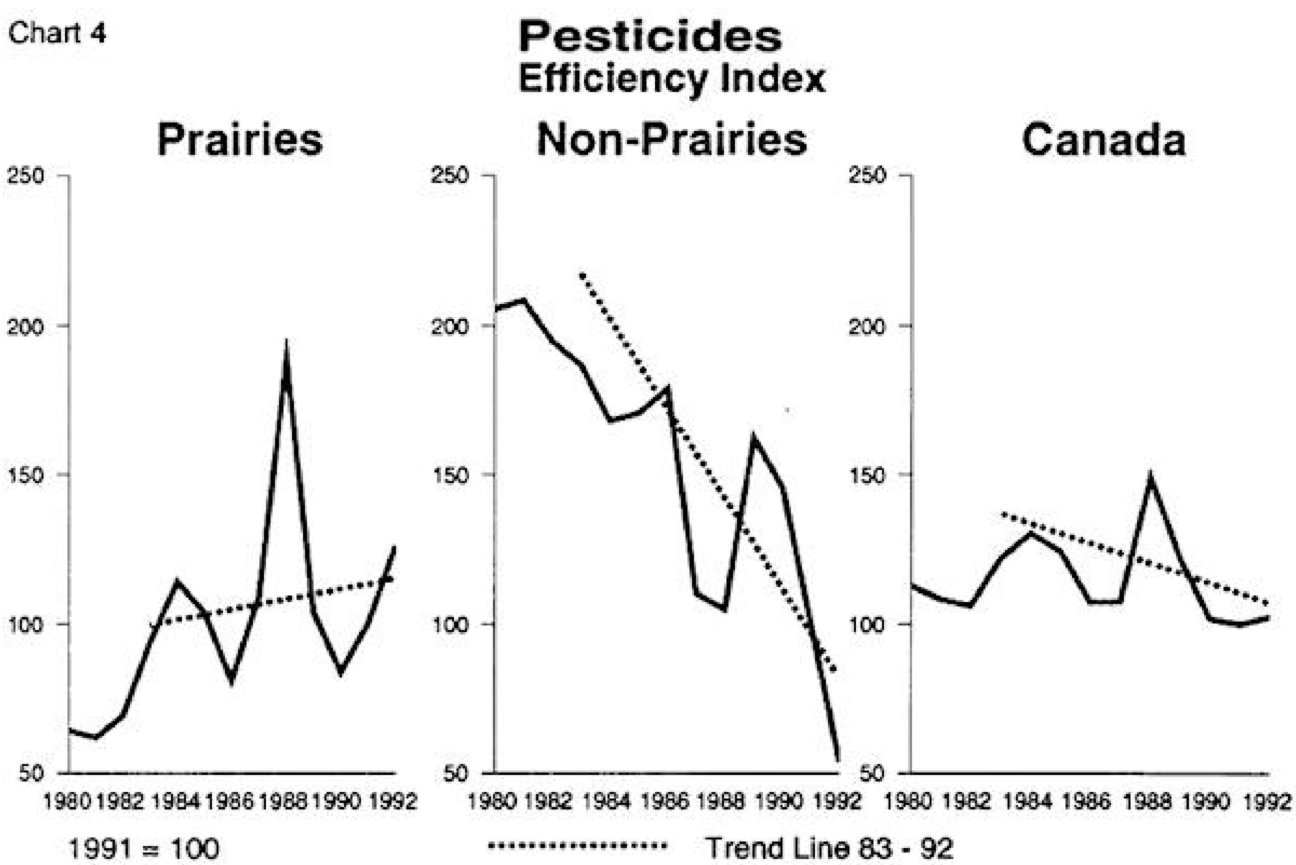


Chart 4



Nationally, the variability pattern in this index was more akin to non-prairie pattern (Chart 4). The indexes peaked in 1984 and 1988 and troughed in 1982 and 1986. The trend in the index was distinctly downward with a moderate slope, largely due to the influence of the negative non-prairie trend. This reflected an increase in use efficiency at an annual rate of 2.5%. This result, however, masks the declining pesticide use efficiency trend in the prairies and therefore, the interpretations should be properly qualified.

6.3. Energy

6.3.1. Total Use and Related Total Output

Chart 5 and Appendix table 3 give the quantities of energy used by regions over the 1962-1992 period. Compared to total use of fertilizers and pesticides individually (charts 1 and 3), it is evident that energy use is much higher in all the regions. Also, energy use in the prairie region exceeds energy use in the non-prairie region, by a narrow margin in the 1960's and by a wider and relatively steady margin in the 1970's and 1980's. In the prairie region, energy input grew at an annual rate of 3.5% in the 1960's (1962-1971), 0.9% in the 1970's (1971-1980), and -1.0% in the 1980's (1980 -1992). In the non-prairie region, the corresponding annual growth rates were, 3.0% in the 1960's (closer to prairies), -0.9% in the 1970's and -1.8% in the 1980's.

Sixty eight percent of the total energy use in the prairies and sixty percent in the non-prairie region was of fossil fuel origin. The use of electricity was higher in the non-prairie region because of the large supply of hydro and nuclear electricity in that region. For Canada as a whole, this translated to 3.2% annual growth in total energy use in the 1960's, 0.09% or close to zero growth in the 1970's and a negative 1.3% growth in the 1980's. Overall, energy use grew in the 1960's and early 1970's, levelled off and fell since 1980. From an environmental point of view this is quite encouraging. Cost (economics), energy and soil conservation efforts appear to have contributed to this phenomenon.

Total output (crop and livestock), to which energy use efficiency is related to, is shown in Chart 8 and Appendix table 4 for the 1962-1992 period. As can be seen, total output in the non-prairie region always exceeded the output in the prairie region. This is primarily due to the predominance of livestock and high value cash crops (horticulture, soybeans) in the non-prairie region. However, the gap between them appears to narrow considerably by the early 1990's. Total output in the non-prairie region grew steadily at an average annual rate of 1.2% over the 1962 to 1992 period. In the prairie region, the annual growth rate over the same period was higher at 2.3%, but the year to year variability was also higher, indicating the risks and uncertainties of the dry prairie climate. For Canada overall, total output rose at an average annual rate of 1.7% over 1962-1992.

6.3.2. Use Efficiency

Chart 6 and Appendix table 3 give the energy use efficiency indexes over 1961-1992. The trend in the indexes is sharply downward in both the prairie and non-prairie regions which indicates increasing energy use efficiency over this period. In the prairie region, where energy is used less intensively, index movement between 1961 and 1992 shows a high year to year variability and a consistent downward trend. This implies a consistent increase in input use efficiency over this period estimated at an annual rate of 1.7%. In fact, the use efficiency increased the most over the 1980-1992 period at an annual rate of 3.8%. The variability pattern (high's and the low's) in this index was similar to fertilizer and pesticide inputs. The impact in the drought years (1984 and 1988) was relatively mild because livestock output was not seriously affected by drought and energy use for major operations (harvesting and drying) was saved.

In the non-prairie region, where energy is used very intensively in livestock and horticulture enterprises, the year to year variability in the index levels over 1961-1992 was considerably lower. The index trend was sharply downward with a slightly higher slope than in the prairie region, indicating a higher increase in energy use efficiency estimated at 2.3% per annum. The growth in use efficiency was very slight (0.6% per annum) over 1980-1992 - more or less flat.

Nationally, the energy use efficiency index levels remained in the middle range *between* prairie and non-prairie regions over 1961-1992, by and large reflecting the dominant prairie pattern in slope and year to year variability. This indicates consistent gains in energy use efficiency estimated at 1.9% per annum.

These achievements of energy efficiency gains, both nationally and regionally, are likely due to improved genetics and plant productivity, greater use of no-till agriculture, and improved energy efficiency in farm buildings and machinery. This is positive and significant in terms of diffusing the environmental pressures associated with energy use (eg. carbon dioxide and particulate emissions), as well as for conserving non-renewable fossil fuel resources.

7. Limitations of the Input Use Efficiency Indicators

Inherent in the measurement of the input use efficiency indicators, as well as in the study procedures, *are* several limitations as described below.

- Implicit quantities of inputs, used in the derivation of the indicators, partially overcome the problem of lack of actual and consistent data, and aggregation of heterogenous input items. But this limits direct comparison of total use and efficiency index levels between inputs and by commodity. Comparison between regions for the same input is justifiable provided the regional price deflators are weighted properly.

Chart 5

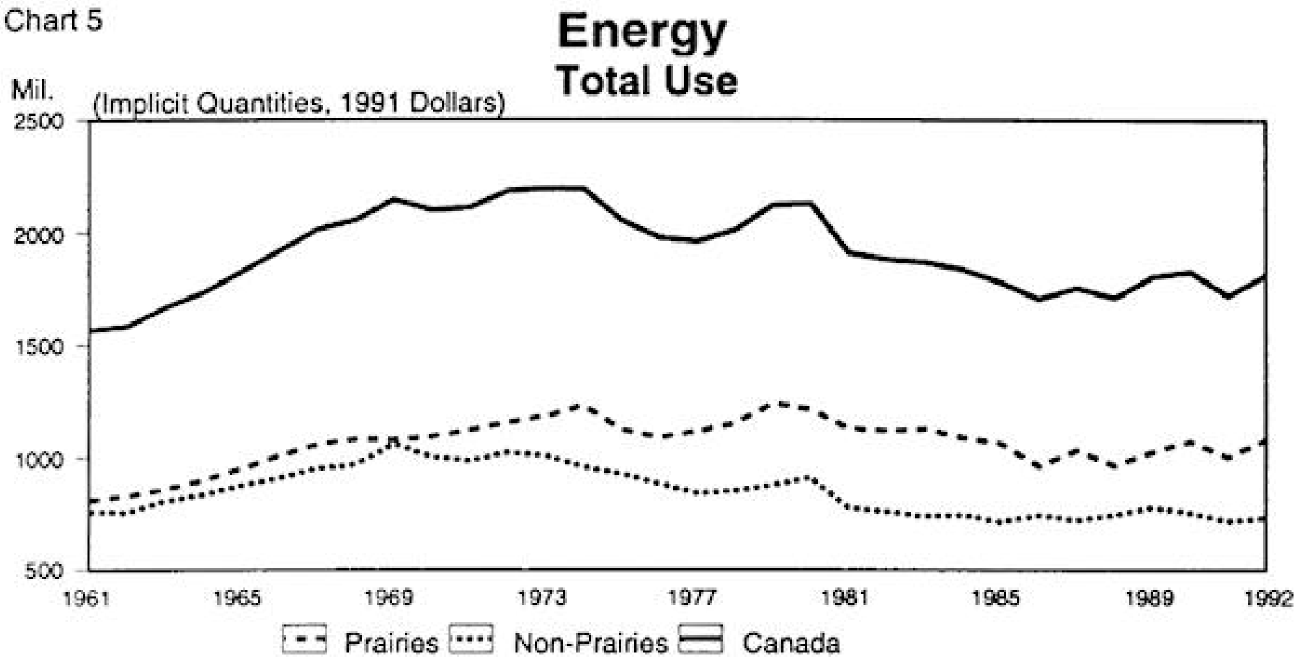


Chart 6

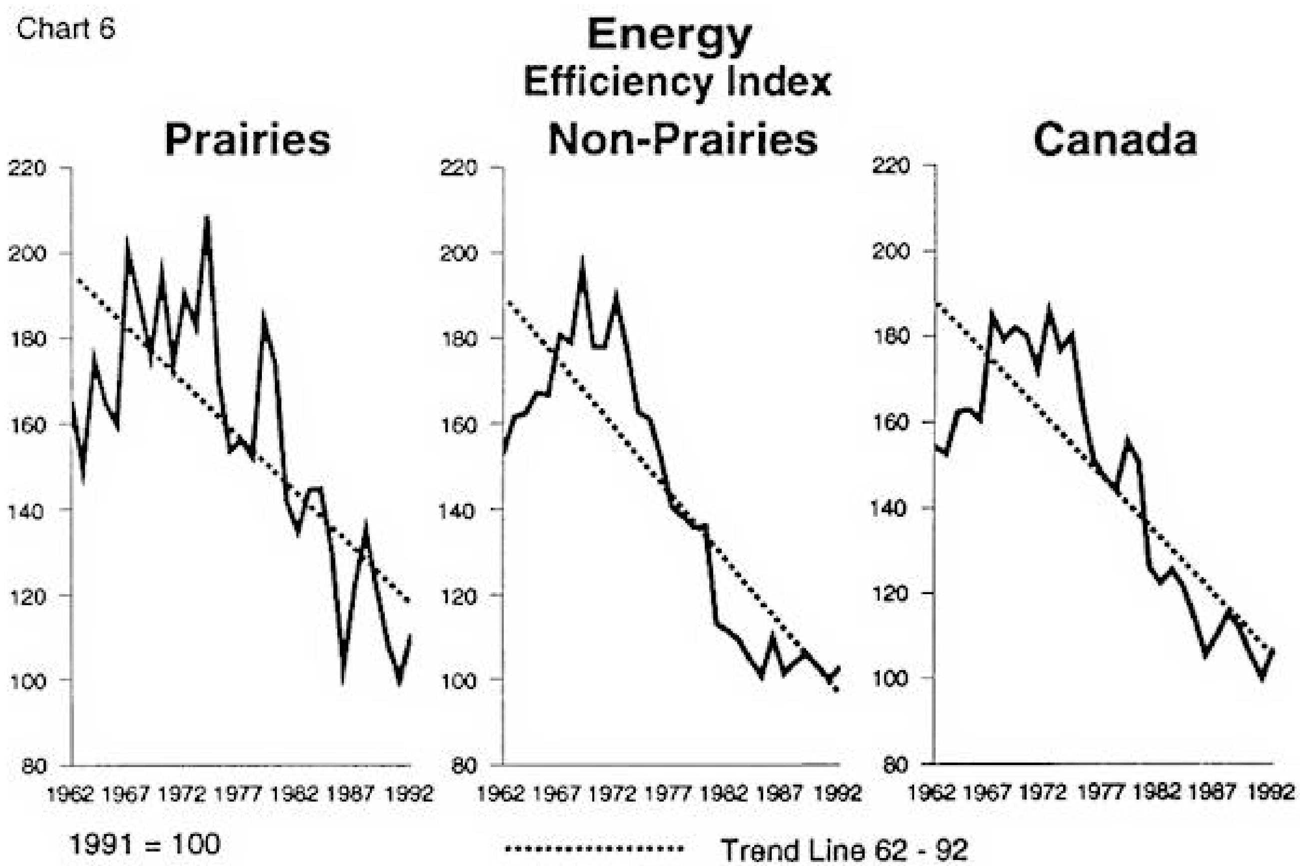


Chart 7

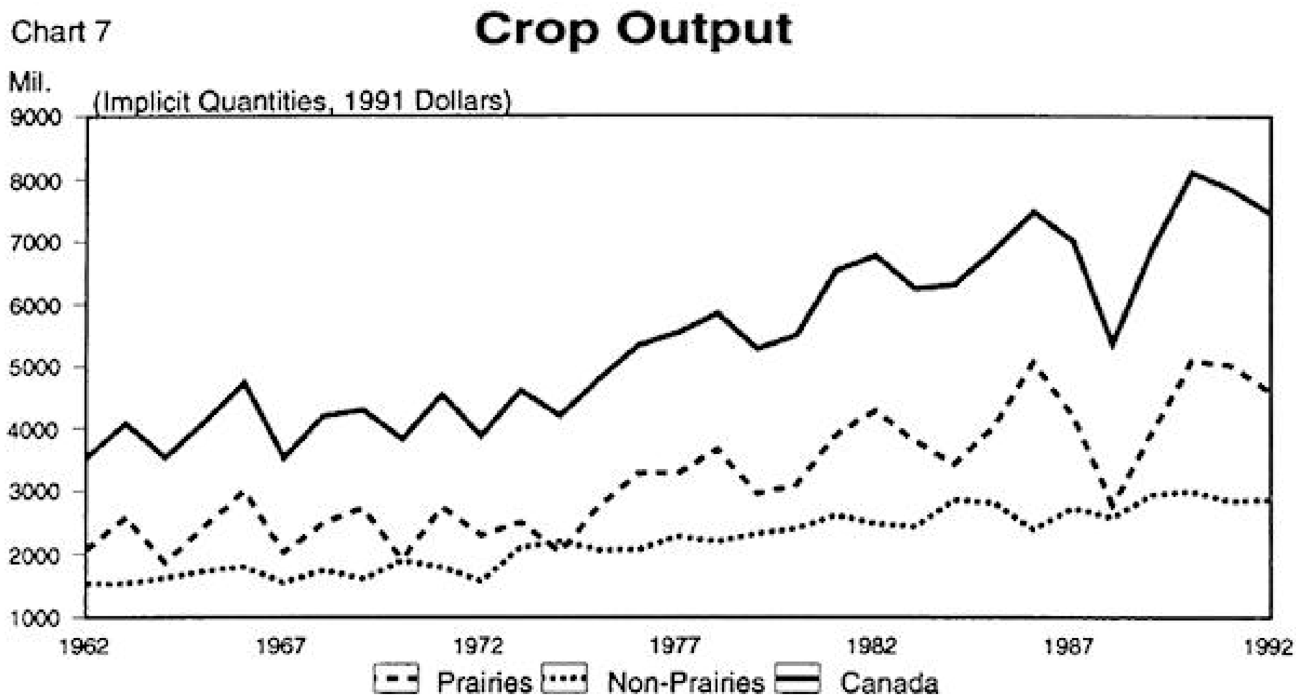
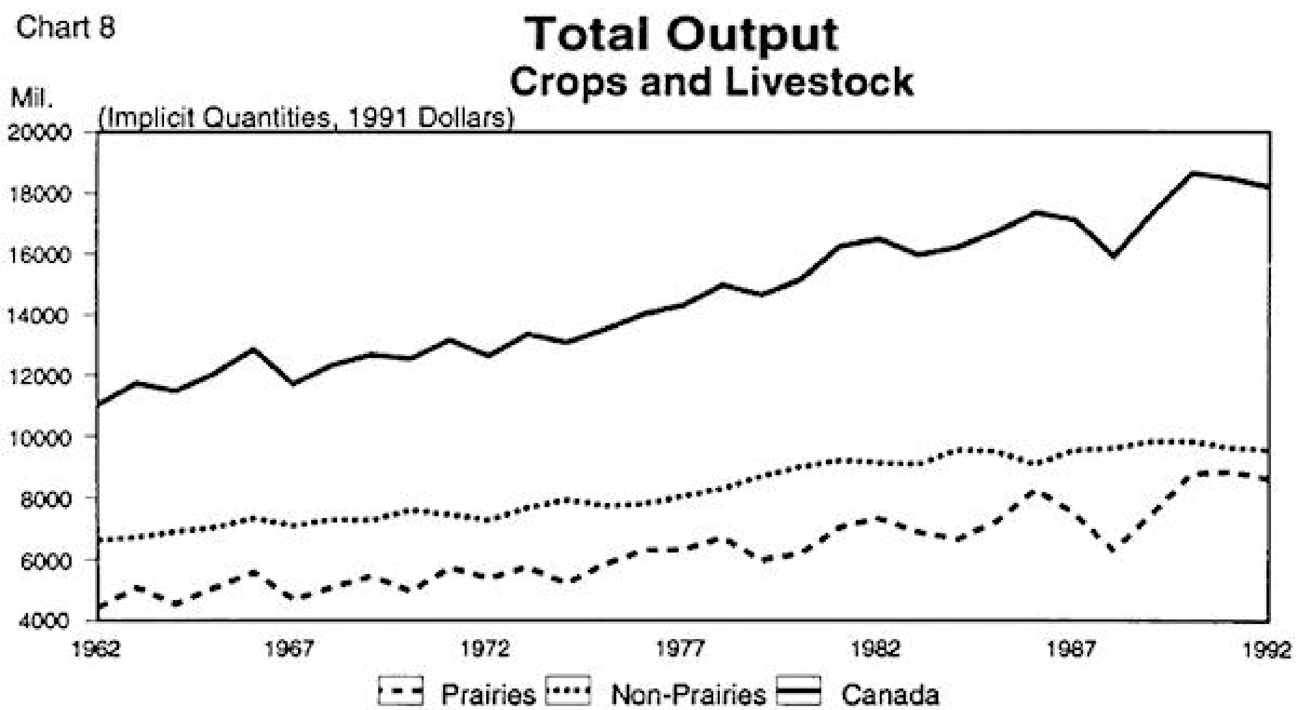


Chart 8



- The indicators are aggregative and lumpy; i.e separate ingredients are combined into one input eg. N, P, and K fertilizers, and various pesticide compounds. This limits the scope to use the indicator to target policy actions toward specific input ingredients with relatively higher adverse environmental risks.

- The indicators cannot be assessed against a performance objective or standard because no such standard exists. Therefore, the change and the direction of change in the indicators are used as a means for assessing the results.

- The input indicators per se do not to provide quantitative explanations of the causes for the changes and trends in them, nor do they capture their indirect environmental impacts or benefits. These are explained qualitatively based on available extraneous information (eg. drought). Absence of full information and complementary indicators impose limitations in fully explaining the causalities and indirect environmental consequences. A case in point here is the herbicide substitution of mechanical weed control under reduced tillage which leads to increased pesticide use and a declining trend in the pesticide use efficiency indicator. Neither the herbicide substitution, nor the indirect environmental benefit of the reduced tillage, can be directly interpreted from the pesticide use efficiency indicator.

8. Summary and Conclusions

Conclusions presented here follow mainly from the analyses of input use efficiency trends (direction) and growth rate (change) for prairie, non-prairie and Canada regions.

8.1. Fertilizer

Fertilizer use efficiency settled to a stable pattern only after the late 1970's. Over 1983-1992, in the prairie region, chemical fertilizer use efficiency rose by 2.3% per annum. Over the same period, in the non-prairie region the fertilizer use efficiency declined slightly by 0.5% per annum.

In terms of implications for the environment, the increasing fertilizer use efficiency trend in the prairie region implies a positive and favorable trend for environmentally sustainable agriculture, at least from a water quality perspective. This trend could also mean diminishing or under use of chemical fertilizers for crops compensated by the residual soil nutrients and organic matter, depleting soil health (i.e land degradation /soil mining) . However, this interpretation is questionable as it does not take into account the manure produced and applied to farmland, which replenishes soil fertility.

In the non-prairie region, on the contrary, the environmental consequences of the declining trend in chemical fertilizer use efficiency appears very adverse until 1986, with subsequent improvement. This is because the intensity of chemical fertilizer and manure application to farmland is basically much higher in this region, further aggravated by the higher potential for water contamination and leaching due to a wetter climate. Recent developments in this region, such as conservation tillage, input management practices, environmental farm plans, increased soil testing and increased legume (soybean) acreage offer some potential for mitigating and reversing the trend in efficiency in the future.

8.2. Pesticides

Pesticide use efficiency also settled to a stable pattern only after the late 1970's. Pesticide use efficiency In the prairie region had a declining trend over 1983-1992. at a rate of 1.6% per annum. Although this may have some negative consequences, the decline is primarily attributable to the rapid increase in the adoption of conservation tillage in the 1980's, which substantially boosted herbicide use for weed control. Several environmental benefits accruing from conservation tillage are not captured by this indicator.

In the non-prairie region, the pesticide use efficiency over the same period showed a very strong increasing trend at a rate of 8.8% per annum. This is very positive and a significant trend for this region where the intensity of pesticide use, and the risks of leaching and water contamination, are higher.

8.3. Energy

Total energy use in Canadian agriculture expanded from 1960's to about mid 1970's in both the prairie and non-prairie regions and then declined consistently - relatively more in the non-prairie region. Energy use efficiency improved consistently over 1961-1992 showing a steady rising trend at an annual rate of 1.7% in the prairies, and 2.3% in the non-prairies. Year to year variability in efficiency was considerably less in the non-prairie region, more or less flat since 1987. The trends regionally and nationally underscore consistent energy efficiency gains in Canadian agriculture over the long term (1962-1992), which is conducive to environmentally sustainable agriculture and non-renewable resource conservation. These improvements are likely due to improved genetics and plant productivity, greater use of no-till agriculture, and improved energy efficiency in farm buildings and machinery.

8.4. General

It is important that the trends in input use efficiency be assessed in conjunction with other relevant indicator(s) such as risk of water contamination and soil degradation risk, to arrive at proper inferences.

The ability to develop environmental indicators for Canadian agriculture from economic data, offering agricultural trends of environmental significance, is demonstrated. As demonstrated in the paper, these indicators can be developed on a regional basis, and by input categories, further enhancing their usefulness.

9. Future Work.

Recommendations for future work stem mainly from refinement possibilities and comments from professionals and stakeholder groups[3]. These are as follows:

- Develop indicators by ingredient category (i.e. fertilizer by N, P, K elements) and/or by crop in order to study trends by input ingredients with their associated environmental impacts. This will remove the limitations imposed by lumping and will provide information to target policy actions at specific environmentally sensitive input sources and commodities. Although this should be feasible, some data problems are envisaged, particularly for disaggregating the indicators by crop.

- Establish threshold/critical levels (i.e standards or levels based on environmental and economic factors) to quantitatively interpret input use efficiency indicators. Such levels should be based on ensuring adequate output, and defined by agro-ecological regions for each input ingredient, not lumped. They would serve as a benchmark to producers to adjust inputs against in order to minimize environmental impact. Further investigation is necessary to determine the possibility of establishing such thresholds.

- Develop separate energy efficiency use indexes by crop and livestock outputs (not applicable to fertilizer /pesticide efficiency which is related to only crop output). Disaggregating Indexes by ingredients and outputs will reveal trends which will help to focus policy actions.

- Develop input use efficiency indicators by converting fertilizer, pesticide, and energy inputs and outputs into standard energy units based on available conversion coefficients and then divide the energy units of input by energy units of output to arrive at the indicators. This will greatly enhance the validity and interpretation of efficiency indexes. Further investigation is required to determine the feasibility in terms of data and information requirements and availability. This also offers scope to develop indicators by commodity and smaller spatial levels (crop district or ecological district level).

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3 Comments from professionals and stakeholder groups were obtained at the Second National Consultation workshop on Agri-Environmental Indicators for Canadian Agriculture held in Fredericton, New Brunswick February 9 and 10, 1995, and from the participants of the Agri-Environmental indicator project work planning workshop, May 11-12,1995, held in Ottawa.

- Develop input use efficiency indexes for other countries (U.S., E.U.) for comparison of trends with Canada. This is feasible at the country level and for aggregate input categories as done in this paper. Comparable data from the U.S and E.0 are available.

- Although separate from the actual indicator analysis, the availability of quantitative input use data (particularly by nutrient and pesticide type) by crop and region (eg. watershed or soil landscape polygon) would significantly enhance the scope of the indicator

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APPENDIX TABLES

Table 1.

	Fertilizer					
	Total Use. Implicit Quantities (1991 Mil.$)			Input Efficiency Index (1991 = 100)		
	Prairies	Non-Prairies	Canada	Prairies	Non-Prairies	Canada
1961	49.1	144.3	193.4	45.5	17.0	24.0
1962	57.7	153.6	211.4	20.4	56.0	39.3
1963	79.8	158.8	238.6	22.5	57.6	38.4
1964	112.9	173.7	286.7	44.2	59.8	53.3
1965	130.9	194.8	325.8	39.0	62.8	52.1
1966	191.1	212.6	403.7	46.4	65.9	55.9
1967	238.9	223.6	462.5	86.4	80.6	86.1
1968	267.6	236.2	503.8	78.5	75.5	78.8
1969	162.3	226.4	388.7	43.5	78.7	59.4
1970	123.1	226.9	350.0	47.1	66.7	60.2
1971	167.6	236.6	404.2	44.6	73.6	58.5
1972	181.4	238.2	419.6	57.7	84.6	71.2
1973	233.5	324.7	558.2	68.1	86.1	79.6
1974	301.8	371.1	672.9	109.0	94.2	105.4
1975	346.4	364.4	710.9	91.5	98.9	97.4
1976	301.6	352.3	653.9	67.1	95.1	80.5
1977	329.9	381.4	711.3	73.6	93.4	84.4
1978	436.0	443.4	879.3	87.2	112.9	98.8
1979	511.6	464.7	976.3	126.7	111.5	121.5
1980	475.2	395.8	871.0	112.3	91.7	104.2
1981	513.9	372.4	886.3	96.6	79.4	89.2
1982	545.5	398.0	943.5	93.2	89.4	91.6
1983	653.3	404.2	1057.5	126.1	92.5	111.4
1984	678.1	423.8	1101.9	144.5	82.8	114.8
1985	725.3	470.4	1195.7	131.8	93.1	114.5
1986	799.5	517.0	1316.6	115.3	120.2	115.6
1987	770.8	531.5	1302.3	133.9	108.6	122.2
1988	704.5	502.8	1207.3	185.3	108.8	147.9
1989	721.3	519.4	1240.7	134.4	98.5	118.3
1990	707.9	504.8	1212.7	101.7	94.2	98.3
1991	684.6	508.1	1192.7	100.0	100.0	100.0
1992	743.1	483.2	1226.3	118.5	94.2	108.2

Table 2.

	Pesticides					
	Total Use. Implicit Quantities (1991 Mil.$)			Input Efficiency Index (1991 = 100)		
	Prairies	Non-Prairies	Canada	Prairies	Non-Prairies	Canada
1961	40.1	95.7	135.8	51.3	28.0	28.7
1962	34.1	115.7	149.8	16.6	104.5	47.4
1963	33.6	123.8	157.4	13.1	111.4	43.1
1964	32.7	129.8	162.5	17.7	110.8	51.4
1965	33.2	132.9	166.1	13.6	106.1	45.2
1966	43.4	169.6	212.9	14.5	130.4	50.2
1967	47.8	189.2	237.1	23.9	169.1	75.1
1968	55.7	220.9	276.6	22.5	175.0	73.6
1969	44.2	198.4	242.6	16.3	171.0	63.0
1970	38.5	176.1	214.7	20.3	128.3	62.8
1971	43.8	178.6	222.5	16.1	137.8	54.7
1972	61.7	207.7	269.4	27.1	182.9	77.8
1973	80.5	318.3	398.7	32.4	209.3	96.7
1974	68.4	292.2	360.5	34.1	183.9	96.1
1975	78.8	268.2	347.1	28.7	180.5	80.9
1976	113.9	271.7	385.6	35.0	181.9	80.7
1977	147.1	271.9	419.1	45.3	165.0	84.6
1978	206.1	308.5	514.6	56.9	194.7	98.4
1979	256.7	348.7	605.5	87.7	207.5	128.2
1980	197.0	357.7	554.7	64.3	205.4	112.8
1981	238.4	394.1	632.5	61.8	208.3	108.3
1982	293.6	349.4	643.1	69.2	194.6	106.1
1983	352.1	328.9	681.0	93.8	186.7	122.0
1984	388.1	347.0	735.1	114.1	168.1	130.3
1985	414.5	347.9	762.4	103.9	170.7	124.2
1986	407.7	310.4	718.1	81.1	179.0	107.3
1987	455.9	217.7	673.5	109.3	110.3	107.5
1988	519.3	195.7	715.0	188.5	105.1	149.0
1989	405.1	345.1	750.2	104.1	162.3	121.7
1990	423.4	314.8	738.2	83.9	145.6	101.8
1991	496.2	204.9	701.1	100.0	100.0	100.0
1992	572.0	111.7	683.7	125.9	54.0	102.6

Table 3.

	Energy					
	Total Use. Implicit Quantities (1991 Mil.$)			Input Efficiency Index (1991 = 100)		
	Prairies	Non-Prairies	Canada	Prairies	Non-Prairies	Canada
1961	810.2	758.1	1568.3	213.1	105.3	131.5
1962	829.4	755.6	1585.0	165.1	153.0	154.5
1963	861.1	807.5	1668.6	149.6	161.6	152.7
1964	900.3	835.4	1735.7	174.9	162.5	162.3
1965	951.2	876.9	1828.1	164.8	167.2	162.9
1966	1010.5	910.6	1921.0	160.0	166.6	160.5
1967	1062.0	953.7	2015.7	200.5	180.7	184.8
1968	1085.5	971.4	2055.0	188.6	179.0	179.3
1968	1083.3	1063.4	2146.7	175.8	136.1	182.0
1970	1095.2	1006.2	2101.5	195.2	177.9	180.1
1971	1125.3	986.9	2112.2	173.8	177.8	172.5
1972	1158.6	1025.7	2184.4	190.0	189.4	185.8
1973	1186.9	1009.0	2195.9	183.0	176.8	176.7
1974	1233.9	959.3	2193.2	208.9	162.6	180.2
1975	1126.5	928.5	2055.0	170.2	161.2	163.4
1976	1092.6	885.4	1977.9	153.8	152.5	151.4
1977	1119.4	842.3	1961.7	156.3	140.6	147.1
1978	1156.7	855.6	2012.2	152.4	138.4	144.2
1979	1242.9	879.7	2122.6	183.9	135.8	155.5
1980	1215.9	913.1	2129.1	173.6	136.1	150.7
1981	1133.5	777.3	1910.8	142.1	113.1	126.1
1982	1122.0	759.6	1881.6	134.9	111.4	122.5
1983	1129.0	739.2	1868.2	144.6	109.2	125.5
1984	1090.9	745.1	1836.1	144.8	104.5	121.5
1985	1065.7	714.1	1779.9	130.2	100.7	114.1
1986	962.0	743.7	1705.7	102.7	109.7	105.5
1987	1033.3	721.6	1754.9	121.6	101.3	110.0
1988	965.4	744.9	1710.4	135.0	103.9	115.3
1989	1027.6	777.6	1805.2	120.8	105.9	111.5
1990	1073.5	754.2	1827.7	107.8	102.9	105.2
1991	1003.0	718.5	1721.5	100.0	100.0	100.0
1992	1081.6	731.8	1813.4	110.5	102.7	106.9

Table 4.

	Output					
	Crops (Implied Quantities, 1991 Mil.$)			Total (Implied Quantities, 1991 Mil.$)		
	Prairies	Non-Prairies	Canada	Prairies	Non-Prairies	Canada
1961	788.4	4717.4	5292.6	3354.3	9652.6	12803.8
1962	2066.2	1530.4	3530.4	4431.1	6626.0	11016.4
1963	2595.8	1536.2	4077.2	5076.8	6702.7	11733.7
1964	1866.2	1619.5	3534.8	4541.0	6897.5	11483.8
1965	2450.9	1730.8	4109.4	5090.6	7035.3	12049.2
1966	3006.5	1798.2	4743.8	5571.0	7330.4	12847.9
1967	2021.6	1546.6	3527.7	4672.3	7079.2	11710.9
1968	2491.5	1744.9	4202.3	5076.8	7280.9	12321.1
1969	2729.1	1603.7	4299.5	5434.0	7272.7	12663.8
1970	1911.4	1896.9	3821.9	4950.1	7584.9	12527.4
1971	2745.0	1791.6	4541.5	5710.6	7443.4	13148.2
1972	2297.9	1569.8	3869.0	5377.6	7264.4	12621.8
1973	2506.3	2102.3	4609.0	5722.3	7655.2	13343.1
1974	2022.7	2196.7	4194.0	5210.6	7915.7	13068.1
1975	2765.5	2054.9	4792.3	5838.1	7728.4	13504.5
1976	3283.9	2065.3	5339.1	6266.2	7789.2	14025.8
1977	3276.5	2277.8	5537.9	6316.5	8037.7	14314.4
1978	3655.2	2190.0	5844.2	6694.1	8294.4	14986.3
1979	2949.7	2323.2	5278.0	5961.6	8688.1	14654.8
1980	3090.8	2406.8	5493.6	6178.1	8996.8	15170.2
1981	3887.3	2615.6	6525.6	7037.3	9216.2	16267.7
1982	4276.8	2481.8	6770.1	7338.5	9146.6	16497.9
1983	3785.3	2435.6	6238.4	6888.6	9081.8	15988.8
1984	3428.6	2854.6	6304.6	6646.1	9563.1	16228.5
1985	4022.0	2816.9	6860.0	7218.5	9509.1	16749.7
1986	5066.8	2397.9	7479.5	8261.3	9089.8	17368.3
1987	4205.7	2729.0	7000.9	7498.6	9555.3	17127.0
1988	2778.1	2575.2	5362.1	6306.5	9616.0	15934.2
1989	3922.2	2939.4	6888.7	7505.4	9844.8	17379.7
1990	5087.3	2988.4	8105.1	8786.3	9831.8	18657.2
1991	5002.4	2832.4	7834.8	8847.8	9637.0	18484.8
1992	4580.4	2860.0	7447.5	8634.3	9556.5	18207.8