Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 7 (1): 1-14, 2013
ISSN 1819-3412 / DOI: 10.3923/rjes.2013.1.14

Implications of Fitting a Regression and Pearson Correlation Models in the Relationship Between Food Production, Production of Wood Products, CO_2 Emissions and Climate: An Analysis of Time Series Data

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ABSTRACT

This study investigates the most significant determinants of food production in Canada from among the following variables: Production of wood products, CO_2 emissions from agriculture and forestry, CO_2 emissions from fossil fuels, rainfall and temperature. It also verifies the relationship between food production, production of wood products, CO_2 emissions from agriculture and forestry, CO_2 emissions from fossil fuels, rainfall and temperature in Canada. The data for the analysis was essentially time series data spanning the period 1961-2010. The data on food production and production of wood products was obtained from FAOSTAT. The data on CO_2 emissions from agriculture and forestry and fossil fuels was obtained from FAOSTAT and the US Department of Energy. The data on rainfall and temperature was obtained from Environment Canada, 2012. Data analysis was performed in the SPSS platform in which both multiple linear regression and bivariate linear correlations were used to fit the models. The results show that CO_2 emissions generally increase with food production. Food production and CO_2 emissions from agriculture and forestry have a correlation of about 0.87 while food production at the same time has a correlation of 0.84 with CO_2 emissions from fossil fuels. Both CO_2 emissions from agriculture and forestry and fossil fuels have a correlation of 0.94 which shows that they reinforce each other. The most significant variable that significantly correlates with food production is CO_2 emissions from agriculture and forestry with a t-value of 2.63 and a p-value of 0.12.

Key words: Food production, CO_2 emissions, agriculture, forestry, fossil fuels

INTRODUCTION

With the global increase in human population and a parallel increase in standards of living especially in the North, the need to produce more food remains urgent (Kissinger, 2013; Chameides *et al*., 1994). The results of this have been the development of agricultural technologies or inputs that can result in high yields (Chameides *et al*., 1994). For a long time, most advanced nations have laid emphasis on fossil fuels to run the industrial systems that produce the expected farm inputs as well as run farm machineries (Kissinger, 2013; Chameides *et al.*, 1994). Globally, the relationship between food production, fossil fuel burning, cutting of forests to create farmlands and their resultant CO_2 emissions are more pronounced in North America, Europe and parts of Asia (Chameides *et al.*, 1994). As such, CO_2 emissions from food production are becoming central in the entire food production debate (Kissinger, 2012).

Canada has for a long time been a net producer and exporter of a wide range of food products such as legumes, cereals, oils, meat and fruits inter alia (Kissinger, 2013; FAO, 2012). In 2006, Canada produced over 75 million tons of agricultural and food commodities out of which about 55% was exported (FAO, 2012). A look at Canada's food consumption charts shows that most of Canada's staple food comes from domestic sources; there is however a growing chunk of Canada's food supply spread all over the world (Statistics Canada, 2008a; b). For example, about 15% of meat and 35% of oils consumed in Canada are currently imported (FAO, 2012). As a result, in recent literature, the concept of food miles has evolved. This has to do with the distance a food commodity travels from the point of production along the chain with related energy and CO_2 emissions along the way (Paxton, 1994; Kissinger, 2012). Considering the fact that in 2006 55% of the 75 million tons of food produced in Canada was exported, there is reason to verify the relationship between food production and CO_2 emissions from agriculture and forestry and from fossil fuels.

Theoretically, this schematic representation is driven by the desire to increase production either through farmland expansion or agricultural technologies. In the farmland expansion scenario (Fig. 1) it is expected that due to sufficient rainfall and adequate temperature, food production will be high. However, the desire to cultivate more crops is often at the expense of forests which equally leads to increase farmlands, increase yields in the short run and increase atmospheric CO_2. Also, reduced forests will mean less rainfall in the long run and ultimately reduced food production (Epule *et al.*, 2011, 2012a). Increase atmospheric CO_2 will equally reduce production in the long run. Reduction in forests will also directly increase atmospheric CO_2 and will increase temperatures. The second scenario is based on agricultural technology such as mechanization and use of fertilizers inter alia (Fig. 1). These intensive farming technologies are often run from fossils fuels. If this obtains, then on the positive side there will be higher yields in the short run but increase CO_2 emissions which ultimately will increase temperatures.

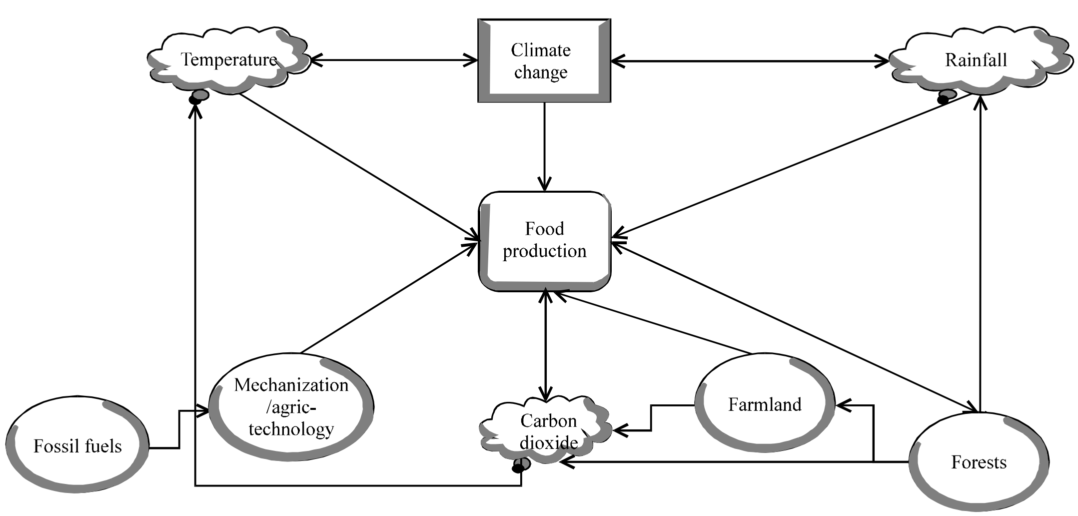

Fig. 1: Schematic causal loop representation of the key variables under consideration

It has been argued that the food supply/production landscape of Canada is shaped by factors such as climate, wood production, CO_2 emissions, soils, slope, standards of living that are extremely high, commercial marketing and ethnic diversity inter alia (Agriculture and Agri-Food Canada, 2009; Kissinger, 2012; Kissinger, 2013). However, this study is restricted to analyzing only the relationship between food productions, production of wood products, CO_2 emissions from agriculture and forestry, CO_2 emissions from fossil fuels, rainfall and temperatures because these have not been verified. This is because all the variables that affect food production cannot be brought into the equation at the same time; however, those selected here are some of the very important ones that are currently steering much of the debates on food production.

MATERIALS AND METHODS

Data Sources and properties: This study is a national scale study that covers data for the whole of Canada. The two main objectives are to determine from a number of pre-determined variables, the variable(s) that affects food production most and the level of bivariate correlation between these variables. The variables under consideration are subdivided as follows: food production in tons (the dependent variable in objective one), production of wood products in tons, CO_2 from agriculture and forestry in million metric tons, CO_2 emissions from fossil fuels in thousand metric tons, average annual rainfall in mm and average annual temperature in °C (independent variables). Lobell and Field (2007) and Almaraz *et al.* (2008) have also used similar techniques. All the data used in this study was time series data covering the period 1961-2010. The data on food production, production of wood products, CO_2 emissions from agriculture and forestry was obtained from the Food and Agricultural Organization FAOSTAT data base (FAO, 2012). Data on CO_2 emissions from fossil fuels was obtained from the U.S Department of Energy carbon dioxide information analysis centre (Boden *et al.*, 2011). The data on average annual rainfall and temperature was culled from Environment Canada's official climate data website (http://www.climate.weatheroffice.gc.ca/climate Data/canada_e.html).

Statistical analysis and empirical model specification: The data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 19. In the case of objective one, the emphasis was to determine the variables that affect food production in Canada. The multiple linear regression approach was used to fit the model as specified by Motulsky (1999). This method was used to verify which of the independent variable(s) (production of wood products, CO_2 emissions from agriculture and forestry, CO_2 emissions from fossil fuels, rainfall and temperature) affects the dependent variable (food production) more. The equation used to fit such a model is given as:

$$y = \beta_{0+} \beta_{1\times1+} \beta_{2\times2+} \beta_{3\times3+} \beta_{4\times4+\varepsilon t}$$

where, y is the dependent variable (food production), β_0 is the intercept, $\beta_{1+} \beta_{2+} \beta_{3+} \beta_4$ are the partial regression coefficients, x1+x2+x3+x4 are the independent variables, ε' is the error term and t is time (i.e., year).

To achieve the second objective, the bivariate correlation between all the variables (dependent and independent) was calculated using the Pearson correlation statistical tool (Motulsky, 1999). The equation used to run a Pearson correlation is given as follows:

$$r = \frac{\Sigma(x-\mu)(y-\mu)}{\sqrt{(x-\mu)^2 \, \Sigma(y-\mu)^2}}$$

where, r is the Pearson correlation coefficient, x is the independent variable, y is the dependent variable and μ is the mean of both variables. Both methods were selected because of their suitability in exploring the relationship between dependent and independent variables.

In addition, three period running averages were used to smooth out short-term fluctuations in the time series data and highlight long term trends or to verify the link between the actual trends in the data and the simulated.

RESULTS AND DISCUSSION

In Canada, it has been observed that between 1961 and 2010, the production of wood products exceeded food production. The actual and simulated 3 period running averages shows that food production is generally below 20 million tons while by 1969 the production of wood products exceeded 20 million tons and this situation has been the same all through (Fig. 2). This is a reflection of the possible long term effects of too much deforestation and food production.

Observations of the trends of actual and simulated CO_2 emissions from agriculture and forestry show that emissions from agriculture and forestry are generally higher throughout the simulation and at the end in 2010 (>15 million metric tons) (Fig. 3a, b). Those from fossil fuels are generally lower throughout the simulation (<160 thousand tons) (Fig 3a, b).

The trends for actual and simulated temperature show that generally average annual temperatures are generally close to 0°C. Their range is about 2°C (MAX-MIN= -4- - 6 = 2). Average annual rainfall is highly variable and has a range of 250 mm (450- 200 = 250) between 1961 and 2010 (Fig. 4a, b).

After a multiple linear regression model was fitted to the time series data to verify the most significant variables affecting food production, it was found that CO_2 emissions from agriculture and forestry had a t-value of 2.62 and a p-value of 0.12. The implication here is that this variable is more closely related to food production than do the other variables. The p-value of 0.12 denotes a 12% possibility of obtaining a difference as large as observed, meaning this variable is fairly reliable (Table 1). The least significant variable here is temperature with a t-value of -0.06 and a

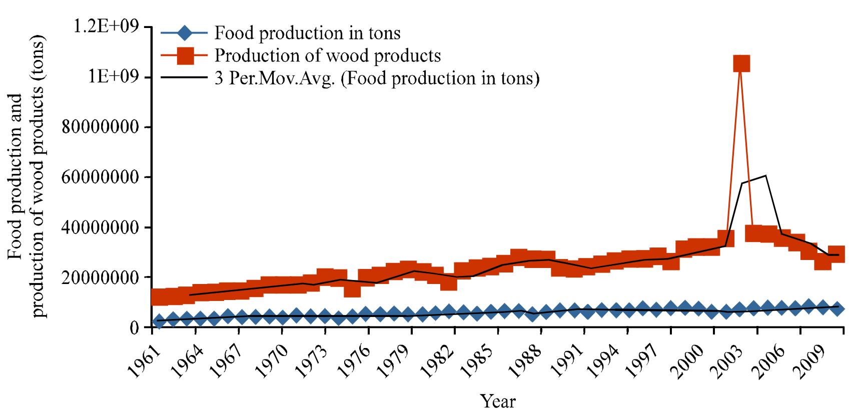

Fig. 2: Trends in food production and production of wood products and their simulated 3 period running averages for Canada between 1961-2010

Table 1: Results of the multiple linear regressions showing the most significant determinants of food production and their respective t and p-values

Independent variables	Standardized coefficient	Standard error	t-value	p-value
Production of wood	0.02	0.10	0.23	0.82
CO_2 from agriculture/forestry	0.64	0.07	2.62	0.12
CO_2 from fossils fuels	0.20	0.14	0.83	0.41
Avg annual Temp	-0.01	0.92	-0.06	0.96
Avg annual rainfall	0.09	0.22	1.07	0.29

Dependent variable: Food production in tons, Independent variables are: Production of wood in tons (represents the extraction of trees to produce various wood products), average annual rainfall in mm and average annual temperature in °C, CO_2 emissions from agriculture and forestry in million metric tons, CO_2 emissions from fossil fuels in thousand metric tons, Average (Avg), The total No. of observations = 50, r = 0.88, r^2 = 0.77, adjusted r^2 = 0.75, f = 28.68

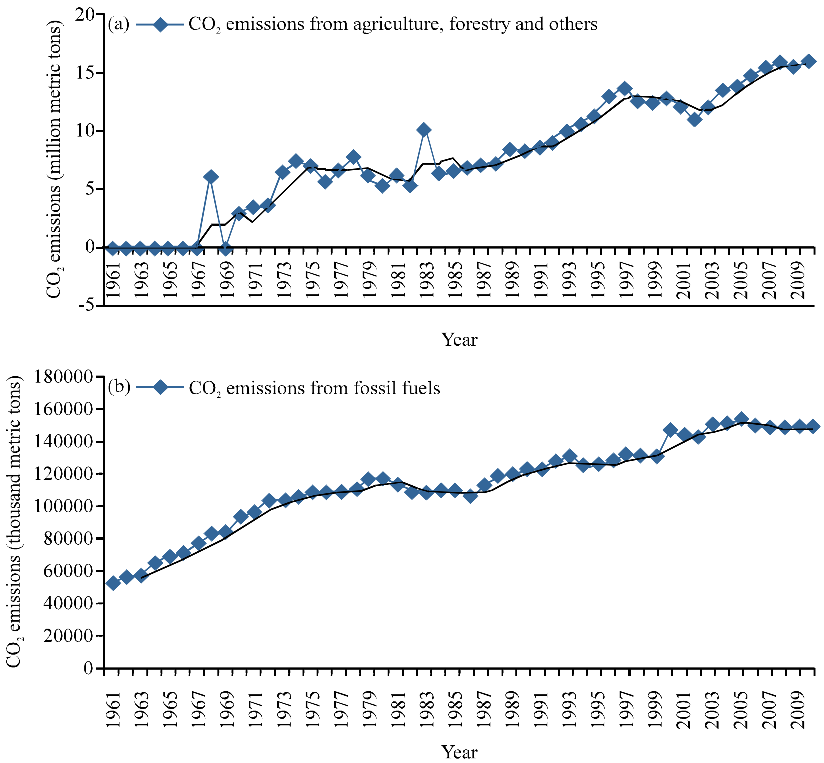

Fig. 3(a-b): Trends in CO_2 emissions from (a) Agriculture and forestry and (b) Fossil fuels and their simulated 3 period running averages for Canada between 1961-2010

p-value of 0.96 depicting a 96% possibility of obtaining a difference as large as observed (Table 1). These results are consistent with reports that CO_2 emissions from agriculture and forestry are more dominant than those for fossils fuels.

In terms of correlations, it is observed that the highest bivariate correlations exist between CO_2 emissions from agriculture and forestry on the one hand and CO_2 emissions from fossil fuels. These variables have a Pearson correlation of 0.94 or 94% which denotes a perfect positive correlation. The parallel coefficient of determination (r^2) is 0.88 which depicts that there is about 88% of reliability in the observed trend (Table 2, 3, Fig. 5a-e). In terms of the second most significant bivariate correlations, it is observed that the bivariate correlations between food production and CO_2

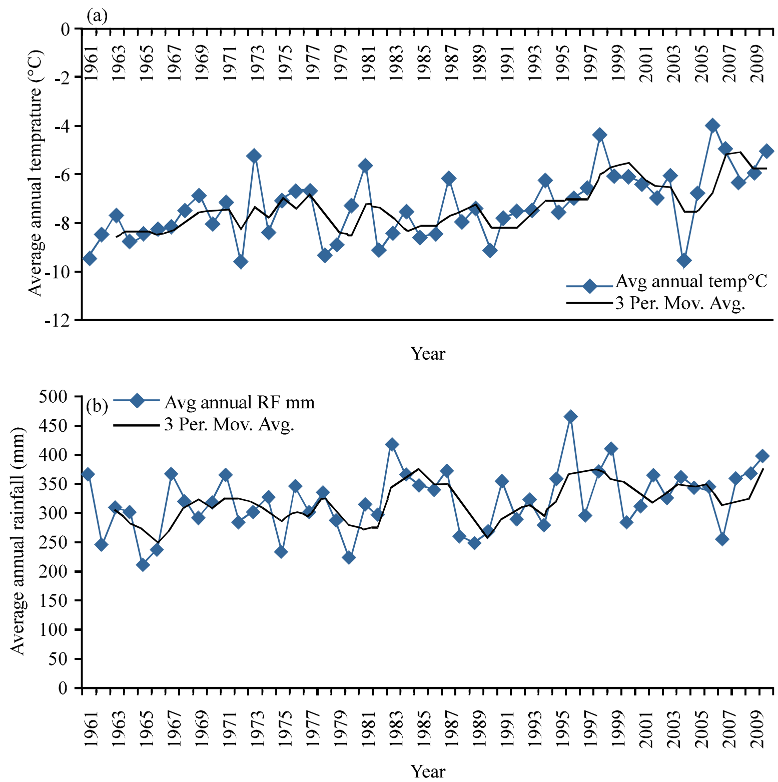

Fig. 4(a-b): Trends in (a) Average annual temperature and (b) Rainfall and their respective simulated 3 period running averages for Canada between 1961-2010

Table 2: Results of the bivariate-pearson correlation and coefficient of determination

Independent variables	Dependent variable	Bivariate correlation	Coefficient of determination
Food Production	Production of wood	0.50	0.25
Food Production	CO_2 from agriculture/forestry	0.87	0.76
Food Production	CO_2 from fossils fuels	0.84	0.70
Avg annual Temp.	Food production	0.45	0.20
Avg annual rainfall	Food production	0.40	0.16
Production of wood	CO_2 from agriculture/forestry	0.53	0.28
Production of wood	CO_2 from fossils fuels	0.62	0.38
Production of wood	Avg. annual Temp.	0.31	0.10
Production of wood	Avg annual rainfall	0.16	0.03
CO_2 from agriculture/forestry	Avg annual Temp.	0.52	0.27
CO_2 from agriculture/forestry	Avg annual rainfall	0.39	0.15
CO_2 from fossils fuels	Avg annual Temp.	0.47	0.22
CO_2 from fossils fuels	Avg annual rainfall	0.28	0.08

Food production in tons, production of wood in tons (represents the extraction of trees to produce various wood products), average annual rainfall in mm and average annual temperature in °C, CO_2 emissions from agriculture and forestry in million metric tons, CO_2 emissions from fossil fuels in thousand metric tons, Average (Avg)

emissions from agriculture and forestry are significant. The actual bivariate correlation here is 0.87 or 87% while the coefficient of determination (r^2) is 0.76 or 76% (Table 2, 3, Fig. 5a-e). The implication of this relationship is that there is a strong positive correlation between food

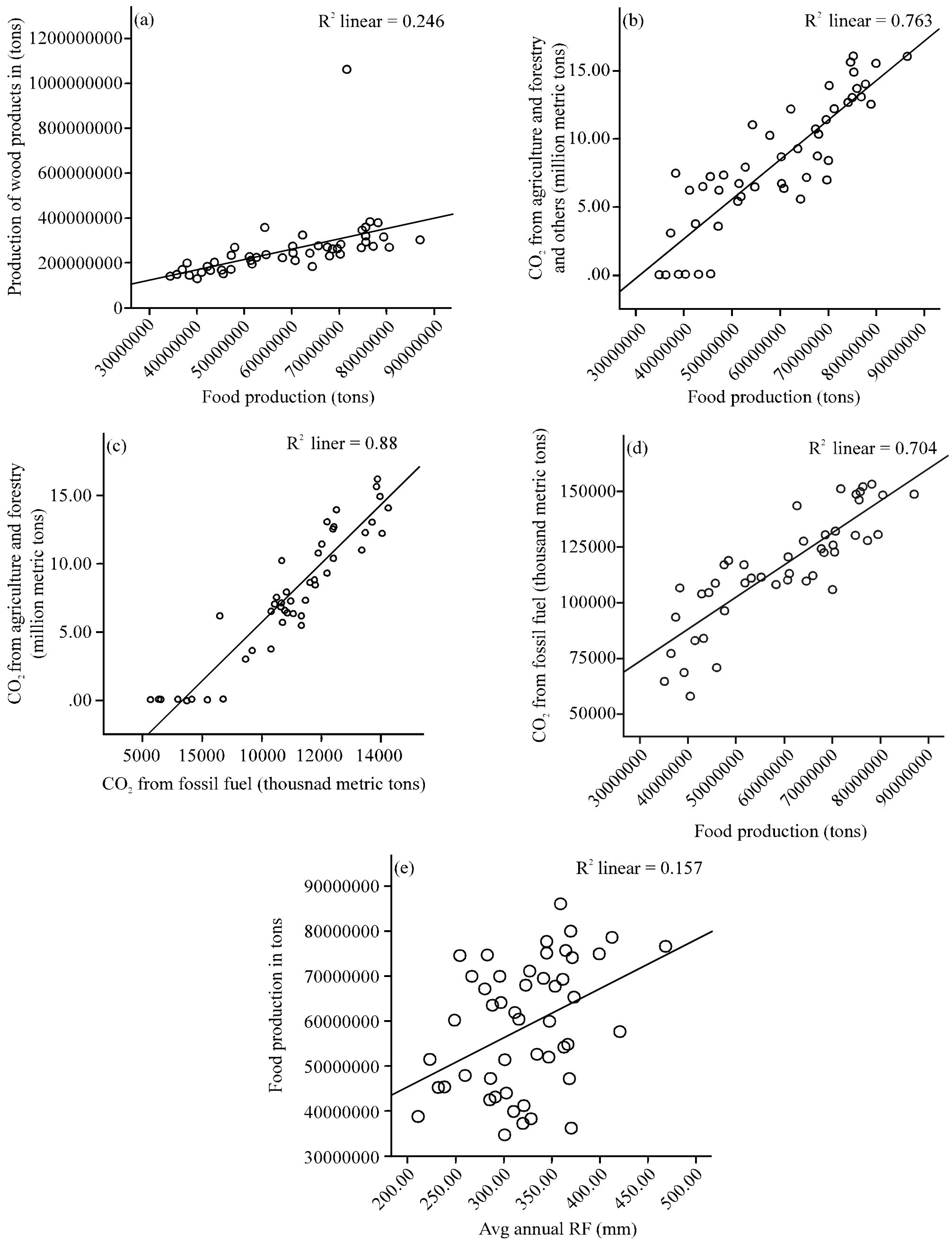

Fig. 5(a-e): Scatter plots of the correlation between (a) Food production and production of wood products, (b) Food production and CO_2 emissions from agriculture and forestry (c) CO_2 emissions from fossil fuels and CO_2 emissions from agriculture and forestry, (d) Food production and CO_2 emissions from fossil fuels and (e) Average annual rainfall and food production

production and CO_2 emissions from agriculture and forestry. With the r^2 of about 76%, it can be said that this model has 76% reliability in explaining the observed trends.

Generally, when it is said that there is a perfect positive correlation between CO_2 emissions from agriculture and forestry and CO_2 emissions from fossil fuels on the one hand and food production

Table 3: Correlation matrix of all the variables under study

Variable	Food production	Average annual temperature	Average annual rainfall	Production of wood products	CO_2 from agriculture and forestry	CO_2 from fossil fuels
Food production	1.00	0.45	0.40	0.50	0.87	0.84
Average annual temperature	0.45	1.00	0.17	0.31	0.52	0.47
Average annual rainfall	0.40	0.17	1.00	0.16	0.39	0.28
Production of wood products	0.50	0.31	0.16	1.00	0.53	0.62
CO_2 from agriculture and forestry	0.87	0.52	0.39	0.53	1.00	0.94
CO_2 from fossil fuels	0.84	0.47	0.28	0.62	0.94	1.00

The correlation matrix is a summary table of all the bivariate-pearson correlations between all the variables under study

and CO_2 emissions from agriculture and forestry it means as one increases so does the other. Actually, based on the data, both sets of variables have been increasing towards the same direction. This is because as food production increases, more forests are cut and as such more CO_2 from agriculture and forestry is emitted. The even higher correlation between CO_2 emissions from agriculture and forestry and CO_2 emissions from fossil fuels further shows that agriculture and forestry are not the only CO_2 emission source. Increase use of fossil fuels to power machines in mechanized farms has also contributed intensely to the emissions. However, some of these emissions may be from other industrialization processes. Therefore, the more the use of fossil fuels, the more emissions from agriculture and forestry.

The relationship between food production and CO_2 emissions from fossil fuel (Table 2, 3, Fig. 5 a-e) can be explained by the fact that the desire to increase production through agricultural technologies leads to the exploitation of fossil fuels which also has a daunting effect on global emissions. The rest of the correlations are generally weak positive correlations, the reason why the focus has been on the relationship between food production and CO_2 emissions (Fig. 6a-e). As seen on Fig. 7a and Table 4, average annual rainfall is around 300 mm while the rainfall for the other seasons of the year is generally below 300 mm. In the case of temperatures, it is observed that the average summer temperatures are above 10°C while those for the other seasons are below this threshold (Fig. 7b, Table 4). For a complete picture of the trends in annual rainfall and temperature as well as the raw data used in this study (Fig. 7a, b and Table 4).

The results presented in this study are consistent with those of other studies (Cumming *et al.*, 2001; Hobson *et al.*, 2002; Van der Werf *et al.*, 2009; FAO, 2012; Kissinger, 2013). Firstly, there is a lot of evidence to show that food production in Canada is rising but this might not be forever. In 2006, about 75 million tons of agricultural commodities were produced in Canada and consumed locally as well as exported (FAO, 2012; Kissinger, 2013). It is however argued that much of this increase in food production has been due to two reasons. These are increase forest loss and agricultural expansion to create more cropland or pasture (Van der Werf *et al.*, 2009). For example, the agricultural sector in Western Canada in general and around the Saskatchewan-Manitoba border is heavily unregulated. As a result of this, a lot of forests in these areas have been transformed into farmland for the production of cereal, oilseeds and cattle (Hobson *et al.*, 2002). Between 1966 and 1996, the area referred to above experienced a total of 4368 km^2 of forest loss; this is equivalent to -0.8% in terms of annual rate of forest cover change (Hobson *et al.*, 2002). Again, between 1966 and 1996, the amount of land not used for agriculture in 39 municipalities of the same area above decreased from about 44219 to 17646 km^2 (Hobson *et al.*, 2002). According to the FAO (1999), although much of the deforestation in the region occurred around the era of the Second World War, the rate quantified for the period between 1966-1996 was higher than the

Table 4: Raw data of the various variables used in running the models

Year	Food production (tons)	Production of wood products (tons)	CO_2 from emission agriculture and forestry (million metric tons)	CO_2 emission from fossil fuel (thousand metric tons)	Average annual (temp.°C)	Average annual (RF) (mm)
1961	22416503	116090615	0.01	52954	-9.5	364.80
1962	35125464	123800402	0.00	56500	-8.5	245.80
1963	40288738	127109356	0.00	57570	-7.7	308.90
1964	34919385	135459306	0.00	64849	-8.8	300.50
1965	38988340	138862153	-0.01	68763	-8.5	211.10
1966	45763723	145569506	0.00	70717	-8.3	237.80
1967	36345527	144286251	0.00	76874	-8.2	368.60
1968	41335238	153254139	6.17	82776	-7.5	320.30
1969	43076882	167365380	0.00	83829	-6.9	289.80
1970	37352085	165200115	3.02	93124	-8.1	319.70
1971	47390194	167143690	3.55	96157	-7.2	367.00
1972	42601423	175661777	3.70	103937	-9.6	285.30
1973	44031489	200011434	6.49	104069	-5.3	301.50
1974	38314952	192966804	7.48	106346	-8.4	326.70
1975	45485796	158119334	7.16	108302	-7.1	232.30
1976	51983913	195070051	5.72	108895	-6.7	345.70
1977	51533759	205222858	6.70	108583	-6.7	301.30
1978	52815032	220839793	7.90	110670	-9.4	333.80
1979	47420581	227407749	6.18	116627	-8.9	285.60
1980	51380509	219944337	5.44	116866	-7.3	222.50
1981	60717644	206152411	6.32	113472	-5.6	314.20
1982	64254288	181624989	5.55	109159	-9.2	295.40
1983	58043059	222190567	10.22	108308	-8.4	419.20
1984	54813315	235053072	6.38	110912	-7.5	365.20
1985	60350598	240469993	6.61	109587	-8.6	346.50
1986	69730536	250523300	6.94	105596	-8.4	339.80
1987	65415883	273341446	7.22	112286	-6.2	371.50
1988	48179632	271978092	7.30	118446	-8.0	259.90
1989	60294430	269687872	8.62	120090	-7.4	248.40
1990	70171902	235694770	8.43	122737	-9.2	267.60
1991	67944717	231239153	8.73	122458	-7.8	352.30
1992	63685097	243515982	9.25	127529	-7.6	289.10
1993	68114116	252415773	10.36	130330	-7.5	322.40
1994	67490133	262667528	10.74	123941	-6.3	279.50
1995	69678682	269036032	11.46	125386	-7.6	360.40
1996	76918013	272264009	13.12	127593	-7.0	465.70
1997	70198712	276970584	13.93	131779	-6.6	294.20
1998	74333899	264033611	12.70	130592	-4.4	371.30
1999	78950102	308473243	12.58	130316	-6.1	410.80
2000	75078502	317105808	13.02	146551	-6.1	283.10
2001	62297572	319663391	12.27	143750	-6.4	311.00
2002	54313418	352890170	11.05	142305	-7.0	362.20
2003	71399457	1058232007	12.24	150935	-6.1	326.90
2004	75985371	373709353	13.72	151586	-9.6	362.60
2005	77755041	375410506	14.06	153476	-6.8	344.00
2006	75425301	356830865	14.94	149633	-4.0	344.11

Table 4: Countinue

Year	Food production (tons)	Production of wood products (tons)	CO_2 from emission agriculture and forestry (million metric tons)	CO_2 emission from fossil fuel (thousand metric tons)	Average annual (temp.°C)	Average annual (RF) (mm)
2007	74652656	339049030	15.66	148397	-5.0	254.2
2008	86442734	300302554	16.09	148375	-6.3	358.1
2009	80028356	266737828	15.58	148587	-6.0	368.7
2010	75313221	292910133	16.15	149245	-5.1	398.2

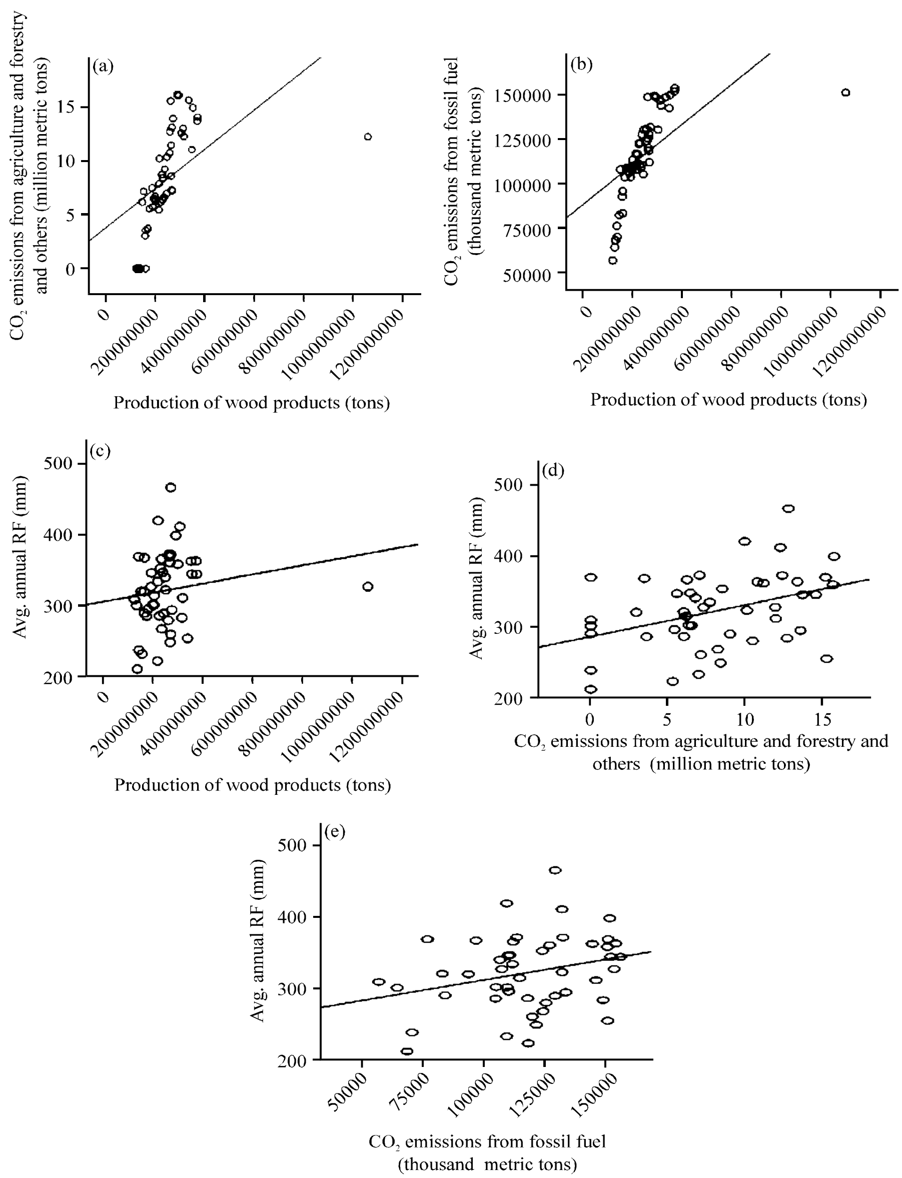

Fig. 6(a-e): Scatter plots of the correlation between (a) Production of wood products and CO_2 emissions from agriculture and forestry, (b) Production of wood products and CO_2 emissions from fossil fuel, (c) Production of wood products and average annual rainfall, (d) CO_2 emissions from agriculture and forestry and average annual rainfall and (e) CO_2 emissions from fossil fuel and average annual rainfall

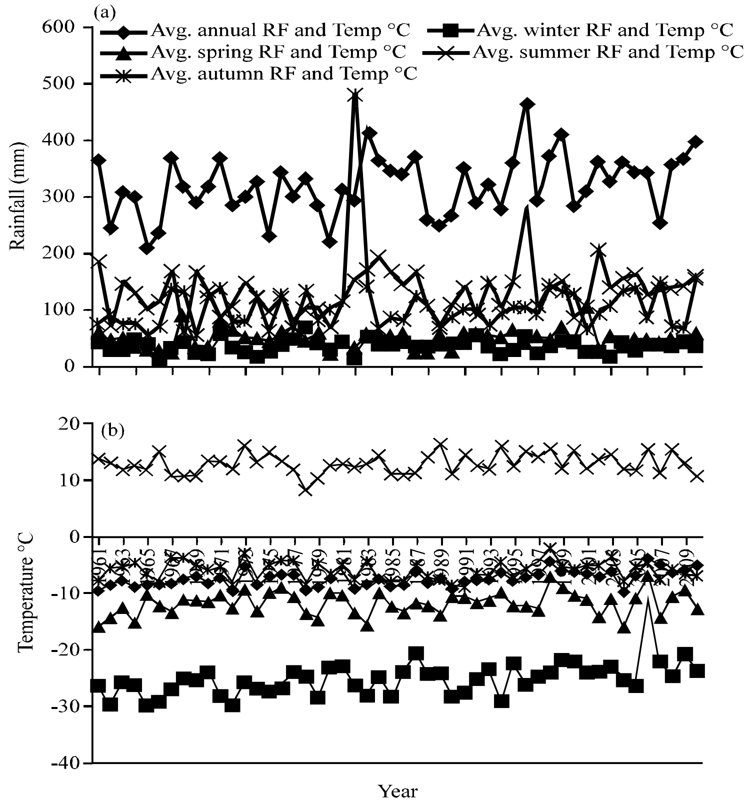

Fig. 7(a-b): Average annual, winter, spring, summer and autumn (a) Rainfall and (b) Temperature for Canada between 1961-2010

global average of 0.3% per year. In the south of the Saskatchewan-Manitoba border, very little forest is left with most of the land converted to cereal and cattle production. In other parts of Canada's boreal and the global temperate forests, similar findings have been obtained showing rates of deforestation of about 0.8-1.7% per year (Cumming *et al.*, 2001).

However, it is necessary to state that, not all forest lost in the boreal of Canada is as a result of agricultural expansion. Lightening, droughts and insects have also been reported responsible for huge forest loss in the boreal forest (Weber and Stocks, 1998; Peng *et al.*, 2011; McCullough *et al.*, 1998).

A key repercussion of the increase clearance of forests in favor of farmland is CO_2 accumulation in the atmosphere (Adams and Piovesan, 2002; Fang *et al.*, 2001). In fact, it has been argued that deforestation is the second largest anthropogenic source of carbon dioxide to the atmosphere because carbon emissions from deforestation account for about 20% of the global anthropogenic CO_2 emissions (Van der Werf *et al.*, 2009). It is now reported that the amount of CO_2 in the atmosphere is currently increasing at a rate of 0.5-3 parts per million (ppm) per year (Keeling and Whorf, 2001; Adams and Piovesan, 2002). Whatever the case, it is pertinent to argue that a good fraction of this annual CO_2 input into the atmosphere is linked to the burning of fossil fuels (Falkowski *et al.*, 2000; Van der Werf *et al.*, 2009). Today, food production systems all over the world depend a lot on fossil fuels. As a result of this, machines and various agricultural inputs such as fertilizers have been produced to enhance food production (Epule *et al.*, 2012b; Tomczak, 2005). While the objective of increasing food production has been attained from the use of fossil fuels and increase deforestation, there has been a parallel increase in CO_2 emissions which heralds long run food declines (Timmer, 1975). In addition to the emissions of CO_2, the production of fertilizers to enhance food production has been responsible for increase use of fossil fuels and the seepage of pollutants into rivers as well as general flora and fauna degradation (Epule *et al.*, 2012b; Maeda *et al.*, 2003).

CONCLUSION

This study has shown that, among the set of factors under consideration, CO_2 emissions from agriculture and forestry and fossil fuels have the strongest correlations with food production. This is obvious because when forests are cut in favor of farmlands and fossil fuels are burnt to produce agricultural inputs as well as run intensive farming systems, a myriad of CO_2 emissions are spurred into the atmosphere. As seen in the discussion, these findings are consistent with other studies that have studied the relationship between food production and CO_2 emissions.

A major question now is, will food production keep rising with rising CO_2 emissions from these sources? Obviously, with rising CO_2 emissions and the resultant negative feedbacks that this will have on long run food production, much has to be done. The long run effects of deforestation on the other hand are food and water scarcity (Epule *et al.*, 2012c). This study is therefore proposing that more investments be made in the area of renewable energy sources such as bio-fuels, wind to name but these. Deforestation in favor of farmlands could be adverted through the enactment of policies that encourage farmers to farm intensively against the backdrop of renewable energies and organic fertilizers.

It would however be necessary to carry out further research by bringing in several other variables not used here into the regression function. Again, regional scale studies over different parts of Canada could be carried out to test for regional disparities.

ACKNOWLEDGMENT

We are thankful to the NSERC Canada Discovery grant and the FARE merit based scholarship board of the University of Quebec for funding this study.

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