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Impact of climate change on crop production and food security in Newfoundland and Labrador, Canada

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ABSTRACT

Newfoundland and Labrador (NL), the easternmost province of Atlantic Canada, has a food security issue caused by shortage of agri-foods produced in the province. This is due to short supply of suitable agricultural land, short growing seasons, a limited range of agricultural produce (industrial or mono cropping) farmed on existing farms and few facilities for secondary processing. The food security issue has been exacerbated in the last decades by climate change (extreme temperatures, heavy rains and more frequent droughts) which has impacted the province's agricultural industry. This research investigates the impact of climate change on crops and food security in the NL province and identifies the measures taken by the provincial farmers to reduce the GHG emissions and aims to assess whether agro-ecological practices could be expanded in the NL province. It is based on quantitative and qualitative data, collected through surveying a sample of NL crop farmers and through a literature review of peer-reviewed articles, published government reports and documents and news articles. The research results show that any attempt to solve the multi-faceted problems of the NL agri-foods sector impacted by climate change should involve policies supporting an agro-ecological approach to farming in the province. Generalizing agro-ecological farming practices on highly integrated and diversified farms (small, medium and large) is one sustainable alternative that can potentially eliminate the negative consequences of modern industrial farming, make the farming sector more resilient to global climate change and enhance food security in the province. The research results show that there are incipient agro-ecological practices in the province, that farmers are aware of climate change and the need to adopt more environmentally friendly farming practices. New policy frameworks and work plans are needed to speed up the transition from the current unsustainable farming practices to a more resilient agro-ecological-food system.

1. Introduction

A consensus is building among scientists that modern, industrial agriculture practices that involve intensification, concentration, and monoculture have harmful environmental and social consequences [1–4]. According to environmental and ecological economists, high input agriculture is mostly interested in producing "commodities" instead of producing nourishing food, and exclusively aims to maximize yields and profits; by doing so, it impacts food security through monoculture, reducing soil health or damaging farmlands and harming neighboring and downstream economies [5,6]. During the latter half of the twentieth century, scientific advances and technological innovations, including the development of new plant varieties, the use of chemical fertilizers and pesticides, and the growth of extensive infrastructures for irrigation, have contributed to boost food production in what is referred to as industrial agriculture [5,7]. The immediate effect of industrial agriculture was a spectacular growth in agricultural production, and the new era was hailed as the "Green Revolution" [8,9]. During the "Green Revolution", yields per hectare of staple crops such as wheat and rice increased, food prices declined, the rate of increase in food production generally exceeded the rate of population growth, and chronic hunger diminished [5,7,10]. Industrial agriculture was based on the assumption that the soil fertility could be maintained and increased through the use of chemical fertilizers and very little attention was paid to the significance of organic matter in the soil. But a few decades later, the dark side of chemical agriculture became painfully evident when the

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world food systems started facing threats due to emergence of new agricultural diseases, increased public health concerns, rising costs of the physical factors of production (land, water, energy), biodiversity loss and climate change [7,10,11]. Food production and consumption are key drivers of climate change. The food industry has a wider impact on the environment as a whole by "destroying forests and savannahs to produce animal feed and generating climate-damaging waste through excess packaging, processing, refrigeration and the transport of food over long distances, despite leaving millions of people hungry" [12,13]. Industrial agriculture's high productivity comes at a steep price, including the ability of agriculture worldwide to adapt to an earth on which droughts, floods, heat waves, heavy snow and extreme weather events have become commonplace and the biosphere goes through major shifts with potentially severe consequences for the growing of food [5,14]. A large number of experts–policy analysts, politicians, scientists, economists, environmental specialists, researchers, and even business leaders-believe that the industrial methods that dominate the world food system today will not be able to sustain food abundance over the long-run and are also causing great harm to people and to the earth's life-support systems [15–17].

Agriculture plays a dual role in climate change because it is both a source of greenhouse (GHG) emissions, like CO_2 emissions which contribute to climate warming, and a sink for GHG emissions, as healthy agricultural soils and forested areas on the farms have the capacity to sequester carbon, offsetting the sector's overall contribution to climate change [18]. Lately, agriculture has become more a source than a sink for GHG emissions [18,19]. Thus, excessive amounts of heat have been trapped by the greenhouse effect resulting in the global warming of the earth's atmosphere beyond safe levels [5,20]. The global average land-sea surface air temperature increased by 0.5 °C in the 20th century and is projected to further increase by 1.5 °C–4.5 °C in this century [21]. Warmer air means that there is more energy and more moisture in the atmosphere, which can lead to longer growing seasons in northern countries but can also produce a wide variety of consequences - floods, rising global sea levels, tornados, hurricanes, droughts, heat waves, and wildfires [20,22,23]. Climate change factors such as increase in temperature, change in precipitations, increase of CO_2 concentration in the atmosphere, frequency and intensity of extreme weather events may have significant negative effects on agriculture. It is estimated that because of global warming, the global agricultural productivity will decline between 3 and 16% by 2080s, whereas in developing countries, this percentage varies between 10 and 25% [24–26].

The future world requires a transition from industrial agriculture to a sustainable agro-ecological farming system that focuses on the use of alternative techniques such as diversified cropping systems, better integration between crop and animal production, and increased incorporation of trees and wild vegetation [12,27,28]. The increase in crop diversity would, in turn, increase the production potential and food security, and the incorporation of organic matter would progressively improve soil fertility, and preserve environmental quality by creating virtuous cycles of higher productivity and higher availability of organic matter [5,29,30].

This research investigates the impact of climate change on food production and food security in the Canadian province Newfoundland and Labrador (NL), a province whose food insecurity problem has been exacerbated by climate change. It also aims to identify the measures taken by the provincial farmers to reduce GHG emissions and to assess whether agro-ecological practices could be expanded in the NL province. It also aims to develop some policy recommendations which might facilitate the transition to a sustainable agriculture based on agro-ecological practices in the province. This study's working hypothesis is that the industrial agricultural production systems have significant impacts on GHG emissions and on global climate change, as well as on agricultural food production and food security. It explores the potential contribution of an agro-ecological approach to fighting climate change and solving the problem of food insecurity and assesses the possible ways of transitioning from an industrial agriculture system to a sustainable one by incorporating agro-ecological practices.

2. Literature review

According to researchers, the relation between industrial agriculture and climate change is twofold. On one hand, industrially based food systems are energy-intensive (consuming around 30% of the world's total fossil-fuels based energy), and are relying on chemical fertilizers, pesticides, herbicides, and non-therapeutic antibiotics, thus contributing significantly to climate change [20,31–33]. An important wing of agriculture, global livestock raising, uses around 77–80% of global farming land for producing animal feed and grazing, and is responsible for 18% of the anthropogenic greenhouse gas emissions mainly in the form of methane and nitrous oxides [34–36]. On the other hand, the crops grown in the genetically homogeneous monocultures that are representative of industrial farming are neither resilient to the climate extremes that are becoming more frequent and more violent nor able to feed the world's growing population [20,31,37]. All of these consequences are threats to agricultural activity and global food security. Introducing new crop varieties, changing planting, and harvesting dates, applying hormones and improved fertilizers and expanding or improving irrigation will not radically change the monoculture nature of the dominant agroecosystems but may reduce the negative impacts for short periods [37,38]. It is considered that an agroecological transformation of monocultures will bring long-term and more durable benefits through diversification of agroecosystems in the form of polycultures, agroforestry systems, crop-livestock integrated systems accompanied by management of soil organic matter, conservation of water and soil and enhancement of agrobiodiversity [37]. More recent studies explore agroecological systems through socio-metabolic transitions [39], reconnecting crop and livestock production in synergetic regional bio-economic models [40], and by deliberately linking agricultural support policies to environmental protection targets [41].

Canadian agriculture is an important player in the international agricultural markets, as it was the 5th largest exporter of agricultural commodities in 2020 [42]. The agriculture and agri-food sector generated $139.3 billions of gross domestic product (GDP) in 2020, which accounted for 7.4% of Canada's GDP. The average farm size in Canada was 820 acres in 2016 [43]. This means that Canadian farmers' practices belong to industrial or commercial farming, but the farmers have to follow strict rules and regulations when using fertilizers and pesticides, as well as for land development, waste management and the safety of human health and the environment. Canada has a long history of government support for an export-oriented agriculture based on economies of scale, mechanization and standardization, and supply-side management, which run counter to policies aimed at significantly expanding agro-ecological production [44,45]. Greenhouse gas emissions from agriculture represent 8.1% (59 Mt CO_2 eq.) of Canada's total emissions, through agricultural activities like manure management, agricultural soil management, urea and other carbon-containing fertilizer application, food transportation, food processing and even food waste [46–48]. While Canada's emissions from agriculture are smaller than the global average (in 2019 approximately 31% or 17 billion tonnes of the global GHG emissions occurred from agricultural facilities) [49], the high global temperatures, prolonged summers, unhealthy soil, and polluted air and water make Canada's food production system more insecure [50]. According to Statistics Canada [51]; one in seven Canadians or 14.6% of households were food insecure in 2020 and 9.3% Canadians reported that they depend on free food or meals from community organizations. Another hard truth is that, in Canada, one in every six children under age 18 is affected by food insecurity and this situation is worse in Indigenous communities. For instance, two in every three Inuit children face food insecurity [52].

Based on Statistics Canada data, Canadian land use for industrial agriculture has concentrated and intensified between 2011 and 2016, as

the area (in ha) under field crops, as well as the total crop land under commercial fertilizers, insecticides and conventional tillage has increased 6%, 13%, 39%, and 5% respectively [18,53]. This concentration and intensification contribute significantly to greenhouse gas emissions and climate change [54]. The impacts of climate change vary across Canada as well as across seasons. High temperatures and longer growing seasons increase productivity and help to introduce new and importantly more profitable crops in the northern, southern, and central prairies [55]. On the other hand, changing temperatures and precipitation patterns increase dependency on irrigation and water-resource management mainly across the prairies and the interior of British Columbia, where traditionally irrigation has not been needed earlier [55]. In addition, flooding, wildfires, and storms may cause loss of crops, lower grain quality and relocation of livestock, affecting livestock heating, cooling and automated feeding and milking systems, reducing milk and egg production, increasing pests and diseases and even livestock mortality [55].

Newfoundland and Labrador (NL) has the smallest number of farms among all the Canadian provinces, accounting for less than 1% of all farms in Canada [56]. According to the most recent report, there were 344 farms in the province in 2021, down 15.47% from the previous census in 2016 [57]. According to the Canadian Community Health Survey (2011–2012), 7.8% of the households were food insecure in the NL province [58]. The people of NL suffer from both a deficit of agricultural food production and food provision locally [59], with approximately 90% of the fresh vegetables consumed being shipped into the province from out of provincial sources [60,61]. Due to weather conditions, like winter storms which disrupt land and water transportation, people face shortages of fresh food at the grocery stores and buy highly processed items with a long shelf life [62]. Numerous households are struggling to afford enough healthy food and are depending on food banks or family and friends when emergency food programming is absent [60]. The provincial food and farming system faces numerous challenges and unsustainable conditions, including biophysical dimensions such as climate change [63], environmental pollution, escalating loss of biodiversity, and deteriorating ecosystem services [64–67]. In addition, NL is exposed to natural hazards like floods, drought, snowstorms, rainstorms, and wildfires which hinder agricultural activities and enhance the province's food security issue [68].

The declining number of farms and the ageing farmer population are the more recent problems which affect the agriculture sector of the province [68,69]. The average farm size increased from 152 acres to 174 acres between 2011 and 2016 [46], which indicates that the NL agriculture becomes more concentrated and more industrialized. At the same time, the NL agriculture contributes to greenhouse gas emissions. In 2019, GHG emissions in NL were 11 Mt CO_2 eq., out of which 91 kilotons of carbon dioxide equivalent emissions were from agricultural activities [48]. The provincial unsustainable agriculture and food insecurity are issues of concern not only for the people of the province but also for the Canadian and provincial decision makers. In 2021, the federal and the provincial governments have taken the initiative to introduce in the NL province the Living Lab model [70], a model aiming to identify and co-develop innovative practices and technologies to mitigate agri-environmental impacts and develop collaboration among farmers, scientists, and other external partners [71,72]. The major aim of the Living Lab initiative is to increase carbon sequestration and reduce greenhouse gas emissions, as well as to increase productivity, profitability and socio-economic resilience for farmers and local communities [72].

3. Research methods

In this research, the theoretical framework is the economics of strong sustainability [73], as it applies to complex socio-ecological farming systems. The concept of weak sustainability assumes that natural capital and manufactured capital are essentially substitutable at the margin [74] and considers that there are no essential differences between the kinds of well-being they generate [75,76]. The only thing that matters is the value of the aggregate stock of capital (manufactured, human, natural, social, and technological), which should be at least maintained or ideally increased for the sake of future generations [77]. Authors writing on strong sustainability consider that natural capital cannot be viewed as a mere stock of resources; rather, it is a set of complex systems consisting of evolving biotic and abiotic elements that interact in ways that determine the ecosystem's capacity to provide human society a wide array of functions and services [75,78,79]. [80] have demonstrated that natural capital is not supplementary but complementary to man-made capital and constitutes the limiting condition in the total capital frame. This limiting condition highlights the need to maintain the ecological integrity and functioning of natural systems above certain thresholds of degradation in order to conserve the capacity of natural capital to renew itself and provide the ecological services which are critical for human existence and well-being [75,78,79]. Many experts and policy makers believe that industrial agriculture should be replaced by more sustainable food systems based on agro-ecology [5], which is defined as "a science that draws on social, biological and agricultural sciences and integrates these with traditional and farmer's knowledge" [81] to secure both sustainable agriculture and food systems and ecosystem integrity.

The Newfoundland and Labrador province was selected as a study area to assess the contribution of the agricultural sector to climate change and how food production and food security were affected by environmental degradation and climate change. In order to identify the natural hazards that affect agricultural production in the NL province, and the farm practices that have contributed to climate change, as well as the actual barriers to adopting agro-ecology principles within the province, self-administered surveys were developed and utilized to gauge the opinion of NL farm operators. The surveys contained 71 questions related to crop farms which referred to the farm size, operations, land preparation, impact of natural hazards, agricultural activities creating greenhouse gas emissions, sustainable farm practices, farmers' interest in organic, agro-ecological and integrated farm practices and support received from the government.

The surveys were mailed to 45 randomly selected farms identified through the Young Farmers' Forum. The response rate was 17.78%. Using the snowball sampling method, the researcher interviewed an additional number of 8 farmers by attending the 2019 Annual General Meeting of the Newfoundland and Labrador Federation of Agriculture and by visiting farms. The secondary data has been collected from relevant literature related to agriculture and the environment, including published journal articles, reports of government departments and international organizations, periodicals, newspapers, and conference papers. The key variables that have provided guidelines for collecting secondary data included: industrial food production systems, food security in NL, global temperature and greenhouse gas emissions, impacts of agricultural activities on greenhouse gas emissions in NL, and the effects of climate change on agricultural production and food security in the province.

The study used content analysis and both inductive and deductive approaches [82] to analyze collected data. A deductive method was used to analyze secondary data, and an inductive approach was used to analyze both qualitative and quantitative primary data. Statistical data collected through surveys and interviews with farmers were entered into an electronic data file for analysis, using the IBM Statistical Package for the Social Sciences (SPSS) Edition 23 to calculate frequencies of responses, demographics, as well as other inferential statistics, and the Microsoft Office Excel spreadsheet was used to calculate the averages, maximum and minimum values, and to draw figures, charts and tables, etc.

4. Results and discussion

The research results are organized under four headings, discussing the natural hazards impacting the crop production in the province and showing that climate change is real, the impact of agricultural activities on climate, the measures taken by the farmers in order to reduce climate change impacts, and trends identified by farmers showing the potential of a transition to strong sustainability farming practices in the province.

4.1. Natural hazards affecting the crop production in Newfoundland and Labrador

The study has found that farming activities are impacted by extreme temperatures. As Table 1 shows, 37.5% of the crop farmers faced the challenge of extreme high temperatures, as they needed more water for irrigation and experienced a lower quality of the vegetables and crops. The study confirmed what Ruth Mottram, an environmental expert of the Danish Meteorological Institute, had predicted, namely that the year 2019 would be a temperature record-breaking year for the North Pole, as the icebergs or large chilly ice in the North Atlantic Ocean started melting at the beginning of June 2019 [83]. Indeed, the weather station Kana in Greenland recorded 17.3° Celsius on June 12, 2019, which was 0.3° Celsius above the temperature recorded on June 03, 2012. The Newfoundland and Labrador province is near Greenland and this higher temperature has impacted its agriculture. As Table 1 shows, 43.8% of the crop farmers indicated that extreme low temperatures reduced the growth of plants and delayed maturing of crops, with poor yields and crop quality. For instance, temperatures below −25° C may damage or kill the vegetables, forages, winter annuals or the tender fruit trees. Long winters mean short growing seasons, which is a major challenge for the farm operations in NL, as identified by 75% of the crop farmers. Sometimes, farmers have had to wait until mid-June to start their farm operations, which increased the harvesting risk since early winter may damage the crops. Similarly, short growing seasons limit the opportunity of growing more than one crop in the same field in a year. The same percentage of respondents (75%) faced challenges due to late spring frost or early fall frost that affected both the yield and quality of cereal crops, and vegetables. Additionally, late spring frosts during blooming period, reduced production more frequently and made harder to store the crops [84,85].

In addition, the survey report indicated that 25% of the crop farmers were affected by heavy rains and rainstorms, and they raised the question whether the strong rainstorms are a normal occurrence or the result of climate change. The report refers to Sean Dyke, a cranberry farmer in Wooddale South, who faced floods from rainstorms on two occasions. The floods washed away newly constructed berms and filled parts of his fields with debris [86]. These rainstorms or floods, never experienced in the previous seven years, washed out the crop fields and the access roads which remained impassable for several days.

"Newfoundland and Labrador province is in the throes of the most intense storm on the planet, according to a meteorologist in Gander" [87] which mentioned that sometimes the wind and the waves were so strong that the island was shaking [87]. The high winds or storms are very dangerous for young plants, and they destroyed vegetables, crops, and fruits, as identified by 37.5% of the crop farmers. The effects of high temperatures and global warming have been observed by the NL farmers, since more than 50% of the surveyed farmers mentioned that they had to use more water for irrigation due to more frequent droughts, and some were planning to install new water pumps on their farms. Several independent studies have claimed that drought and heat are the major abiotic stresses that reduce crop yields by as much as 50% and weaken regional as well as global food security [88]. Even the mildest heat and drought stress have the ability to negatively affects crop and vegetable yields [88]. In 2018, not only Newfoundland and Labrador, but also most of Manitoba, Ontario, New Brunswick, Alberta and Saskatchewan, have been ranked as abnormally dry [89]. A stressful environment due to a changing climate is predicted to impact negatively the diversity and abundance of insect-pests, and ultimately to extend the damage to economically important agricultural crops [90]. Outbreaks of insect-pests and diseases have significant consequences for crop production, and existing research has shown that more than 40% of crop losses are due to pests worldwide [91]. The farm operators in NL face insect-pest problems as indicated by 37.5% of the crop farmers who had to use synthetic as well as organic pesticides to control pests and diseases. The insect-pests not only affect perilously the agricultural production but also the livelihood of farmers who are directly depending on climate sensitive sectors such as agriculture [90]. An environmental expert claimed that the climate change forecasts would seem to suggest good news for agriculture in NL in the coming decades, but there is a forewarning, as ongoing changes also provide conditions ripe for shifts in disease, and expanded range of some pests [86]. Though few respondents (12.5% of the crop farmers) indicated that landslides and soil erosion hampered the crop production after clearing trees and leveling hills for land development, mono cropping and tilling, as well as rainstorms/floods may increase the landslide or soil erosion problems in the province. The survey result shows that 25% of the respondents worry that the crop production will be affected by the wet season, as experts mentioned that more rain and more storms are expected, with warm temperatures in the province. Frequent rains and dull weather may create difficulty to access the farm and may decrease the crop yields [86].

This research confirmed that climate change is impacting the NL province, and its sensitive agriculture industry, affecting crop production and increasing the food insecurity problem. The most important finding of this research is that provincial farmers need to change the way of doing farming by taking into account the changing climate, and by applying new techniques and methods to protect their crops as well as by implementing sustainable farming practices.

Table 1
Natural hazards affecting the crop production as identified by respondents.

Natural disasters affecting the farmers	Crop farm (% of "yes" respondents)
Extreme high temperatures: above 35° C	37.5
Extreme low temperatures: below −25° C	43.8
Long winter/late spring	75.0
Heavy snow/snow storm	25.0
Late spring frost	75.0
Rainstorm/heavy rain	25.0
More frequent drought	56.3
Short growing season	75.0
High winds/wildfires	37.5
Pest/disease outbreak	37.5
Flood	18.8
Land slide/soil erosion	12.5
Wet season	25.0
Cyclones/tornadoes	–

Source: Field survey, 2019

4.2. Agricultural activities contributing to climate change

Greenhouse gas emissions from agriculture, especially from industrial agri-food systems, have an impact on climate change, mainly due to deforestation, land use and land-use changes, use of chemical fertilizers and pesticides, burning fossil fuels, waste management and industrial food processing [49,92]. The results of this research confirm the above findings. A significant number of surveyed farmers (43.8%) believed that industrial or conventional farming contributes to climate change. The remaining crop farmers believed that their farm practices were not contributing to climate change, as they were making efforts to apply the best management methods recommended by Canadian farming regulations. Table 2 shows that 25% of the crop farmers agreed that mono cropping had negative effects on soil depletion and contributed to reduction in diversity of soil nutrients. This single cropping system is

Table 2
Agricultural activities contributing to climate change as identified by respondents.

Agricultural activities contributing to climate change	Crop Farms (% of "yes" respondents)
Mono cropping	25.0
Land clearing and field burning	37.5
Soil tillage	25.0
Manure management	25.0
Irrigation	12.5
Using pesticides	31.3
Use of chemical fertilizers	37.5
Use of fossil energy or fuels	37.5
Size of farm operation	25.0
Food waste	12.5
Food production/processing	12.5
Food transportation	31.3

Source: Field survey, 2019

commercially efficient and profitable, but provides an unbuffered niche for parasitic species, increasing crop vulnerability to opportunistic insects, plants, and microorganisms, and also increasing farmers' dependency on pesticides and artificial fertilizers. Using more chemical fertilizers and synthetic pesticides ultimately increases greenhouse gas emissions such as N_2O. The field survey indicated that 87.5% of the crop farmers had cleared trees to prepare the farmland, and 37.5% indicated that land clearing and field burning contribute to greenhouse gas emissions and climate change. Indeed, land clearing and field burning enhance greenhouse gas emissions in two ways, when farmers cut trees (deforestation) for preparing the land for agriculture, and when they burn crop residues in the field releasing carbon dioxide into the atmosphere. At the same time, both activities destroy the green plants which take in carbon and release oxygen during photosynthesis and reduce the carbon sequestration capacity of the ecosystems [93]. The soil quality and structure are not optimal, being rocky, less fertile and more acidic, in the NL province [59], and an increased number of tillage operations is necessary for preparing the soil. As Table 2 indicates, 25% of the crop farmers agreed that tillage is related to greenhouse gas emissions, and they were trying to reduce the number of tillage operations or apply minimum/zero tillage techniques [94]. have shown that soil tillage techniques have a deep influence on the physical properties of soils and on the greenhouse gas balance (store minus release). These authors also recorded a significantly higher (26–31%), net global warming potential under conventional farming, than with zero tillage farming. At present, conservation tillage practices, such as reduced/minimum/zero tillage, and direct drilling are widely getting popularity to protect soils against erosion and degradation of structures, to increase carbon sequestration, to enhance soil organic matter content and to mitigate greenhouse gas emissions [95–97].

Manure management has a profound contribution to greenhouse gas emissions, especially methane emissions, if it is not handled properly. 22.2% of the surveyed farmers were aware about the negative consequences of improper manure management and reported that with the help of environmental farm plans (supported by a national program) they regularly composted manure or spread/incorporated it on the crop land during the spring and fall, according to existing recommendations. However, they also reported that they needed more information and support about sustainable farming practices related to manure handling, water management, chemical inputs and sustainable land management [98].

The farmers surveyed used chemical or synthetic pesticides as one of the several tools to control, prevent, destroy or mitigate pest-insects and diseases in the crop and vegetables field. Due to introduction of organic pesticides and bio-control methods and increased awareness of the farmers about the negative health and environmental effects of chemical pesticides, the use of chemical pesticides is gradually decreasing in the study area. Canadian farmers strictly follow the regulations concerning pesticides use, as enforced by the federal, provincial, and municipal governments, and because of this reason, relatively few respondents (31.3%) believed that their use of chemical pesticides had an impact on environmental pollution and climate change.

Using chemical fertilizers for crops, vegetables and grain production has direct effects on producing greenhouse gas emissions, and water and soil pollution. These effects are more serious in NL, as farmers need to use more chemical fertilizers to reduce soil acidity and maintain soil pH and nutrients levels and achieve a cost-effective production [99]. Though most of the farmers in the surveyed area are trying to use organic fertilizers alongside chemical fertilizers and limestone, only 37.5% of the farmers believed that the chemical fertilizers and the limestone they used in the fields have negative impacts on the environment. Studies show that chemical fertilizers do have an impact, as they contaminate everything in the environment and their residues are found everywhere in the soil, water, land and air [100]. From the respondents' comments, it was found that the crop farmers who also have livestock have the opportunity to use more organic fertilizers compared to the crop farmers who have no livestock.

Being highly mechanized, Canadian agriculture requires numerous tractors, harvesters, and farm equipment which are mostly running on fossil fuels. Farmers also use fossil fuels for personal vehicles and for food/grain transportation. Survey results indicate that 37.5% of the crop farmers mentioned that fossil fuel use was one of the major sources of air pollution and climate change. Ontario has recently imported one tractor from US which is running on renewable solar energy, but the researcher did not find any electric vehicles or farm equipment running on renewable energy in the NL province. With its action plan on climate change, the Way Forward on Climate Change, the provincial government imposed a carbon tax on fossil fuels in NL, but this program will not reduce pollution created by agricultural farms as this sector is exempted from the carbon tax [101,102]. The Newfoundland and Labrador government developed in 2021 a Renewable Energy Plan with the collaboration of the public, Indigenous governments and communities, industry, and stakeholders, aiming to reduce the use of fossil fuels, provide renewable energy at affordable prices and supplying surplus energy to Atlantic neighbors and beyond [103]. The government of Newfoundland and Labrador has a five-year plan to achieve its net-zero commitments by 2050, fight climate change, create employment opportunities for local people, and demonstrate leadership as a Clean Energy Centre of Excellence through using the province's rich hydro, wind, biomass, solar, and wave/tidal resources [103].

The average farm size in NL is increasing which means industrial concentration leading to mono cropping and massive application of chemical fertilizers and pesticides. As Table 2 indicates, 25% of the crop farmers believed that large scale farm operations contribute to environmental pollution and climate change, and 75% of the farmers stated that there are advantages in small-scale farming. Though the discussion about existence of economies of scale in farming is controversial, fact is that the industrial agriculture's drive to achieve economies of scale is the reason for increasing the size of the farms [104,105].

Food transportation is one of the big sources of environmental pollution, as mentioned by 31.3% of the crop farmers surveyed. Though Newfoundland and Labrador is a less populated province, its communities are scattered and more than 50% of its residents live in rural areas. Most of the farmers sell their products in the nearest city, grocery stores or farmers markets and sometimes they offer home delivery. Thus, they need to travel more frequently and farther distances using personal vehicles, which increases greenhouse gas emissions. The study also revealed a very low percentage (12.5%) of food processing on farms. More food processing is essential for a province challenged by food insecurity.

Therefore, all kind of farm practices are contributing more or less to greenhouse gas emissions. Among these, land clearing and field burning, using chemical fertilizers and pesticides, as well as burning fossil fuels, and manure management have significant impact on climate change. At

the same time, it is difficult to ignore that climate change effects are more severe in the agriculture sector, which ultimately is increasing the pressure on food production and food security in NL as well as worldwide.

4.3. Measures taken by the NL farmers to reduce GHG emissions and keep the environment intact

The research showed that while most respondents in the surveyed area used large amounts of fossil fuels, some of them (18.8%) were interested in producing energy from alternative sources, such as solar power, wind, tidal energy, or even geothermal energy. But due to lack of provincial government permission and the monopoly power exerted by Newfoundland and Labrador Hydro, the largest electricity supplier in the province, farmers have no right to produce renewable energy and sell the surplus to the national grid [106].

The respondents are aware about the negative effects of chemical fertilizers on the environment and many of them (43.8%) were trying to use fewer chemical fertilizers. Among the measures taken by the farmers are: following the minimum recommended doses, discussing with soil scientists about soil health and nutrition, using granular fertilizers (a mix of chemical and natural fertilizers), planting green manure crops, using all natural amendments and using more organic fertilizer, such as manure. The majority (93.7%) of the crop farmers use manure on their farms, and 25% do not use any chemical fertilizers, considering the negative environmental and human health effects. After introduction of organic pesticides and of integrated pest management techniques, most of the farmers in the study area, namely 50% of the crop farmers, have tried using fewer synthetic pesticides. Moreover, as alternative techniques, they did apply bio-control, crop rotation, cover crops, spreading sawdust at the edge of the farm and sterile insect techniques to control pest attacks.

To reduce the pressure on ground water and to benefit the environment, 37.5% of the crop farmers collected rainwater, and 43.8% used surface water. As Table 3 highlights, 62.5% of the crop farmers grew diversified crops, 68.8% applied crop rotation and 31.3% practiced intercropping to increase soil health and the farm income and to reduce the risk of crop loss. All these practices, directly and indirectly, benefit the environmental. Crop rotation, crop diversification, intercropping, using organic fertilizers, and producing green manure plants are beneficial to soil conservation and 62.5% of the responders followed some of these practices. The survey results also show that 87.5% of the responders keep trees in the farm area. This is one of the environmentally friendly practices, as standing trees or forests are the best carbon sequesters, while keeping the weather cool. To reduce the effects of carbon emissions from transportation and reduce their costs, most of the responders (68.8%) were trying to supply agricultural produce to the local markets.

Table 3
Measures taken by the farmers to reduce GHG emissions and keep the environment intact.

Various measures	Crop farms (% of "yes" respondents)
Use alternative energy sources	18.8
Use less chemical fertilizers	43.8
Use no chemical fertilizers	25.0
Use organic fertilizers/manure	93.7
Use alternative pesticides	50.0
Collect rain water for farm usage	37.5
Recycling used water	6.3
Using surface water	43.8
Crop diversification	62.5
Crop rotation	68.8
Practice intercropping	31.3
Soil conservation	62.5
Keeping trees in the farm area	87.5
Plan to supply more product to local markets	68.8

Source: Field survey, 2019

Overall, it can be said that crop farmers were more or less conscious about the environmental effects of their agricultural activities and knew about the increased challenges they faced in food production and food security due to climate change. Most of them have taken several mitigation measures and also have plans to transition to more environmentally friendly farm practices.

4.4. Trends showing feasibility of transition to agro-ecology practices and make current agricultural practices more resilient to global climate change

The present trend in Canadian agriculture is industrial concentration, with the number of farms decreasing while the average size of farms increasing [56]. This indicates that industrial agriculture is hurting the traditional small-scale Canadian family farm [54]. The industrial agriculture model may increase short-term yields of targeted crops in certain geographic and climatic zones; however, it is also linked to a number of environmental problems, and contributes to a new array of social problems, including widespread income inequality, financial indebtedness of farmers, loss of farmer knowledge, increasing the number of agri-food corporations and forcing small farm owners out of business [107]. To develop diverse pathways of resistance to these challenges, a growing number of farmers, social movement organizations, and institutions are recognizing the importance of agro-ecology as a prominent alternative to industrial agricultural production [108,109]. An agro-ecological approach recognizes the multifunctional dimensions of agriculture and helps to extend farming practices toward working with nature not against it and achieving a broad range of socially equitable and sustainable goals, such as increasing ecological resilience, improving soil health and nutrition, conservation of natural resources, economic stability, climate change mitigation and increased social resilience and institutional capacity [15].

To increase ecological resilience and reduce the risk of changing environmental conditions, practices such as using diversified crop rotation, soil conservation, using fewer chemical fertilizers and pesticides, producing renewable energy on the farm using solar or wind power, applying animal manure, keeping trees in the farm area and having access to surface water sources, are significant for preservation of the ecosystem [110]. All these practices contribute to reducing greenhouse gas emissions and climate change vulnerability, as well as enhancing ecological resilience in NL. The survey results mentioned that 68.8% of the crop farmers have plans to make their farm more environmental-friendly, which increases the expectation of implementation of agro-ecological principles/practices.

As Table 4 indicates, 62.5% of the crop farmers increased their farm size in the last 5 years and at the same time, 50% of the crop farmers have plans to increase their farm size in the near future. This may enhance the supply of fresh food and help to achieve the provincial government's goal of increasing provincial food production from 10 to 20% by 2022 [111].

Improving human health and nutrition requires more diverse, nutritious, and fresh food. This can be achieved by reducing the incidence of chemical fertilizers and pesticides used in farming which are potentially poisoning the farmers, consumers, and the environment. Though the respondents used a high amount of chemical fertilizers, at the same time, a large percentage of farmers used organic fertilizers and were trying to use less chemical fertilizers and pesticides.

Though organic production or certified organic production fails to capture the multiple dimensions of agro-ecological practices and motivations, the number of Canadian farms cultivating organic products has increased 65% between 2011 and 2016, indicating a trend towards increased ecological farming across the country and possibly a transition to the adoption of more ambitious agro-ecological practices. In the entire Newfoundland and Labrador, only 1.2% of the farms in 2016 have produced organic products [46]. This is due to the high cost and stringent conditions involved in certification of organic farms, which are

Table 4
Farm practices that help transition to agro-ecology, as identified by respondents.

Farm practices that help transition to agro-ecology	Crop farms (% of "yes" respondents)
Did your farm increase the size of production or livestock in the last 5 years?	62.5
Do you have plans to increase the size of farm production or livestock in the near future?	50.0
Do you also practice integrated farming (livestock and crops) on your farm?	43.8
Do you think that there are advantages in small scale farming?	75.0
Do you have a plan for making your farm more environmentally friendly?	68.8
Do you have knowledge about agro-ecological farm practices?	68.8
Are you interested in agro-ecological farm-practices?	93.8
Do you have plans to introduce organic farming on your farm?	37.5
Do you think that integrated farming can promote sustainable farming on your farm?	93.8
Did you benefit from any program/financial support from the provincial or federal government for promoting sustainable agricultural development in NL?	62.5

Source: Field survey, 2019

prohibitive for farmers to seek organic certification. For this reason, many farms call themselves environmentally friendly (Wright family farm, the Greenhouse, etc.). The survey results show that 37.5% of the crop farmers have plans to introduce organic products on their farms.

Economic stability in agriculture depends on a more diversified cropping system, on integrated farm practices, and on the spread of labor requirements and production benefits over time, as well as on reduced vulnerability to single commodity price swings [112]. Of the farmers surveyed, 43.8% practice integrated crop-livestock farming, whereas 93.8% (Table 4) believed that integrated farming enhanced the sustainable income sources and the food security in the province. Moreover, if the respondents have access to forest and surface water for aquaculture, then the farms could be more integrated and could offer more employment and could earn more money [107]. Most of the crop farmers in the NL province are running rather large-scale farm operations, but interestingly, 75.0% of the crop farmers believed that small scale farming is more efficient and sustainable, since smaller farms can be managed more easily. This belief is confirmed by a FAO report that stated that globally small scale farmers produce over 70% of the world's food and provide employment for millions [113].

Agro-ecological knowledge, training, scientific research [37], as well as government and non-government support networks play positive roles in increasing ecological and social resilience and institutional capacity which are the main goals of agro-ecological practices. As Table 4 pointed out, 68.8% of the crop farmers in the study area have knowledge about or training in agro-ecological farm practices, and 93.8% are interested in agro-ecological farm practices. Table 4 also indicates that 62.5% of the respondents received federal or provincial government financial and technical support for promoting sustainable agricultural development. This support has allowed farmers to engage in conservation of natural resources, like keeping organic matter in the soil, preserving biodiversity and high-water quality, and ecosystem services, like pollination. Pollinators, such as bees and butterflies, provide important environmental services and economic benefits to agricultural and natural ecosystems, with more crop diversity and food productivity [114]. It is a known fact that NL bees and honey are of exceptional quality and there is a provincial ban on import of bees from outside NL, in order to protect the health of local bees.

Climate change mitigation measures such as increased energy efficiency, reduced dependency on fossil fuels and fossil fuel-based agricultural inputs (fertilizers), increased carbon sequestration and water capture capacity in the soil are some of the goals of agro-ecological practices [112]. Due to lack of government permission to produce renewable energy at individual levels, and due to recent government regulations, that exempt the agriculture sector from carbon pricing, there are few incentives to reduce dependency on fossil fuels and fossil fuel-based inputs in the NL agriculture. But if the government will implement the Renewable Energy Plan and introduce electric vehicles successfully in the province, then farmers can be expected to use more clean energy for heating, transportation, fertilizer production and even for running farm equipment [103].

The provincial as well as the federal government provide several support programs through Agriculture and Agri-Food Canada, the NL Federation of Agriculture, Environmental Farm Plans, the Canadian Agricultural Partnership (CAP), Provincial Agrifoods Assistance Program (PAAP), and The Way Forward programs. However, most of these support programs are directed to large-scale farming operations. More recently, the Young Farmers' Forum, and Food First NL aim to make NL's agriculture and the food supply system more secure, resilient to climate change and sustainable. The overall discussion shows that the NL agriculture industry is at the middle stage of adopting agro-ecological farm practices. Farmers are highly interested in adopting more environmentally friendly agro-ecological farm practices and to achieve these goals more initiatives promoting research, training and government support are needed.

5. Policy recommendations and conclusion

To mitigate climate change impacts, increase food security and enhance sustainable ways of practicing agriculture, by using agro-ecological practices in the NL province, the respondents' opinions and comments can provide useful information for the government and policy makers to address these issues in a more comprehensive way.

1. To stop decreasing the total number of farms in NL and to reverse the trend, in 2017 the government made available 64,000 ha of land, spread out over 62 agricultural areas, which was supposed to almost double the amount of land available for farming. This land should have been allocated specifically to small-scale and young farmers that are interested in applying agro-ecological and environmentally sustainable principles of farming.
2. To increase the number of farmers, incentives and support should be available for farmers to develop viable succession plans, and easy access to education for future young farmers should be secured through a system of scholarships. A separate and specialized agro-ecological college, or campus under Memorial University of Newfoundland could satisfy the need for education, training and research in sustainable agriculture. Such a unit could also initiate and build collaboration between universities, farms, relevant industrial sectors, the general public and the government and NGOs, for raising general awareness about the environmental and human health benefits of agro-ecology.
3. Farmers indicated that they needed more training in agro-ecological farming techniques. Such training needs to be provided both in an institutionalized manner and through organized dialogues, or exchanges of good practices, making farmers understand why it is important to apply less lime and chemical fertilizers to maintain soil pH and nutrients and to apply more organic fertilizers (manure), and familiarize them with innovative techniques.
4. In order to encourage use of more organic fertilizers on the farms, stronger integration at the farm level should be encouraged, for instance by incorporating livestock in the crop farms, as well as by promoting regional linkages between farms themselves and industry, for instance by enabling crop farmers to buy surplus manure from dairy farms, or compost, green manure plants, or fishery discards from fishery plants.

5. The establishment of commercial links between agricultural farms and tourism industry, public and private institutions and local restaurants, schools [115] and hospitals should be actively promoted and advertised, aiming to increase the demand for locally produced fresh and sustainable food and to enhance the agri-foods business sector. Logistic and financial support should be available for local farms' integration into a local or regional food producing and processing sector embedded in a circular economy scheme including farming, fisheries and forest sectors.
6. Improvements are required in the clean and green energy sector policies and regulations that will support farmers in their efforts to reduce consumption of fossil fuels and convert fossil fuel powered farm machines and equipment into electric powered machines, to produce more energy from biomass and renewable sources on the farms, and to remodel greenhouses and livestock sheds to heat and light them by geothermal, wind or solar energy. Use of renewable energy on farms could encourage farmers to increase the percentage of produce that is processed on farms.
7. With the help of the NL Federation of Agriculture and other NGOs, farmers should be able to have access to affordable crop insurance, mentoring, mental health services that can reduce mental stress and financial risks.
8. Currently, the government agricultural support policies favor large scale farming operations and do not encourage agro-ecological practices. The government should reward and proritize financial assistance to farmers who currently practice or plan to incorporate in their farms integrated farming (crop, livestock, forest and aquaculture), multi cropping, renewable energy sources, anaerobic digester technology, greenhouse or electric machines and equipment, irrespective of the farm's size. Financial support in the form of low interest loans, tax credits or subsidies needs to be available for the new, young and small-scale farmers who want to start agro-ecology farming or wish to adopt new advanced technologies in agro-ecology practices.

The Canadian province of Newfoundland and Labrador has a food security issue due to a small agriculture sector, challenged by scarcity of suitable agricultural land and a declining and aged population of farmers, short growing seasons, and unsustainable agricultural policies promoting conventional industrial farming practices, which result in a limited supply of agricultural produce and no or very few facilities for secondary processing. The food security issue has been exacerbated in the last decades by climate change events (extreme temperatures, heavy rains and more frequent droughts) which have negatively impacted the province's agricultural industry and compromised the efforts to achieve the doubling of provincial food production by 2022. In the attempt to solve the double faceted problem of food security and climate change, one important solution is pursuing a generalized agro-ecological approach to farming in the province.

This study has found that there are incipient agro-ecological practices in the province. The surveyed crop farmers are more or less aware about climate change impacts on agricultural activities and have taken some individual, decentralized, not-coordinated measures to reduce GHGs emissions. These are not sufficient to fight serious climate change impacts and to lead the farms towards sustainable ecological and economic operations. New policy frameworks and work plans are needed to speed up the transition from the current unsustainable industrial farming practices to a more resilient agro-ecological-food system made up of diversified farms, small, medium and large scale, using agro-ecological practices. Provincial, municipal, as well as federal government support, and collaboration among educational and research institutions, agricultural farms, non-government organizations and the general public will contribute to agricultural diversification and integration and more environmentally friendly farm practices within the province. These will ameliorate the food security issue, by increasing the supply of locally produced and processed fresh and healthy food, will provide additional financial benefits to farm owners, and will protect the local as well as the global environment, also increasing the resilience of local communities. Working with nature not against it, the NL farming system will provide both good food for the province's residents and sustainable livelihoods for farmers, protecting at the same time the pristine environment of the province.

Declaration of competing interest

The authors named Mohammad Selim Reza and Dr. Gabriela Sabau declared that we have no involvement in any organization or institution with financial interest like educational funds, honoraria, membership and employment contract, consultancies, patent-licensing or other equity interest, and also we have no non-financial interest like personal, professional or family relationship, engagement and contract, knowledge or belief in the subject matters or resources discussed in this manuscript.

Data availability

The data that has been used is confidential.

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