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Project Directory

Project #19102

The Social Implications of Genomic Agrifood Technologies: Ensuring Equity, Diversity and Inclusion in the Transition to Climate-Resilient Canadian Agricultural and Food Systems

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Keywords for Proposed Investigation

Research	Methods & Technologies
Inclusion Diversity Equity and Accessibility, Emerging Agri Genomic Technologies, Resilient and Climate Smart Food Systems, GE3LS	Emerging agri-genomic technologies including cellular agriculture and functional genomics and gene editing and others

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Social implications, Trade Offs, Equity and Marginalized Communities, Policy Pathways, Sustainable and Just Food Systems	Mixed Methods, Systematic Reviews, Case Studies, Survey, Modelling and Scenario Analysis

Project Summary

Emerging agri-genomic technologies, such as cellular agriculture, functional genomics, and gene editing, are positioned to make significant inroads on achieving Canada's 2050 climate goals by increasing agricultural production efficiency, sequestering carbon, and reducing food waste. However, these technologies do not exist in a vacuum—they are developed and implemented in an unequal world. While emerging agri-genomics hold incredible potential for improved climate-related outcomes, they are likely to come with trade-offs, including poorly understood social implications for already marginalized communities in both local and global contexts.

For Canada to be a global leader in agri-genomics, it must also be a leader in prioritizing equity in genomics across the value chain, from research to implementation. The purpose of this proposal, therefore, is to help policy makers, researchers, and technology developers and users address challenges associated with social equity and social justice for emerging agri-genomics with climate mitigation potential. Through this project, our team of equity experts and social scientists will develop tools for minimizing potential risks and maximizing benefits for marginalized communities, including: farmers facing livelihood disruptions from emerging technologies, precariously employed migrant farm and food workers, Indigenous communities with deep relations with their territories, food insecure consumers, remote and northern communities, and groups historically excluded from the STEM innovation chain.

Our main objectives are to: O1) Create a greater understanding of the climate mitigation potential of emerging agri-genomic technologies; O2) Anticipate the potential risks and

benefits these technologies hold for marginalized communities, and O3) Develop policy recommendations and resources to facilitate meaningful contributions from agri-genomics to creating more sustainable and equitable food systems.

These objectives will be achieved through the following research activities: A1) Systematic literature reviews to assess the state of knowledge on emerging agri-genomic technologies and their potential for GHG reductions. A2) A national survey to assess potential consumer demand for products created using these technologies, potential for adoption among producers and likelihood of public acceptance and opposition. This will inform different possible future implementation scenarios. A3) Input-output modeling(I-O) to anticipate the potential for GDP growth, job creation, and GHG reduction using an environmental extension under different implementation scenarios. A4) Qualitative community-based case studies in collaboration with innovative companies and NGOs working to transform the food system to explore the potential harms and potential mitigation strategies for marginalized communities that these technologies pose. A5) We will mobilize the results through two deliverables: D1) A "White Paper" distributed through our team's government, community, and academic networks. We will also synthesize the results and deliver D2) a "Toolkit" for best practices for equity in agri-genomics through a series of workshops and events with agri-genomics experts, including members of other ICTs, and equity experts from our team's extended network. These outputs will be designed to deepen the commitment among Canadian genomics leaders, including teams across the ICT portfolio, to social justice in building the food systems of the future.

Project #19108

Evaluating the role of Canadian kelp production as an atmospheric carbon dioxide mitigation strategy

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Keywords for Proposed Investigation

Research	Methods & Technologies
Kelp, Yield, Resiliency, Carbon transport and storage, Emissions reductions	Farming harvest, Whole genome sequencing, Mesocosm experiments, eDNA, Sediment organic carbon analysis

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Carbon dioxide removal, socioeconomic, equity, revenue, climate	Emissions accounting, Trade-off analyses, Interviews, Surveys, Literature data

Project Summary

There is a current surge in participation and investment in Canada and globally around seaweed and kelp production systems, where farmed or harvested kelp is consumed directly by humans or used secondarily in other food systems. This interest is bolstered by new research pointing to the role of kelp forests in the ocean carbon cycle and their potential to offset emissions from other agricultural and aquaculture pathways. However, major data and knowledge gaps have prevented a more complete understanding of 'kelp use pathways', from the perspective of CO2 removal. This project will build three integrated research activities that use genomic approaches and tools in combination with interdisciplinary environmental science, climate change research and economics to address these gaps and move towards carbon accounting and policy guidance for the kelp sector in Canada.

A detailed understanding of the underlying genetic and phenotypic structure of the dominant canopy-forming kelps along the West Coast of North America will be determined to support the prioritization and use of carbon-rich, climate-resilient populations and species in the kelp sector. A subset of kelp genotypes and traits will be chosen for common garden experiments to inform genome-wide association studies (GWAS), and for mesocosm experiments that will subject kelp to future climate scenarios and quantify changes in kelp carbon uptake associated with warming and acidification.

Information on kelp use pathways from two case studies will be used to trace the proportion of kelp-derived carbon stored in the ocean and the potential off-set of carbon emissions from other food systems. Research activities will examine the role of kelp farming and harvests on changes in CO_2 fluxes at the ocean-atmosphere interface, and transport/burial of kelp carbon in sediments. In a set of case studies, emissions displacement will be examined through the use of kelp biomass in soil fertilizers and fish food, as well as the co-culture of aquaculture species with kelp.

Project deliverables include a genomics data repository and biobank of kelp germplasm cultures; tools for carbon monitoring and reporting in ocean-based systems; models for case studies to support industry development and knowledge translation; and carbon and cost accounting approaches to contribute to robust and equitable policy development, with industry, government, and community engagement. Partners in this project include early career and established researchers and HQP, industry and government end-users, Indigenous and coastal communities, and regional initiatives and institutions, reflecting a transdisciplinary approach to data management, training, and research.

To synthesize and apply results to benefit the industry and impact Canada's climate change mitigation goals, kelp pathway carbon tracking will be combined with economic, environmental, and social data to develop a full cost accounting of various pathways, and to evaluate access of local coastal communities to the emerging kelp industry. These approaches will result in models and tools for adaptation in other industry sectors and geographical regions, and will provide the foundations for considering kelp as part of Canada's "blue economy", including ways that ocean-based resources and industries can contribute to reducing Canada's carbon footprint

Project #19204

Combining omic technology and grassland management to enhance soil carbon sequestration and reduce greenhouse gas emissions

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Keywords for Proposed Investigation

Research	Methods & Technologies
Grassland carbon sequestration, GHG mitigation, Root soil microbe interactions, Sustainable beef cattle production, Decision tools	Systems biology, Chemiomics, Metagenomics, Phenomics, Machine learning

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Adoption barriers and drivers, Long term market and nonmarket benefits and costs of best grazing management practices, Public policy supporting adoption	ADOPT, Cost-benefit analysis, Choice experiment, Risk analysis, Dynamic optimization

Project Summary

The Canadian Government has recently released the large-scale "2030 Emissions Reduction Plan" that outlines a sector-by-sector path for the country to reach its green house gas (GHG) emissions reduction target of 40% below 2005 levels by the year of 2030, and net-zero emissions by 2050.(1) The agricultural sector in Canada plays a crucial role in the fight against climate change, and is ready for this challenge! Within this proposal our grand ambition is to ultimately store 31.8 M tonnes of carbon throughout Canadian grasslands. To achieve this, we will first build fundamental knowledge on the mechanics of grazing management practices aimed at carbon sequestration and storage in our soils, and interactions with the plants and animals they support. The use of omics technologies will be initially employed to understand the functional biology associated with increased carbon sequestration and reduced GHG emissions as a result of improved grazing practices, and successively be used to develop improved methods to accurately quantify changes in both. This will provide a basis for developing carbon markets and policies by governments at local, national, and international levels, and provide knowledge and verification of implementing climate-smart grazing practices for grassland managers. Taken together, our efforts will elevate Canada to become global leader in sustainable grazing.

We will assess barriers to adoption of beef cattle grazers to changes in grazing management and conduct a cost-benefit analysis to assess long-term economic and environmental benefits, costs, and risks of adoption for best grazing management practices. We will evaluate the economic viability of their adoption and examine trade-offs between economic viability and carbon sequestration. Identified adoption drivers and barriers will guide

modifications to grazing management experimental design on an ongoing basis. Our project is intimately connected to the AAFC ACS Living Labs initiative, which facilitates interactions directly with producers implementing improved grazing management. This coordination also allows our project to greatly increase data we can collect with respect to the efficacy of grazing practices to store carbon. Our project also has connections with a suite of projects investigating implications of different grazing management practices, and we are a part of international networks investigating relationships between microbes, omics, and grazing cattle, that can help combat climate change. We will use these networks to leverage both the expertise that they bring, and the impact of our research on a global stage. To achieve this goal, we have initially assembled a team with expertise in: grassland ecology, plant-soil interactions, soil and microbial omics, GHG measurement and modelling, root biology, and beef cattle production.

Last, but not least, this project will produce HQP that can thrive in inter-disciplinary, diverse environments, who will have the skills to become national and international leaders in the areas of agriculture, climate change, and sustainable grazing.

(1) https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030.html

Project #19205

Novel and Adaptive Rumen Microbiome targeted solutions for GHG mitigation in cattle

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Keywords for Proposed Investigation

Research	Methods & Technologies
Rumen microbial genomics solutions, Breeding and supplementation strategies, Methane emission mitigation on farm adoptions, Machine learning for predictive microbial markers	Metagenomics, Microbial genomics, Rumen microbial metabolomics, Cattle genomics, Machine learning

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Evaluating economic and social trade offs associated with omics technologies and ruminant methane emissions, Examining factors affecting adoption of new omics technologies, Assessment of current and potential regulatory approaches, Examination of consumer and producer perceptions and preferences for omics approaches to reduce methane emissions	Cost/benefit and market level modelling, Simulation modelling for decision making, Public surveys, Focus groups to establish range of attitudes and barriers to adoption

Project Summary
Methane (CH4) is the second most important greenhouse gas (GHGs) that contributes to climate change, and it is the most significant source of emissions from ruminants in the Canadian agriculture sector. Canada is committed to the Global Methane Pledge which has a target of reducing global CH4 emissions by 30% from 2020 levels by 2030. Enteric CH4 is produced through rumen microbial fermentation and a recent FAO report (ICPP 2021) has identified targeting rumen methanogenesis in cattle as one of three key climate change mitigation strategies. Beef and dairy farmers are one of key sectors of Canada's livestock industry and combined contribute ~ 50 billion CAN to Canada's GDP. The GHGs footprint of Canadian beef and dairy production represent 3.1% of Canada's overall emissions (beef 2.6% and dairy0.5%). The Canadian beef industry has set the goal of reducing GHG emissions by 33 % by 2030 and the Dairy Farmers of Canada have the goal of achieving carbon neutrality by 2050. Reducing enteric CH4emissions in cattle is imperative if these goals are to be achieved. This project will develop novel microbiome-targeted tools to reduce CH4 emissions and improve feed efficiency in both beef and dairy cattle by 1) determining causal effects of the rumen microbiome on CH4 emissions using machine learning (ML); 2) developing novel microbial solutions to reduce GHG emissions from both beef and dairy sectors by manipulation of targeted microbial members in the rumen

microbiome; 3) implementing "BigData" and "Analytical Solutions" for precision management of the rumen microbiome, genetics, and nutrition interplay for reducing CH4 emissions; 4) assessment of the Canadian and international regulatory environments and economic and social impact of the anticipated CH4 reductions along the
19 / 25Canadian beef and dairy value chains. Collectively, this will improve the sustainability and production efficiency of cattle. The proposed targeted manipulation solutions will lead to novel breeding and dietary supplementation strategies and targeted precision management to lower CH4 emissions without reducing production so that the dairy/beef cattle industries can meet their GHG reduction targets. Approaches outlined in the present proposal will reduce Canada's overall cattle's GHG emissions by1.0%, contributing to the sustainability of Canada's beef and dairy industry and confirming their active contribution to Canada's climate change commitments. Reduced emissions in the livestock sector, along with potential feed and production efficiencies will be an important contribution to support Canada's goal of a net-zero economy by 2050 (Canadian Net-Zero Emissions Accountability Act, 2021). Such action will ensure that both industries retain a social license to operate and contribute to consumers' confidence of Canadian meat and dairy products in both domestic and international markets.

Project #19206

Genomics-guided pre-breeding for improved root system architecture in wheat and canola, for biological carbon sequestration, drought resilience, and resource use efficiency

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Keywords for Proposed Investigation

Research	Methods & Technologies
Root system architecture, Carbon sequestration and quantification, perennializing annual wheat, quantify the soil organic carbon, measure greenhouse has emissions in annual and perennial cropping systems	High throughput array based genotyping, High throughput root and canopy phenotyping, genomic selection, soil gas flux chambers to measure GHG exchange between soils and atmosphere, GC MS or synchrotron based techniques measure persistence phytochemicals like plant lignins and polyesters in soil

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Producer behaviours, Market adoption, STEEPLE analysis, Economic impact, GHG mitigation evaluation	Soil C-storage, Root biomass C-storage, GHG emission reduction, Metrics related to water use and fertilizer use

Project Summary

Wheat is the largest crop in Canada with majority of production concentrated in the Prairie provinces. Avery important challenge in Canada is the mitigation of carbon (C) emission and footprint. This is further compounded by the increase in intensity of severe water scarcity events, occurring at a higher frequency in the past decade due to climate change, like the severe drought in the 2021 growing season, which lead to a steep decline in wheat production. Improving the root architecture of cereals and integrating the screening for better root traits as a part of the breeding process, are important for developing enhanced C-sequestration and drought-tolerant cultivars by targeting deeper and denser roots. Perennial grass species including intermediate wheatgrass (Thinopyrum intermedium), and perennial wheat accessions derived by crossing annual wheat with intermediate wheatgrass have an extensive and deep root system with benefits ranging from improved C sequestration and water use efficiency. In this project, we propose to integrate genomics, transcriptomics, phenomics, bioinformatics, soil C sequestration, greenhouse gas (GHG) emissions and GE3LS components for characterizing the root system architecture(RSA) in a diverse panel of wheat with novel alleles introgressed from its progenitor - Aegilops tasuchii(goat grass), and unearth the genetic basis of the trait of 'perenniality' in perennial wheat and promoting a new sustainable perennial cereals-based cropping option to the Canadian producers. GE3LS will critically investigate producers' acceptance of this paradigm shift in cultivation practices by including perennial wheat as one of the cereals for crop

rotation and barriers in its adoption. The novel genomic regions governing the RSA, and traits underlying perenniality will be unravelled using high throughput genotyping, employing the state of the art exome arrays developed from the international wheat genome sequencing consortium's (IWGSC) wheat assembly, and non invasive hyperspectral and X-ray tomography imaging based phenotyping strategies. High throughput phenotyping of canopy traits using thermal cameras will also be carried out as a proxy for characterizing and selecting ideal root traits. Genomic prediction models including machine learning methods will be developed for implementation in wheat breeding for selecting root ideotypes suitable for enhanced C-sequestration (deeper and denserRSA) and drought resilience (narrow root angle and high root biomass). A business model and a roadmap for the adoption of the perennial wheat by the producers and a participatory model for determining the constraints, will be designed. The economic- and environmental impacts and the consequent societal benefits of this step-change new cropping system will be understood. The project will adapt and develop technologies to accelerate the screening of roots development that could be useful in other projects identified in the portfolio of this competition. The improved RSA of the current annual wheat lines, and the introduction of new perennial wheat lines can play a critical role in enhancing soil organic C, C sequestration at the plant-soil interface, and can contribute as a nature based solution towards Canada achieving its net-zero emissions target by 2050.

Project #19208

PEACE (Pea Climate-Efficient): Developing climate-resilient, low carbon footprint field pea as a preferred rotation crop through inter-disciplinary integration of genomic technologies

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Keywords for Proposed Investigation

Research	Methods & Technologies
GHG reduction, Field pea diversity, Climate resilience, N fertilizer mitigation, Gene regulation	Long read sequencing, genotyping by sequencing, mutagenesis, phenotyping and predictive data analytics, Estimation of GHG reduction

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Economic value of advancing climate resilience in pea, Modelling carbon dioxide and nitrous oxide emissions, Social acceptance of gene editing, Economic modeling of returns to genetic advancements in pea, International market assessment	Consumer preference surveys, Regulatory impact analysis, National and International stakeholder engagement, Expert interviews, Discrete choice experiments

Project Summary
Fertilizer use contributes to over 17% of all agriculture sector-based greenhouse gas (GHG) emissions[12.75 Mt CO_2] in Canada. Most of these emissions arise from the use of fossil fuels to produce nitrogen fertilizers, and from the release of nitrous oxide from soil from the use of nitrogen fertilizers. However, nitrogen fertilizer use is an essential and irreplaceable component to profitable yield and grain quality in oilseeds and cereal crops. In contrast, legumes can fix atmospheric nitrogen through a symbiotic relationship with nitrogen-fixing rhizobia and require negligible amounts of nitrogen fertilizer compared to oilseeds and cereals. Therefore, the most efficient way for Canada to reduce GHG emissions is to enhance crop rotation with a legume-based cropping system. If producers increased field acreage under pea in Canada, GHG emissions would be reduced by 22 – 37% compared to wheat and canola. To grow more pea, producers need improved pea varieties that are root rot-resistant, higher-yielding, climate-change resistant, and that have improved seed quality traits. In this PEACE project, we will use an inter-disciplinary approach and state-of-the-art genomic technologies to elevate the quality and profitability of peas grown in Canada. By providing breeders with the tools they need to improve pea varieties, this project will reduce carbon emissions by enabling producers to switch from carbon-intensive crops to carbon-efficient peas.

A global panel of diverse germplasm will be subjected to field phenotyping, modeling CO_2 and N_2Oemissions to explore the genetic diversity to reduce carbon footprint. Cutting-edge sequencing, genotyping and regulatory genomics technologies, as well as predictive data analytics approaches will be applied to unravel genomic variations underlying climate resilience and root-rot resistance. We will also improve existing elite pea varieties by creating new genetic variations and assessing for change in climate resilience, yield and root rot resistance. Improved pea germplasms will be delivered to breeders to incorporate the elite traits into existing cultivars or to enhance adoption of the new pea varieties in Canada. Increasing cultivation of climate/stress-resilient and high-yielding pea will lead to enhanced reduction in GHG emissions while simultaneously boosting the Canadian agriculture industry by providing direct benefits to farmers, industries, and processors.

Through GE3LS research, we will explore the factors influencing stakeholder decisions in adopting enhanced pea cultivation in crop rotation and incorporate these factors into our research design to develop pea varieties with desired agronomic traits. A knowledge base of international pea trade and global protein market trends and economic resilience of the crop production sector will be created when adopting climate-smart pea varieties. We will also model greenhouse gas emissions and assess the environmental impact of the reduction in GHG emissions. The know-how of consumer preferences, market trades and the effectiveness of the Canadian regulatory framework for plants with novel traits will be useful in guiding policy discourse on the acceleration of genetic advancements in peas. Accomplishing the goals of this project can create a significant impact on the Canadian mandate to reduce the GHG emissions arising from fertilizer application by 30% below 2020 levels, by 2030.

Project #19303

Native plant diversity to enhance carbon storage and other ecosystem services in grazing systems

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Keywords for Proposed Investigation

Research	Methods & Technologies
Native forage, Carbon sequestration, Genetic diversity, Stress tolerance, Pollination	Genotype by sequencing, Microbial community sequencing, Insect phylogenomics, eDNA

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Ecosystem service valuation, Indigenous valuation of biodiversity and ecosystem services, Cost effectiveness of genomic indicators	Non market valuation, Stated preference methods, Willingness to pay benefit, Opinion surveys

Project Summary

Increasing species and genetic diversity in grazing systems by including native species in seeded pasture represents a major opportunity to mitigate greenhouse gases by enhancing carbon storage, while also enhancing other ecosystem services including forage productivity, pollination, and pest control. These benefits can further mitigate greenhouse gases by reducing fertilizer and pesticide inputs. Plant diversity also enhances climate change resiliency, potentially amplifying these benefits. These systems develop slowly, however, and more immediate indicators of future ecosystem services are required to encourage the use of native species. Microbial and insect communities change rapidly and can predict future ecosystem services. We propose using genomic tools (genotype-by-sequencing and environmental DNA sequencing) to quantify how microbial and insect biodiversity relate to plant genetic and species diversity in native grassland systems as indicators of diversity effects on carbon storage and other ecosystem services (forage production, nutrient retention, pest suppression, pollination). We will then test whether these microbial and insect indicators can successfully predict carbon storage and other ecosystem services in producer-owned and experimental pasture systems containing native and domesticated forage species. Further, we will combine these data with new field trials to determine whether plant species or genetic diversity increase ecosystem services and whether the indicators of these services can be detected early in newly established pasture. As part of this trial, we will also use drought treatments to determine how diversity affects indicators of ecosystem service under climate change. As native species seed is expensive, we will develop improved market and non-market valuation for the ecosystem services they provide to encourage their adoption and thus increase carbon storage and nutrient retention potential in Canadian pastures. Moreover, we will determine whether these valuations can

convince forage producers to adopt genomic tools in the assessment of their management successes. In total, this work will develop new strategies for seeding pasture systems to enhance carbon sequestration while reducing inputs and augmenting other ecosystem services, while providing information and tools to allow producers and other land managers to encourage the adoption of these strategies.

Project #19305

ACTIVATing genomics to accelerate climate-smart crop delivery

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Keywords for Proposed Investigation

Research	Methods & Technologies
Biological nitrification inhibition, Multispecies combinng ability, Decision support, Microbiome, Reduced GHG emissions	Genome introgression, Field trials, Data management tools, Sequencing, Modelling

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Farmer beliefs, Crop rotation adoption, Varietal diffusion, Breeder equation, Climate benefit estimates	Structural modeling, Discrete choice methods, GHG modeling, Survey methods, Farm model

Project Summary

Agriculture was responsible for approximately 10% of Canada's GHG emissions in 2019. While research and production practices are already working to improve nutrient management and reduce emissions associated with crop production, fertilizers remain responsible for a growing share of overall agricultural emissions. In particular, the application of nitrogen (N) fertilizer results in nitrous oxide (N2O) emissions, a potent greenhouse gas with a global warming potential 1000 times that of carbon dioxide. In our research, we will apply a multi-pronged strategy to decrease GHG emissions in crop production in cereal(wheat) and pulse crops. Specifically, we will use genomic technologies to reduce N20 emissions in wheat production by characterizing and deploying introgressions from wild relatives that inhibit nitrification and N20 emissions. Furthermore, we will apply genomics and digital phenotyping technologies to a multi species breeding strategy that maximizes productivity of the crop production system in space and time, while reducing GHG emissions through maximizing nitrogen fixation, photosynthetic capacity, and microbiome interactions. This will require development of a genomics-based, breeder friendly decision support system that will improve selection efficiencies across all species. Our GE3LS research will valuate the impacts of climate change on crop production and develop policies to incentivize crop production systems that maximize productivity while reducing GHG emissions. The result of our research will be climate-smart varieties that are produced in a sustainable production system to help Canada achieve its target of sustainable growth of the agriculture sector while improving environmental performance and strengthening Canada's food system

Project #19306
Designing Climate Adaptive Resilient Canola (DCARC)

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Keywords for Proposed Investigation

Research	Methods & Technologies
Identify target genes for climate change adaptation, Improve CO sequestration and photosynthetic efficiency, Develop water use efficiency for drought tolerance, Reduce greenhouse gas emissions with nutrient use efficient cultivars, Canola cultivars equipped with climate adaptive traits	Canola TILLING population and natural diversity lines, Phenotyping and physiological screening, Genomics and proteomics, Computational biology and bioinformatics, Canola breeding

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Impact of climate change on canola crop performance, Agricultural practices reducing carbon footprint and soil GHG emissions, Carbon sequestration and their implications for producers, Economic benefits of climate adaptive canola to producers and industry	Economic and profitability frameworks, Quantifying GHG emissions, Canola Supply Chain, Social benefits

Project Summary
Climate change is a critical challenge to agriculture because it causes higher average temperatures along with more frequent extreme events such as drought and flooding, resulting in reduced crop yields. Accordingly, there is growing concern about the impacts of this climate emergency on food security, leading researchers to investigate mitigation and adaptation opportunities at the regional, national and global levels. In Canada, climate change is a particularly severe threat to canola, which is an economically important crop with the largest acreage currently in Canadian agriculture. The DCARC project will improve canola agriculture by reducing greenhouse gas (GHG) emissions and sequestering more carbon in the soil. This will be achieved by developing improved canola varieties with larger root systems and higher photosynthetic efficiency (PSE). The new cultivars will also use lower amounts of nitrogen and phosphorus fertilizer, reducing the large carbon footprint of nitrogen fertilizer production and also minimizing the pollution of surface and ground waters by fertilizer runoff. The new cultivars will also be more drought resilient, producing increased seed yields while using less water and fertilizer. To achieve these goals, we will harness the genetic diversity of canola by applying the "targeted induced local lesions in genomes" (TILLING) approach and also by screening natural canola germplasm, helping to identify gene variants that correspond to climate-adaptive traits. This will involve the integration of high-throughput root/shoot phenotyping, photosynthetic screening, genomics,

proteomics, and computational biology to accelerate gene identification and characterization. Subsequent network modeling and the structural/functional characterization of candidate genes will improve water and nutrient use efficiencies (WUE/NUE), drought tolerance and PSE. The new canola genetic resources will maintain or even increase yields while using less water and fertilizer, especially nitrogen and phosphorus, thereby reducing the amount of nitrous oxide (N_2O, a potent GHG) released from the soil. Higher PSE will increase CO_2 sequestration in the shoot and in the soil contributing to the development of larger root systems with higher WUE/NUE, and also the above-ground increase in C could promote increased seed yields. The effect of climate change on Canadian canola crops, and the development of new cultivars to address it, will also have broader socioeconomic impacts. These include direct and indirect societal outcomes, stakeholder engagement, the public acceptance of climate-adaptive canola cultivars, the value proposition for industrial stakeholders, benefits to producers and end users, and contributions that mitigate the environmental impact of climate change. Our GE3LS team has been selected carefully to include scientists with experience in the challenges encountered when deploying game-changing agricultural technologies. GE3LS activities will be integrated into the project's goal to develop new canola cultivars with improved seed yields, enhanced climate resiliency, lower GHG emissions, and a smaller carbon footprint. This will ensure that we address societal, economic and regulatory barriers to achieve a positive impact on the canola economy and the environmental stewardship of Canadian agriculture more quickly and more effectively.

Project #19308

Bio-inoculants for the promotion of nutrient use efficiency and crop resiliency in Canadian agriculture horticulture

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Keywords for Proposed Investigation

Research	Methods & Technologies
Plant growth promoting microbes, Nitrogen fixation, Arbuscular mychorrhiza fungi, Plant transcriptional networks	Metagenomics, Experimental evolution, Plant physiology, Functional genomics

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Environmental impact, Economics, End user and consumer acceptance, Willingness to pay	Geochemical modelling, Life cycle assessment, Production economics, Surveys, Focus groups

Project Summary
Modern agriculture is built upon the intensive application of synthetic fertilizers, namely, nitrogen, phosphorus, and potassium. Fertilizer application accounts for ~17.5% of all emissions associated with Canadian agriculture and is the single largest contributor to the environmental impacts of crop production. Microbial inoculants have the potential to significantly reduce fertilizer application and thus GHG emissions, while promoting crop resilience. Whereas many rhizobial inoculants work in a predictable manner, many other plant growth promoting (PGP) inoculants function unpredictably and below their potential, thus necessitating new strategies to approach this problem. We propose to develop novel inoculants that support crop growth while reducing nutrient inputs and thus mitigating the climate impact of Canadian agriculture. To accomplish this, we will employ a holistic approach using genomics technologies to identify and isolate new microbial inoculants from Canadian soils, and to optimize crop nutrient use efficiency in Canadian soils. We will pro-actively address common problems in industrial scale-up and in-field performance of our inoculants to ensure they are economically viable and environmentally beneficial. Genomic research into crop responses to inoculants will lay a foundation to guide future breeding of climate-smart crops with an improved ability to benefit from microbial inoculants. We will model the environmental impacts and the economics of inoculants from the farmer and inoculant producer perspectives, to identify situations in which inoculants are best employed. We will also investigate perceptions of inoculants and lower emission food crops, to identify regulatory and market-based incentives to promote inoculant use among Canadian food producers.

Project #19401

Leveraging Genomics to Achieve Dairy Net Zero

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Keywords for Proposed Investigation

Research	Methods & Technologies
Quantify impact GHG mitigation strategies, Enhance GHG genomic evaluations, Develop and implement GHG herd monitoring and benchmarking tools, Develop a roadmap for GHG mitigation across ruminant species, Sequence Data analysis	Genomic selection, Selection index, Life cycle Analysis, Bioinformatics, Geneflow modelling

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Socioeconomic assessment, Farmer preferences and consumer willingness to pay, Understand the publics attitude and behaviours relative to emissions reductions, Contextualize and quantify the value of emissions reductions, Identify value chain barriers and opportunities	Economic and bioeconomic modelling, Surveys, Focus groups, shopping studies, Life cycle analysis

Project Summary
Dairy is one of Canada's most important and dynamic industries, and in 2021 supported $7.5B in total net farm cash receipts and $16.8B in dairy products, contributing $35B to Canada’s (GDP). The Canadian industry must now focus on a wider perspective that adapts industry practices to match social and environmental values. The Canadian dairy industry has committed to Dairy Net-Zero Pledge by 2050, with a 30% reduction milestone in 2030. Dairy accounts for around 36% of Canada’s livestock emissions, primarily methane and nitrous oxide. Therefore, our goal is to deliver a roadmap for GHG management in ruminants through integration of cutting-edge knowledge of genetics and nutrition. Our

systems-level approach will leverage previous and current large-scale projects to produce accurate estimates of farm-,regional-, system- and industry- level emissions and to identify system efficiencies and opportunities for mitigation of enteric GHG emissions. In 2020, Canada produced 672 Mt of CO2-eq, 69 Mt CO2-eq from agriculture with livestock contributing 34 Mt CO2-eq (dairy 12.4 Mt). Our target is to reduce these emissions by over 55% (-6.7 Mt directly in dairy), with a further 2.6 Mt CO2-eq in the beef industry). At a current carbon price of $50/tonne, this represents a value of $470 million nationally. Such reductions maybe critical to sustaining market access for Canada’s dairy industry.

We will deliver data, knowledge, management tools and pipelines for GHG-related data (phenotypic, nutrition, genetic) from commercial and research herds to Lactanet. We will develop enhanced genomic evaluations for GHG emissions and new genomics tools using routine data (milk MIR in cows, GHG ingrowing and lactating animals, including beef). We will define emission reductions, public and wider stakeholder attitudes to such reductions, and engage with producers to understand the requirements to ensure uptake of mitigation approaches. The goal of this project is a roadmap for bovine GHG management that reduces emissions by at least 75% (two-thirds in dairy).

Specific objectives include: estimation of individual animal and herd-level emissions; development of scientific protocols that quantify the impact of and uncertainties around GHG mitigation strategies; quantification of economic and environmental benefits of reducing GHG emissions through breeding and nutritional strategies; consolidation of CH4 emissions data (including beef); enhancement of genomic evaluations through MIR-predicted GHG; quantification of the value of reductions in GHG emission and options to incentivize uptake of mitigation approaches.

Our GE3LS activity will inform focus areas for the GHG mitigation roadmap, including contextualization of the value of emissions reductions, LCA, and a comparison of emissions across potential dairy substitutes. Surveys, shopping studies and consumer focus groups will identify elements of public value of reductions. We will quantify how reductions change product perception - does commitment provide consumer value to help producers fund reductions? Does the approach affect how consumers think? How might non-dairy or cellular agriculture products affect demand? Finally, value chain barriers and opportunities will be identified. Stakeholder engagement via interviews and surveys will provide context for roadmap development.

Project #19404

Climate-Smart Cultivars: Development and application of genomic tools to enable low emission crop production

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Keywords for Proposed Investigation

Research	Methods & Technologies
Greenhouse gas emission reduction, Genetic improvement, Selection, Genotype x environment interactions, Decision support tools	Plant breeding, Quantitative genetics, Genomic prediction, High throughput genotyping, Multi environment trials

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Fertilizer emission reduction, Technology adaptation, Agricultural system prediction, Research policy	Agronomic practices, Econometric modelling, Bioeconomic optimization modelling, Social norm nudge evaluations

Project Summary

Agriculture emissions arise from the use of pesticides and especially synthetic nitrogen fertilizers. Although conservation farming can reduce grain crop pesticide and fertilizer applications, substantial reductions in crop inputs can cause major production declines. Plant breeding has a long history of generating new cultivars that have higher grain yields and grain qualities than older cultivars grown with the same inputs. This proposal seeks to accelerate this process in Ontario, Canada for five major field crops: barley, oat, dry bean, soybean, and wheat. We will utilize genomic prediction models developed from variety trials and breeding program trials to improve cultivar selections. We will quantify the fertilizer requirements of current cultivars, and using detailed genomic and environmental data, we will predict cultivar performance throughout the province. Farmers will be able to obtain location-specific cultivar information on a web app. We will also investigate the molecular bases of variation in small cereal disease resistance and dry bean nitrogen fixation. New, improved varieties that require significantly lower fertilizer than classically developed varieties should be approved for distribution at the end of four years. While growers readily adopt new, pedigree-breeding seed, the degree to which germplasm is adopted and the way it is managed across the province determines its system-wide economic and emissions impact. Our GE3Ls team will investigate how on-farm returns and off-farm environmental benefits affect farmers' choices and by extension breeding goals. We expect this work will generate important new cultivars and be a model for low emission crop improvement and farmer outreach.

Project #19406

Omics guided technologies for scalable production of cultured meat

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Keywords for Proposed Investigation

Research	Methods & Technologies
Growth media, Animal cell biology, Biomanufacturing, Tissue engineering, Stem cells	Optimization, Biofabrication, Cell culture and differentiation, Proteomics and lipidomics, Bioprocess control

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Bioethics, GHG emission, Consumer perception, Resource utilization analysis	Life cycle analysis, Ethical social and cultural (ESC) thinking, Perception Surveys

Project Summary

Global meat consumption has grown by 58% in the past 20 years and is expected to further increase due to increased demand both in the developing and in the developed world. Current meat production methods are inefficient resulting in high water consumption, greenhouse gas (GHG) emission (15% of global emissions), accelerated soil erosion and pollution of waterbodies. The industry accounts for 70% of land suitable for agriculture and almost 30% of agricultural water consumption. Cultured or cell-based meat, where animal tissue is grown in bioreactors, is an environmentally friendly and ethically appealing alternative as it has the potential to decrease land use (by 99%), water consumption (by 80%) and GHG emission (by 78-96%).

This nascent field faces several significant challenges. These include 1) current high cost of production as compared with animal meat, 2) need for optimized and widely available animal cell sources; 3) need for low-impact (GHG) biomanufacturing to expand the cells; 3) need for low-cost serum free media and growth factors for rapid growth of cells; 4) scalable, biofabrication methods to produce meat-like tissues with texture and taste; and 5) Comprehensive analysis of the diverse Canadian consumer perception and analysis of environmental benefits of cell-based meat in the Canadian context. In this project, we will develop solutions and technologies for all these challenges and achieve the twin focus of cost reduction (in some cases by 100x) as well as evaluate the GHG mitigation potential of this technology. We will use omics (proteomic and lipidomic) analysis to guide the technology evolution integrated with life-cycle analysis to determine the impact on GHG emissions and ESC thinking to integrate user perception. Towards the end of this project we will develop two prototypes – one for a ground meat type patty and another for slab meat that will demonstrate the feasibility of our approach, validity of the technologies developed and the potential for GHG emission reduction to our industry partners, Canadian public and other stakeholders.

Project #19505

Mycorrhizal Fungi & Soil Microbiota: a sustainable biological solution for an increased soil carbon sequestration and a reduction of greenhouse gas emission in agroecosystems

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Keywords for Proposed Investigation

Research	Methods & Technologies
Carbon sequestration, Greenhouse gas emission, Life cycle assessment, Bioinoculants	OMICS technologies, Soil biochemical analyses, Field and Greenhouse trials

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Carbon footprints, Biotechnology adoption, Decision making, Public perception	Benefit transfer function, Incentive implementation model, Multicriteria decision analysis, Life cycle analysis

Project Summary
Climate change caused by greenhouse gas emissions is humanity's greatest challenge. The Government of Canada has pledge to achieve net-zero emissions by 2050, meaning that economic activities must evolve to either emit no greenhouse gas or offset all greenhouse gas emissions in the next 25 years. Agriculture contributes 10% of Canada's greenhouse gas emissions, releasing 73 Mt CO_2 in 2019.Synthetic fertilizer use was nearly 20% of all agricultural emissions. Fertilizer emissions have increased steadily in the past 15 years and are directly correlated to the amount of fertilizer applied. Solutions must focus on improving application methods and technologies, to reduce fertilizer use in agriculture. The research team has developed mycorrhizal-based supplements with potential for a 25% reduction in fertiliser inputs, which would represent a cut of 1080 tons of fertilizers per year in Canada. This will be confirmed in crop sequences with potato and wheat, major agricultural commodities in the Canadian agri-food sector. We will demonstrate that mycorrhizal-based biofertilizers are highly compatible crop biological inputs that improve plant nutrient acquisition, thereby reducing the synthetic fertilizer inputs and resulting direct and indirect emissions. This work relies on state-of-the-art OMICS toolkits to identify and design the synergistic biofertilizers for crops exposed to various stressors during their growth, and to assess soil and crop microbiota changes following biofertilizers application. We also expect to link the expression pattern of N-cycling genes to nitrogen forms that are susceptible for direct emission, as nitrous oxide (N_2O) and indirect emission, via nitrate (NO_3^-) leaching. Furthermore, mycorrhizal fungi produce extensive biomass that remains in soil, increasing the carbon sequestration in the cropping system, which will be quantified through innovative OMICs-based analysis of microbial metabolism and biosynthesis pathways.

The proof-of-concept for this innovative technology is supported by a dedicated GE3LS team, who will use life cycle assessment to determine the economic value and carbon footprint of biofertilizers compared to conventional fertilizers. Farmer surveys will determine willingness to adopt biofertilizers, and the research team will integrate the survey findings and consider farmer decision-making in the context of relevant to risk, uncertainty and climate change adaptation behaviour. The successful on-farm adoption of novel mycorrhizal-based biofertilizers for commodity crops grown across Canada will be a game-changer in the fight against climate change, given their potential to reduce greenhouse gas emissions and increase soil carbon sequestration.

Project deliverables will result in positive outcomes for farmers – by allowing them to reduce fertilizer use– and for agri-food sector as a whole by reducing greenhouse gas emissions and increasing soil organic matter levels for sustainable agriculture. The sophisticated OMICs-based toolkits created by this project are a new quality indicator for the bioinoculant industry, and for soil-plant heath assessments. These products and services will contribute to the goals of Canada’s Green Agricultural Plan, which builds on the Strengthened Climate Plan (2020), the Minister of Agriculture and Agri-Food’s 2021 Mandate Letter, and the Guelph Statement released by Canadian agricultural ministers in November 2021.

Project #19508

Omics to close the loop: optimized amendment from local agrifood-waste for carbon footprint reduction

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Keywords for Proposed Investigation

Research	Methods & Technologies
Urban agriculture, Food waste, Organic fertilizer, Circular economy, Bioreactors	Metaomics, Precision phenotyping, Targeted bioprospection, Bioengineering, Urban scale

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
Social Acceptability, Market and product development, Nature based climate solutions, Scalability of short circuit circular economy clusters	Stakeholder semi structured interviews, Life cycle analysis, Market opportunity assessment, Monetary valuation framework

Project Summary

Conventional agriculture and food waste management generate 140 MT CO2-equivalents of greenhouse gas emissions (GHGs) annually in Canada. Emerging circular approaches in urban agrifood can mitigate GHGs, upcycling food waste streams into new food and fertilizers, avoiding landfill CH4 emissions, while using nature-based processes to strengthen food systems resilience. Optimizing these developing agrifood systems can no longer rely on a black box approach and must incorporate omics tools. With a unique network of urban farmers leveraging circular economy to upcycle waste into value-added products, our team exploits omics technologies to improve urban agrifood systems and reduce GHGs. We propose a scalable circular agrifood cluster project which aims to shed light on the inherent complex biochemical systems and optimize the microbiota machinery present across an integrated system of living bioreactors. The identification and enrichment of promising microorganisms, consortia and enzymes will use multi-omics approaches like shotgun sequencing, phenomics, cost-effective amplicon surveys, and RT-LAMP assays enabling user process control. Working closely with end-users, meaningful research outcomes will be developed for the agrifood sector at large. Life-cycle analyses (LCA) will demonstrate benefits achieved with waste up-cycling and substitution of conventional agrochemicals and food products. Economical return on investment, business feasibility and acceptability will be evaluated for each individual node within the circular farming cluster. Deliverables will include:

1) Best practice guides for users to adopt these optimized approaches;
2) Molecular monitoring tools to facilitate adoption;
3) LCA models and applications for end-users;
4) Functional by-products, microbial strains and consortia as tools for improved circular agrifood systems.

For every kg of food waste, CO_2-eq emissions of landfilling reach 86 kg CO_2-eq, whereas composting yields only 17 kg and upcycling through insect farming removes 160 kg CO_2-eq. Through omics-improved management of 1500 tonnes food waste annually with composting, insect and mushroom farms our living laboratory will decrease 315,194 MT CO_2-eq and sequester 652,489 MT Corg in soils by2030. In close collaboration with end-users, case studies will document direct benefit on productivity and cost-savings. Added efficiency will lower production costs and increase feasibility, and this will be shared with urban farmers, encouraging initiatives across Canada, and globally.

The close-knit network of co-located systems here represents an asset for cross-portfolio collaboration, representing an excellent test bed for innovative applications in GHG reductions and improve food production from other Interdisciplinary Challenge Teams. The modular nature of the urban agrifood system is directly applicable in a wide range of environments, as the proposed urban living laboratory is both scalable and transferable to rural areas and aligned with Canada’s zero waste initiatives. Close collaboration with Knowledge Mobilization and Implementation Coordinating Centre, governmental representatives and academic institutions will facilitate wide reach, with a wealth of data being shared with Data Coordinating Centre DCC to leverage these unique assets. Overall, the approach proposed here will lay foundations for the advancement of improved circular urban agrifood systems, which will in turn help to mitigate GHG emissions, while increasing food resiliency, and will enable a new generation of farmers to contribute to sustainability.

Project #19514

Meta-twin: A metagenomic driven digital twin for environmentally sustainable forage systems

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Keywords for Proposed Investigation

Research	Methods & Technologies
Soil health, Silage, Greenhouse gas, Metagenomic, Agricultural systems	Digital twin, Artificial intelligence, Sequencing, GHG modeling, Whole farm modelling

Keywords for Proposed Integrated GE3LS Investigation

Research Questions	Methods
User experience, Decision support tool, Legal practice, Return of investment, Consumer perception	Survey, Literature reviews, UX evaluation, GHG evaluation, Focus group

Project Summary

The Canadian dairy industry produces approximately 8.7 megatonnes of CO_2 emissions each year. As its most important feed, forage has a significant impact, not only on emissions, but also on farm profitability, representing annual costs of $1.11B for the Canadian dairy industry. Forage production is the 3rd most important crop in acreage in Canada. The microbiome is intrinsically integrated into every step of the forage production system, meaning that best-management practices by the average producer could see reductions of 624 tonnes of eq. CO_2 and $168K in production costs. To facilitate management of this complex system, a holistic approach is proposed whereby farmers can access and use the microbiome data as well as other agromica data of the forage system to improve the sustainability of Canadian farms. Specifically, the project will develop metagenomic-driven functional indicators of soil, plants, and silage for integration into simulation models that predict forage yield/quality, soil health, silage fermentation and animal feed. Those simulation models will subsequently be incorporated into a digital twin – a real-time synchronized virtual representation of a forage system – for assessing GHG emissions and profitability. To ensure uptake, producer concerns and feedback will be incorporated into iterative versions of the Meta-twin for the beta testing. Real-time optimization will facilitate GHG emission reduction, improve CO_2 sequestration, and increase industry sustainability and profitability. Collaboration with 40 dairy farms (data collection and indicator development) will facilitate this holistic approach, involving experts from diverse domains and providing inputs for, or sharing results with other projects that are looking to address the challenge of our environmental footprint. Metagenomic 19 / 26sequencing of soil, forage and silage samples will generate function indicators to be integrated in simulation models. Additional data will be obtained to provide sufficient variability and power for modelling from our current projects and from collaborating with other interdisciplinary challenge teams through the portfolio approach of Genome Canada.

At the end of the project, we expect to achieve the following deliverables: D1: Development of technical, legal and social recommendations to encourage awareness of the dire need to reduce GHG emissions (GE3LS), to promote subsequent policies through use of the digital twin, and to optimize its interface for ease of use. D2: Functional indicators derived from metagenomics of soil, fresh forage, and silage; D3: A simulation model integrating functional indicators with other parameters for predicting soil health, forage yield/quality, silage fermentation, feed response of ruminants, and reductions in GHG emissions (GE3LS) and financial impact; and D4: Afunctional digital-twin prototype to support producers with their holistic management to reduce GHG emissions and improve profitability by the integration of functional indicators (GE3LS). The ultimate objective is to help Canada in its goal of reducing GHGs by 30% by 2030.