INTEGRATED CROP-LIVESTOCK SYSTEMS AND THE PRAIRIE LANDSCAPE:

A FEASIBILITY ASSESSMENT

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ABSTRACT

Sustainability is a broad term and consequently, there is no concrete definition of what constitutes a sustainable farm. Inherently there is no correct way to improve on-farm sustainability, and it is recommended that farms find their best production fit by assessing a variety of possible methods for their established operation (Sustainable Agriculture Initiative Platform 2015). Integrated crop-livestock systems (ICLS) are opportunities that take ecological advantage of both cattle grazing and cover cropping, but the strength of that option in Canadian prairie conditions is relatively uncertain. The combination of missing research, economic valuations, and innovative supports have potentially established barriers preventing mainstream adoption of ICLS. If ICLS is to be a viable option for Canadian producers, then the system must be evaluated with the rigid and exogenous facets of the agricultural environment in mind.

The analyses made in this thesis are from 503 farmers who responded to an April 2022 survey that assessed opinions surrounding integrated crop-livestock systems and their motivations for use. Due to resource-sharing convenience, ICLS is largely approached by mixed farms (Thiessen Martens et al. 2015), unintentionally moving the system toward a 'niche' standing exclusionary of single-output enterprises. In response to this trend, the survey frames ICLS as a partnership between a neighbouring crop producer and cattle rancher, and question sets partially differ based on (self-identified) farm type. Field data collected from 2019-2021 at the Swift Current Research and Development Centre provides the economic context (performance indicators) for grazing cover crops in the discrete choice experiment (DCE).

Results suggest that there is an interest in integrated systems, but not necessarily in an ICLS partnership. Approximately 75 per cent of participants place trust in their neighbours for novel information and 30 per cent of respondents declared they would not work with someone they do not know, despite assurances. Partnership aside, crop farmers appear to have more ICLS apprehension than cattle producers, suggesting the necessity of stronger information networks for (performance) reassurance. This thesis suggests the social structure of Canadian agriculture is designed to prioritize independence rather than collaboration, which may be just as strong a barrier to integrated adoption as the enviro-economic trade-offs.

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LIST OF ABBREVIATIONS

CV .... Compensating Variation

DCE.................. Discrete Choice Experiment

ICLS....... Integrated Crop-Livestock System

RUM .... Random Utility Model

WTA............................ Willingness to Accept

Chapter 1
Introduction

Agricultural sustainability[1] goals in Canada largely pursue land and resource-use efficiency techniques that promote generational resiliency and stability (Faust et al. 2017; Ma et al. 2017; United Nations 2019). While this should foster a network of production methods adaptable to specific farm needs (Nikoloski et al. 2017), literature suggests that the simultaneous goals of growth and productivity have prioritized capital-intensive techniques with technical requirements outside what is feasible for small family farms (Russelle et al. 2007; Spann 2017; Pigford et al. 2018). Consequentially, market participation relies on financial considerations (i.e., privatization; capital investment; input accessibility) rather than product quality (Spann 2017; Pardey and Alston 2020) and counteracts sustainability progress (Andersen et al. 2013; McMichael 2014; Baker 2020). In the pursuit of true agricultural resiliency[2], it is advantageous for Canadian farmers to be aware of numerous opportunities applicable to farm individuality, so land use (and, ultimately, on-site efficiency) can be sufficiently optimized in response (Ojima et al. 2007; Ogurtsov et al. 2008; Ma et al. 2017).

Integrated crop-livestock systems (ICLS), which use the interaction between animals and cropland with the goal of improving, among other traits, soil nutrient cycling and feed source stability, are one of many systems that can improve on-farm sustainability (Munandar et al. 2015; Cardoso da Luz et al. 2019; Oliveira et al. 2022). For the purposes of this research, ICLS specifically refers to the use of cattle, however the forage available to the herd is comprised of cover crops, which provide additional land benefits. The combination of cover crops and beef cattle is not the only way for a farmer to implement ICLS and it is very realistic that the cover crop-cattle combination should not be used. This punctuates the theme of farm-specific assessment necessity (if the farmer

[1] Sustainable agriculture is a broad term for "productive, environmentally friendly, resilient, and profitable" methods of food production that accommodate the changes within and interactions amongst "economic, environmental, and social dimensions" (Food and Agriculture Organization 2021).

[2] General resiliency is best defined by Thiessen Martens et al. (2015) as "the ability of a system to undergo change while still retaining control of its structure and functions." Therefore, this *change* within agriculture is more akin to an adaptation to exogenous shocks within the social, environmental, and economic dimensions (United Nations 2020).

is interested in change) throughout this research, and therefore the featured analysis is for one of the many production options.

Cover crops are designed to be planted after grain harvest to maintain soil quality when the field is not in (marketable) use; this is one of the primary reasons that crop farmers adopt cover crops into their rotation (Drewnoski et al. 2018; Bergtold et al. 2019). A three-year crop rotation, for example, includes two opportunities to focus the growing season on soil rejuvenation and, by extension, two opportunities to reap the ecological and economical benefits of cover crop use (Kumar et al. 2020). When cattle are also injected into the system, the mixture of crop species used can positively improve animal nutrition without compromising the sustainability effects acting as adoption motives (Drewnoski et al. 2018). With integrated systems, sustainability is achieved through regenerative methods, which broadly refers to those processes whose primary concern is improving the ecological base of production, such that the agricultural system, as a whole, is less reliant on external inputs and more aware of natural resource scarcity (Fenster et al. 2021). Regenerative systems exist on a continuum, meaning the degree to which a farm is considered 'regenerative' is flexible to each farm and determined by the compounding of methods rather than the final production outcome (Sulc and Franzluebbers 2014; Fenster et al. 2021).

Integrated crop-livestock systems rely on the harmonization of two main contributors to build soil and system resiliency: cover-crop polycultures[3] and beef (steer or cow-calf) grazing. Cover crops are praised for their soil and biodiversity improvements when used long-term (Wang et al. 2016; Faust et al. 2017). In this context, biodiversity refers not only to the seed mixture choice, but also to the resulting development of insect and weed competition (Carvahlo et al. 2018; Fenster et al. 2021; McKenzie-Gopsill et al. 2022). The mixture selected also contributes to the benefits that naturally occur in plant-soil interactions (i.e. a legume-dominant cover cropped field is expected to be better at compensating nitrogen requirements than would a grass or grain-dominated field). As a result, the degree to which a farmer can substitute away from external chemicals and fertilizers can be impacted by cover crop use (Fenster et al. 2021; Sekaran et al. 2021), which can effectively merge agri-environmental priorities with income stability improvements (Russelle et al. 2007; Carvahlo et al. 2018).

[3] A polyculture refers to "…the intentional co-planting of several species of plants in the same field or plot." (Government of Canada, 2021a)

One of the major advantages of using cover crops as a forage source is the potential to extend the grazing season and avoid seasonal productivity declines (Lardner et al. 2019; Hillhouse et al. 2021). An extended grazing season is possible in part due to which species are planted in the cover crop mixture; each plant type offers a slightly different maturity date, allowing for sustained growth throughout the entire grazing period if correctly managed (Lardner et al. 2019; Omokanye et al. 2019).

The ability of each feature to improve the agricultural environment is difficult to conclude not only because success is largely species dependent (Lardner et al. 2019; Thompson et al. 2021; Carrell 2022), but it is also under-researched in North America, especially from the cattle production side (Toews et al. 2019; Christensen et al. 2022). The most conclusive research comes from the subtropic regions of Australia and South America, where both mixed farms and ICLS are far more common (Carvahlo et al. 2017; de Souza Filho et al. 2021). Although specific research into the whole-system impacts of ICLS on both the productive and ecological capabilities of Canada is largely absent, this research assumes that the simple principles of cattle grazing benefits apply, and the introduction of animal waste to crop fields has the potential to reaffirm valuable soil nutrients (Thiessen Martens et al. 2015). While the mixture of cover crop species used as forage can impact which beef dietary gaps are filled by the grazing system (Omokanye et al. 2019), differences in carcass characteristics across cows is more reflective of ration formulation as opposed to whether cover crops were used as the forage source (da Luz et al. 2019).

In the case of ICLS, agroecological success is observed in resource-use efficiency (de Souza Filho et al. 2021; McKenzie-Gopsill et al. 2022) or, more challenging to meet, land-use efficiency (Carvahlo et al. 2018; Awada and Phillips 2020). When discussing a farm’s ability to scale up or increase production, land use is particularly limiting, as it must not only be sufficient to meet demand, but also adaptable to changes in the agricultural and climatic systems (McMichael 2014; de Souza Filho et al. 2021). This highlights the importance environmental stability has in meeting agricultural sustainability and production goals (Chapman et al. 2019).

Although fairly niche in Canada, integrated systems are internationally valued amongst smallholder farms, representing the preferred method in upwards of 40 per cent of Asian and sub-Saharan African meat production (Sekaran et al. 2021). The combination of agricultural specialization trends, desired farm independence from institutions, and managerial requirements of the system have pushed commercial ICLS use to be preferred by mixed farms more capable of accommodating the feasibility and (operational) flexibility required for both livestock and crop enterprises to succeed (Russelle et al. 2007; Villano et al. 2010; Chapman et al. 2019). Nastis et al. (2019) draw similar conclusions, stating that small farms tend to prefer off-farm strategies for sustainability improvements opposed to the far more daunting on-farm diversification, in part due to the substantial technological and capital investments required that may be outside the range of what is financially and operationally realistic. While the synergies within ICLS can improve sustainability without sacrificing product quality, the difficulty of cattle inadvertently treats ICLS (and associated research) as a solo niche operation in Canada unutilized without a well-established herd.

Consequentially, the complexity of ICLS—specifically in the comparative managerial intensification of beef opposed to crop production—puts an extreme amount of reliance on farmer decision-making. Sekaran et al. (2021) discuss how the mismanagement or omittance of various cattle considerations such as stocking rate optimization, rotational grazing, and time/labour considerations, can lead to poor ICLS performance. In instances where knowledge gaps act as a deterrent to sustainability solutions, horizontal information sharing between farmers may improve overall community stability, if the community can be sufficiently developed to facilitate trust (Kansanga 2020). Farm-level decisions and innovation adoption rely on social connections and access to community support more heavily than is seen in other technical sectors (Hanson et al. 2008; Garbach and Morgan 2017; Kansanga 2020), and therefore sustainable agriculture relies on a deeper integration of closely related supply chains both within the sector and amongst industries than currently exists (United Nations 2019; Lence and Plastina 2020). I approach assessing this influence via survey, by introducing respondents to a co-management partnership with a nearby farmer for the purpose of stress alleviation and resource sharing. Despite research pointing to a prevalence of mixed farmers in the ICLS space, the pairing is designed to minimize the expected learning curve of implementing a new enterprise and determining the strength of external socioeconomic factors for program acceptance.

In a paper investigating the longevity of Brazilian ICLS, the two primary barriers to widespread system adoption are performance uncertainty and a lack of confidence in managerial requirements (de Albuquerque Nunes et al. 2021). The required managerial confidence in early adopters to successfully operate both enterprises can be inferred throughout Canadian agriculture, as well; a 2020 survey of early cover crop adopters in the prairie provinces determines 70 per cent also manage livestock (Morrison and Lawley 2021). (The results in this thesis generate similar discussions on the niche nature of ICLS and the particular aversion of crop producers to cover crop adoption in Canada.) It is therefore important to understand Canadian adoption hesitation toward ICLS and its components (i.e. cover crop use, extended grazing periods) to definitively conclude whether farmers are disinterested in the program or whether the tangibility of integration (i.e. internal or external support requirements) in ICLS and similar systems is worth improving in prairie provinces.

1.1 Research Priorities

Although the benefits to producers are shared in some research and anecdotally by the farmers who use these techniques, the adoption rate of ICLS in Canada remains low, with very little consensus as to whether the hesitation is dominated by economic or physical barriers (Marshall 2012; Lychuk et al. 2017; Thiessen Martens et al. 2015). Results suggest the initial cost of cover crop seeding dominates economic differences from continuous oilseed production (Marshall 2012), which may constrain ICLS accessibility to a type of large, incorporated farm with extensive financial capital uncharacteristic of a typical Canadian farm (Melheim and Shumway 2013; Statistics Canada 2022). These are only examples of potential barriers to ICLS adoption in Canada, but the specificity of their role is uncertain. What is clear is that decisions about integrated systems—which to use, if at all, and how—are subject to the same complicated network of personal, objective, and structural considerations as any other utility-altering decision (Zentner et al. 2002; Ma et al. 2017).

Research into integrated crop-livestock systems tends to focus on subtropic areas where the system is more commonly used as a diversification rather than a sustainability strategy (e.g. Villano et al. 2010; de Souza Filho et al. 2021). Without understanding how the system performs or what constitutes a good outcome in a more temperate and seasonally variable location, it is difficult to convince producers the adoption is worth the added effort. The limited literature that does apply to Canada is at risk of either overgeneralizing to be a broad discussion on North American possibilities (e.g. McKenzie et al. 2016; Wang et al. 2016) or focusses on cover cropping alone (e.g. Blackshaw et al. 2010; Thiessen Martens et al. 2015). Even stated-preference surveys in this area tend to ask the opinions of farmers already using integrated methods (e.g. Mallory et al. 1998; Morrison and Lawley 2021), which offers little insight into the mechanics of ICLS adoption and the hesitation therein. By asking conventional farmers to evaluate a hypothetical ICLS, we can analyse where system aversion exists in the prairies and whether those feelings of uncertainty can be remedied.

The results included in this thesis are from a larger multi-discipline project reviewing the performance of ICLS and the ability to introduce grazing programs into crop rotations. While insights into the practical field trial component and how it informs the survey will be provided, the research presented in this thesis will focus on evaluating the system for Canadian producers by its (economic) costs and benefits. The grazing scenario presented assesses the decision-making network for adopting integrated techniques and requirements for participation in land-renting programs for cattle and crop production standpoints. In response, this thesis will address the following questions:

1. How do integrated systems (economically) perform in the Canadian prairies?
2. What is the current level of interest in integrated systems from farmers? If there is interest, how can adoption be improved?
3. What is the willingness to accept integrated systems (and grazing partnerships) amongst crop and cattle farmers?

The thesis is divided into five chapters. The following chapter (Chapter 2) develops the random utility model (RUM), and how it informs the final willingness to accept analysis. In the third chapter, the ICLS literature is reviewed, delving into the details of ICLS and discussing both the benefits and risks of the system. The same chapter will also provide some background to the historic specialization trends in agriculture, and how ICLS can be an opportunity to increase sustainability without compromising managerial skills. A discussion into the willingness to accept environment of ICLS is also included, which motivates how willingness to accept can be drawn from the survey DCEs. Chapter five begins by describing the field trials, both its implementation and the results, and justifying the attributes/levels used in the DCE. After an analysis of the survey results, the thesis ends with a brief summary of implications and suggestions for future research.

Chapter 2
Adoption Framework and Scenario Amendments

The theoretical foundation of this thesis is built on the random utility model (RUM), which states that an individual makes choices based on the desire to maximize their own personal utility; utility, however, is not entirely framed around observable traits, and so this framework permits the inclusion of unobserved factors, but as (mathematically) random variables (Paul et al. 2018). The RUM allows each scenario to be ranked as a whole against alternatives, since the randomness of underlying factors is indeterminable (Hoyos 2010). The model accommodates uncertainty not only in how utility is realised, but also in the indirect influences on utility to which an individual is unaware (Holmes et al. 2017). When applied to managerial decisions, direct and indirect considerations are reflective of how the program performs on its own and in response to the individual's specific operational environment (Herweg et al. 2010; Holmes et al. 2017).

Farmers self-identified themselves as a crop or cattle producer, in order to gauge the logistic difference required for each enterprise. In the case of mixed farms, wherein respondents declared crop and cattle production streams, farmers with herd sizes greater than 100 head (i.e. screening for hobby livestock farms) were filtered into the *cattle rancher* stream. (The decision to include this condition is further justified in Chapter 5.) In response to the consideration and responsibility differences associated with both halves of the ICLS partnership, the survey (APPENDIX A – Survey questions (excluding demographic questions)) is designed to get increasingly specific to farm type. The structure of the survey can be grouped accordingly for grain (beef) question sets: whether there is interest in growing cover crops (using cover crops as forage), openness to an external party being responsible for field termination (cover crop maintenance), and overall acceptance of an ICLS partnership given program specifics.

The DCE in this thesis asks respondents to compare production scenarios and choose whichever provides the greatest personal and operational benefits. More specifically, in conjunction with the farmer exclusivity of the respondent pool, the two scenarios compared are the status quo (i.e. however production requirements are currently met) and the hypothetical integrated crop-livestock grazing partnership. The state chosen by each producer (y) takes on the values of 0 for the status quo or 1 if the ICLS hypothetical is preferred. This framework allows for the ranking of expected utilities of each program if that option were chosen. The utility experienced in the baseline or status quo condition (U_0) is expressed in (2.1). (Vectors are bolded throughout the discussion for convenience.)

$$U_0 = u(\pi_0(p,\, \boldsymbol{w_0}),\, \boldsymbol{b_0}) \\ s.t.\ \pi_0 = \max_{\{\boldsymbol{x_0}\}} pf(\boldsymbol{x_0}) - \boldsymbol{w}'\boldsymbol{x_0} \tag{2.1}$$

where $\pi_0(\cdot)$ is the profit function of producing using the same methods based on the output price, p , and the vector of input prices, $\boldsymbol{w}$. Input prices are expected to differ across scenarios because required inputs will vary based on whether any resource-sharing exists, as would be the case in the ICLS hypothetical. Utility is also a function of $\boldsymbol{b}$, a vector of variables which captures the farm- and farmer-specific effort considerations of production that indirectly contribute to system performance. The details included within $\boldsymbol{b}$ will differ across scenarios due to the differences in necessary considerations. The specificity of the hypothetical ICLS partnership, for example, asks farmers to consider the distance from their farm to a neighbour's: a trait otherwise inconsequential in a typical production year.

Given that farmers operate in a competitive market, it is assumed that each individual strives for a combination of inputs ($\boldsymbol{x}$) that maximizes their profit as one of their participation considerations. That ideal bundle is ultimately influenced by the individual's production function, $f(\cdot)$, and exogenous market conditions (i.e., p and $\boldsymbol{w}$). The ICLS scenario to be compared against current production faces a similar utility-maximization problem, but with extra considerations:

$$EU_1 = u(\tilde{\pi}_1(p,\, \boldsymbol{w_1},\, a),\, \boldsymbol{b_1}) \\ s.t.\ \pi_1 = \max_{\{\boldsymbol{x_1}\}} p\tilde{g}(\boldsymbol{x_1}) - \boldsymbol{w}'\boldsymbol{x_1} + a \tag{2.2}$$

Notice that the utility function is now one of expected utility (EU_1) because the final market performance (the specific changes to and influences of $g(\cdot)$) in the ICLS system is unknown at the time of adoption, potentially motivated by the general newness of ICLS. This is attributable to the new production function of (2.2), $g(\cdot)$, which differs from its counterpart in (2.1) due to the assumed resource sharing between the crop and cattle cycles (and subsequent change in $\boldsymbol{x}$ as a result). In this way, the economic structure of the partnership between farmers changes the ways in which perceived benefits can be maximized, regardless of whether they are immediately recognized at the time of adoption.

The adoption profit function also incorporates the payment, a, from cattle ranchers to crop producers for the opportunity to use the cover-cropped field for forage means. This is done to mimic the assumption that the majority of direct production costs will be incurred by crop producers, and the land rental-like payment from cattle ranchers would partially compensate those costs. As such, a is expected to positively (negatively) contribute to the profit position of crop (cattle) farmers and affects the sign of a in the same way. Although not directly observed, the components included in $\boldsymbol{b}$ change as a result of participation. In doing so, additional concerns about ICLS participation which would otherwise be omitted (e.g. trust in other farmers, ease of input substitutability, changes to labour requirements, etc.) are now embedded in the model regardless of whether they are explicitly mentioned in the DCE (Boyce et al. 2013; Skolrud 2019).

A rational decision-maker will therefore attempt to choose outcomes that give the most utility or, depending on priorities, the least disutility (Gollier and Pratt 1996; Paul et al. 2018). By pushing participants into the decision-making process (via DCE), they are similarly pressured to assign value and compare states of being, ranking variables as important in instances where such would normally be ignored (Pradhananga et al. 2017). This concept is explored in (2.3), wherein the ICLS alternative will only be chosen if its discounted expected utility (by δ) from time, $t = 1$ to T is at least the same as the utility experienced when not participating:

$$\sum_{t=1}^{T} \frac{EU_1(p,\, \boldsymbol{w_1},\, a,\, \boldsymbol{b_1})}{(1+\delta)^t} \geq \sum_{t=1}^{T} \frac{U_0(p,\, \boldsymbol{w_0},\, \boldsymbol{b_0})}{(1+\delta)^t} \tag{2.3}$$

In the DCE, the value of T is given by the “time commitment” attribute, which asks respondents to assess the status quo and grazing program across a number of years. Therefore, the temporal component of (2.3) is reflective of productive variability and performance uncertainty year-to-year due to endogenous and exogenous factors.

One (exogenous) component which remains consistent across production states is the output price, p. Normally, when comparing conventional agriculture to unconventional production, the price premium of producing a differentiated product partially compensates for the change in production costs. However, in the context of integrated systems, products move into the same market where there is no price differentiation; the income component is therefore affected by production (yield or weight) improvements and cost (input) reduction. These factors are influenced by managerial and technical capacity, allowing the shadow prices of ICLS efficiency to sufficiently supplement the lack of differentiation for market comparison (Ma et al. 2017; Färe and Karagiannis 2018). The market uniformity is therefore optimal for indirect utility-driven valuations, which are explored in the following sub-section as a method to estimate the monetary equivalent of ICLS adoption in instances (such as this) where attributes, themselves, do not have a monetary value (Holmes et al. 2017).

2.1 Willingness to Accept Valuation

The partnership requirement of the ICLS scenario constrains the utility that can be achieved from the system by an individual farmer. The experiment explicitly limits respondents to a single production stream while also implying that any changes the individual would like to make to the system now has to be approved by an additional farmer. These are foundations of the partnership created but may be enough for respondents to reject the partnership, regardless of specific structure. While accommodating of the managerial or efficiency concerns of on-farm diversification, the separation of enterprises ensures that crop and soil benefits are incurred by crop farmers and the forage benefits reserved for cattle ranchers. However, this also potentially narrows the margins of success if the system losses would be compensated by benefits in the opposing market (Klasen et al. 2016).

In the hypothetical scenario, crop farmers are asked to replace a portion of their existing crop land with a diverse mix of short-season, annual cover crops, ultimately reducing cash-crop revenue while incurring the additional costs of sowing a non-market polyculture. The performance of properly structured and managed polycultures in Canada is comparatively similar to intercropping however, functionally excels by requiring no additional effort beyond what is expected for monocrop production (Thiessen Martens et al. 2015). Although crop production is expected to see long-term improvements to nutrient cycling and input savings (Fenster et al. 2021), the same high quality in benefits are unlikely in the short run (Pabst et al. 2013; Kim et al. 2015). Cattle ranchers, alternatively, pay for access to this diverse annual forage field, which they are told is independent from the grain required to supplement animal dietary requirements in the DCE, through the separation of grazing access cost and changes to feed cost attributes. It was assumed that production specifics such as yardage and transport responsibilities would be determined within the partnership, and therefore are not included as a direct factor of participation consideration. As will be better explained in Chapter 5, this type of oversight likely contributed to the rejection of scenario hypotheticals.

Although a decline in utility from participation is not guaranteed, the ICLS program is set up in such a way that economic costs dominate the decision-making process (APPENDIX B – A comparison of income statements for the typical farm and the best/worst random attribute combinations from the DCE). Therefore, compensation may be required to make up for the perceived utility loss (Grutters et al. 2008; Whittington et al. 2017), which can either be in direct response to the change of financial position (π_y) and/or the unobserved intrapersonal or interpersonal hesitation in the program itself ($\boldsymbol{b_y}$). The monetary valuation of the loss (and payment equivalence that would theoretically be required to forego it) is referred to as the compensating variation (CV or CV , context depending). The utility-based nature suggests the modelling is a truer expression of system value than a stated monetary value, as individuals tend to inadvertently inflate the perceived cost of lost utility (Grutters et al. 2008; Kim et al. 2015; Whittington et al. 2017). Equations (2.4) through (2.6) are adapted from Holmes et al. (2017) and explore the progression from CV to willingness to accept (WTA or WTA , context depending) changes to the productive system.

$$CV = \frac{1}{\lambda}(EU_1 - U_0) \tag{2.4}$$

where $\lambda = \frac{\partial U_y}{\partial \pi_y}$ or the marginal utility of money. By introducing this personal financial impact, the change in utility can be represented by a concrete economic figure. Also illustrated in (2.4) is the necessity for ordinal equivalence between states, which ensures that the magnitude of attribute shifts in the decision-making process are irrelevant, so long as the overall utility experienced across systems remains the same. For example, it should theoretically not matter to an individual that the income effects of participating in the ICLS program outweigh the reduced input requirements if the value of the system, as a whole and across time periods, is identical to that of the reference condition.

The WTA component in the following therefore expands upon CV and considers the economic valuation of non-monetary features ($\boldsymbol{b}$ in (2.1) through (2.3)):

$$WTA = \frac{\boldsymbol{\beta}(EU_1 - U_0)}{\lambda} \tag{2.5}$$

where $\boldsymbol{\beta}$ is a vector of estimated coefficients associated with $\boldsymbol{b}$. In its implementation, WTA is a more holistic estimate of the minimum quantity of compensation required for the individual to be impartial to the welfare loss associated with changing from the status quo conditions (Holmes et al. 2017; Whittington et al. 2017). In order to value the impact of each attribute, however, one must further extend (2.5) to assess the marginal willingness to accept ($mWTA$):

$$mWTA = \frac{\partial U_y}{\partial \boldsymbol{b_{yi}}} / \frac{\partial U_y}{\partial \pi_y(.)} = \frac{\boldsymbol{\beta}}{\lambda} = MRS \tag{2.6}$$

where MRS is the marginal rate of substitution between any attribute and money. Although (2.6) is specific to the variable coefficients, there does exist flexibility in this model for observed heterogeneity, should interaction terms be used in the analysis (Holmes et al. 2017). One possible extension of $mWTA$ allows the ability to directly compare the effects of attributes between states. While this does not guarantee any conclusions in and of itself, it may offer insight into a perceived utility difference in, say, committing to a four-year crop rotation and a four-year ICLS program. It is important to remember that, regardless of the choice made in the DCE (opting into the grazing program or rejecting it), the chosen state is selected because the individual believes it maximizes their welfare.

Chapter 3
Literature Review

Sustainability and, by extension, agri-resilience can be occasionally classified as “boundary terms,” a label which spotlights how easily surrounding discourse can be manipulated and rallied behind, due to the vagueness of technical definitions (Soubry and Sherren 2022). As such, it is worth prefacing this thesis’ discussion: ICLS is certainly not the only way to improve on-farm productivity. Determining whether these types of integrated systems fit an existing farm, and the degree to which it should be included in order to experience maximum returns is individualistic (Rai et al. 2021). To be able to confidently present ICLS as a viable option to improve prairie sustainability, especially when proposing a mutual partnership between farmers, a basic understanding of the system and producer openness are prerequisites.

Although complex agroecological processes such as ICLS are return-comparable to monoculture production, even if those benefits are indirect such as through input savings or sustained land-use efficiency (Krah et al. 2019; Awada and Phillips 2020), the ecological conservation-based origin of ICLS (i.e. grassland management) is often overlooked in favour of simple input substitution. From a pure effort perspective, it is much easier for crop farmers to replace one synthetic fertilizer with another than it is to introduce cattle herds as a manure source, because manure has a higher variability of micronutrients and at a lower concentration than its commercial input counterpart (Government of Saskatchewan, n.d.). In the counter case, it is much easier for a cattle rancher to increase feed supplementation than it is to replace the forage type mid-graze. These are both cost-independent examples of how ICLS is assessed before and throughout implementation as temporal changes occur in the surrounding environment. This reassessment can be daunting given the number of involved enterprises, however ICLS fundamentally uses its on-farm diversity as an opportunity for input substitution (Figure 3.1).

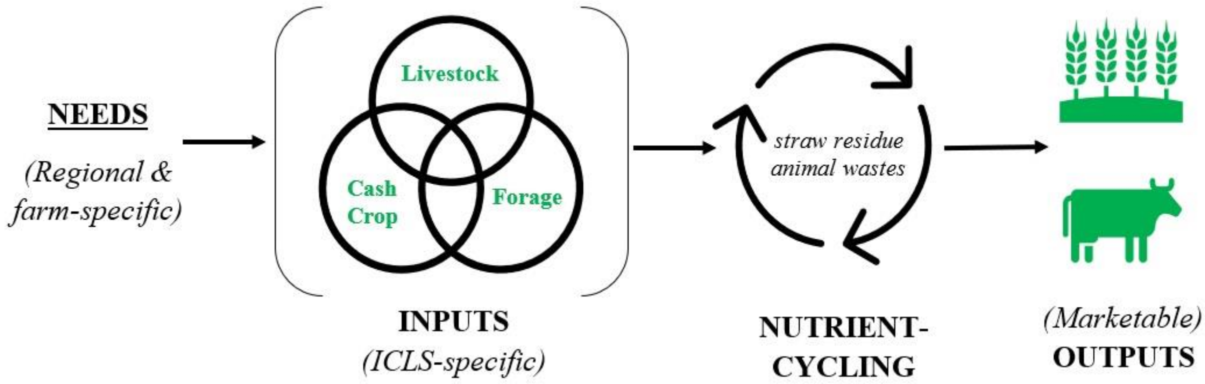

Figure 3.1 The life cycle of an integrated system

Source: Rai et al. 2021; Oliveira et al. 2022

The culmination of beef, crop, and forage (or cover crops, in an ICLS-specific case reflective of this thesis) does not remove necessities from any of the three streams. It is the interaction between these operations that allows for (incomplete) resource sharing and replacement (Rai et al. 2021). 'Incomplete' is used here to reaffirm that inputs are still required for the adequate functioning of ICLS, but perhaps more resource sharing is available than in a single enterprise. For example, although some fertilizer use can be replaced with cattle manure during the grazing season, it does not wholly replace the need for well-timed nitrogen-based fertilizer application (Oliveira et al. 2022). Therefore, it is the interaction between the environment and the system (the nutrient cycling in Figure 3.1) that determines how extensive system benefits affect the agricultural space.

3.1 Integrated Crop-Livestock Systems

Integrated crop-livestock systems are a form of agricultural intensification, a term encompassing practices that offer to producers the opportunity to increase ecological health while also increasing productive capacity (Carvalho et al. 2018; Planisich et al. 2021). However, the overarching issue of ICLS then becomes meeting the specificity of production requirements or, more realistically, assessing whether those specifics fit the established operation (Files and Smith 2001). The empirical data required to ease concerns about performance outcomes are either insufficient for conclusions or inconsistent with the specificity required (Omokanye et al. 2019; Fenster et al. 2021). The use of cover crops alone, for instance, can promote soil health, and the additional factor of grazing can further improve erosion protection, organic matter, microbe diversity, and filtration effects (Sulc and Franzluebbers 2014; Carvalho et al. 2018; Toews et al. 2019). There appears to be a general consensus about the advanced performance of basic regenerative systems, especially in comparison to conventional, high-input systems (Lychuk et al. 2017; Fenster et al. 2021; Filbert et al. 2021), although the degree to which cover crops and cattle separately affect the whole system can be contested (Drewnoski et al. 2018; Omokanye et al. 2019). While ICLS can be used to supplement gaps in cattle nutrition with minimal disruption to average daily gain (Planisich et al. 2021), the impacts of grazing on successive cash crop growing seasons and on market outcomes appears to be an area of concern (Franzluebbers and Stuedemann 2014), especially given the variability of production observed between each farm (Bergtold et al. 2017; de Souza Filho et al. 2021).

The sustainability drivers and desired longevity of ICLS suggest a necessity for prolonged use, especially to compensate the learning curve and experience requirements associated with this type of process (Fenster et al. 2021). A ryegrass grazing trial in southern United States cotton operations found overall improved (but inconsistent) profits across the four years of research (Schomberg et al. 2014); a similar investigation into simple and complex cover crop mixes[4] in Iowa found insignificant differences between farm returns regardless of program duration (Poffenbarger et al. 2017). Although not directly comparable, both highlight the realism of performance uncertainty in cover crop and ICLS use, wherein adoption of unconventional production methods can be negatively impacted by both system uncertainty and the effort required from the individual farmer (Kim et al. 2008).

Canadian cover crop adopters observe ecological benefits within the first three years of use, incidentally on the lower end of implementation length amongst those surveyed (Morrison and Lawley 2021). By increasing risks at the beginning of adoption (i.e. embracing the learning curve, higher initial investment, etc.), Bergtold et al. (2017) claim long–run performance is stable, particularly in regard to one of the largest determinants of cash crop returns: year-over-year yield. This should be encouraging for crop producers who wish to see the market competitiveness associated with prolonged cover crop use (especially when adoption extends beyond what is familiar), as it corroborates the insignificance in the yield differences observed between

[4] Simple and complex cover crop mixes references the diversity that exists in species inclusion. When specifically referencing the field trials of this thesis, *Simple* refers to a two-species mix whereas *Complex* indicates eight species. Both seed mixtures include a combination of crop types (e.g. cereals and legumes).

conventional and integrated fields (Lychuk et al. 2017; Drewnoski et al. 2018). It is therefore suggested that ICLS avoidance is more indicative of required effort than system performance (Pardo et al. 2010).

The decline in production efficiency observed in the transition process to unconventional methods appears to do so at a declining rate, with Jaeck et al. (2014) concluding that the experience associated with persistent use can improve overall efficiency. Regardless, based on survey responses, the majority of producers appear to have continued scepticism toward ICLS, particularly in regard to farmer responsibilities in production (Morisson and Lawley 2021), and the initial tradeoffs may be too burdensome for the mainstream adoption of integrated methods (Files and Smith 2001; Omokanye et al. 2019). This also justifies the necessity for adaptable management in order to accommodate the multi-faceted nature of ICLS and the associated decision-making networks, in the pursuit of benefits that seemingly excel in the long term (Sutherland et al. 2012; Bergtold et al. 2017; Carvahlo et al. 2018).

3.2 Specialization Opportunities

Regenerative systems rely heavily on synergies between the methods used, although the consensus appears to be that multiple techniques are required to maximize (ecological) success (LaCanne and Lundgren 2018). Farms that engage in ICLS follow a similar methodology, striving for efficient resource allocation in order to intensify production (Morris et al. 2017). Färe and Karagiamis (2018) suggest that, in multi-product operations, where the utility of each can be combined into one enhanced system, overall efficiency is based on input allocation. By using this approach to evaluate performance, farm efficiency can be better tailored to the individual site, as optimum resource allocation is based on the combination of inputs rather than the specific quantities used for each (Färe and Karagiamis 2018).

Traditionally, on-farm diversification is triggered as a solution to market risk, as farm longevity can be improved by taking advantage of concurrent markets (Morris et al. 2017). In the case of integrated systems, the coordination of production cycle differences between cattle and crop enterprises such as labour seasonality, performance variability, and age limitations, can protect farms from exogenous conditions which could otherwise exacerbate potential losses (Pardo et al.

2010; Bartolini et al. 2014; Poffenbarger et al. 2017, Planisich et al. 2021). However, institutional barriers to implementation like access to financial capital, time management changes, and the learning curve of working with new products/processes can limit the attractiveness of on-farm diversification (Schomberg et al. 2014; Deaton et al. 2017; Henderson et al. 2018). By extension, it may be that the socioeconomic space prefers the way in which (Canadian) agriculture has already been trending: toward specialization.

Foundationally, agricultural growth is a combination of capital investment, resource allocation, and efficiency (Ma et al. 2017), the combination of which allows for minor flexibility in associative decision making (Nikoloski et al. 2017). As such, there are numerous farm-level solutions to each commercial problem. Agricultural production has a long-standing history of following market trends, and in the pursuit of meeting food requirements, this has resulted in specialization – the productive prioritization of a single (or closely related) product (Emran and Shilpi 2012; Sulc and Franzluebbers 2014; Poffenbarger et al. 2017; de Albuquerque Nunes et al. 2021; Planisich et al. 2021). Spann (2017) writes at length about how intensification relies on an agricultural business strategy that favors a type of growth exclusionary of small farms without the land or financial capacity to improve "in a forward direction." The (financial) power dynamics between stakeholders, for instance, drive the direction of production (Kołoszko-Chomentowska 2016), which changes how 'improved productivity' is approached commercially and addressed at a farm-level (Spann 2017).

The decision to focus on a single product opposed to incurring the effort required to manage crops and livestock is not simply a matter of determining which market best accommodates the limitations of the farm; it also matters if the institutions are in place to encourage market success (Quintero et al. 2022). Specialization evolves to meet the hospitality of marketplace supports. After time, increasingly diverse regions can be disadvantaged by the attempt at self-sustainability because supports are not accommodative of the variety (Emran and Shilpi 2012). It is the technological and scaling capacity of the marketplace that allows specialization success (Emran and Shilpi 2012; Garbach and Morgan 2017) and the implied institutional improvements (i.e. financial and social efficacy) encourage widespread participation (Klasen et al. 2016).

However, integrated systems are excellent examples of the natural trade-off between economic goals and environmental capacity or, as implied, the trade-off between farm management and inflexible conditions (Klasen et al. 2016; Pigford et al. 2018). It is the balance between and strength of sustainability pillars that inform system functionality, including instances when monocultures (the primary concern of specialization) are dominating production (Kołoszko-Chomentowska 2016). When livestock are introduced to production, high grazing intensities can add more environmental rigidity and reduce the amount of managerial influence on system remediation (Planisich et al. 2021). Novel processes that at least partially prioritize ecological foundations will always be limited by their surroundings and, ultimately, to specific scales of commercial success if the marketplace is not structured to accommodate the antagonistic relationship in the economic-environmental space (Klasen et al. 2016).

The systematic barrier of independence limits the pool of available innovations to those that can be implemented with an equally limited list of farmer skills. This is not an inherently negative characteristic of the food production schematic, but rather an opportunity to expand the social networks of which integrated systems are so reliant (Files and Smith 2001). Sustainability should be built with social constraints and abilities in mind but such is often overlooked or pushed as a farmer responsibility. Farmers who do successfully implement integrated systems are unable to operate their farm and improve the social network simultaneously (i.e. human resource sharing, extension, etc.) due to (time) management constraints; therefore, production remains an individual venture, much like the original choice between maintaining status quo and opting into ICLS (Roesch-Mcnally et al. 2018).

3.2.1 Decision-making Complications

Before the degree of program success can be evaluated, Meraner and Finger (2019) posit a 'holistic portfolio approach' to determine which risk management strategies, if any, fit with the pre-existing farm/farmer characteristics. This is not a wholly unique statement, as determining which external factors can and cannot change (either exogenously or by the farmer) to accommodate a proposed change is one of the first steps of optimal decision making (Nikoloski et al. 2017; Henderson et al. 2018). For example, land ownership agreements severely affect whether the farmer is even able to make the transition to ICLS (Deaton et al. 2017). Further, the quality of land and the length of the tenure can negatively affect likelihood of investment, as both contribute to the variability of adoption feasibility (McMichael 2014; Ma et al. 2017; Sheng et al. 2018; Morrison and Lawley

2021). However, the complexity of individual priorities and capabilities can complicate the theoretical certainty (Figure 3.2), as profit maximization on each farm is similarly individualized (Batabyal and Biswas 2005).

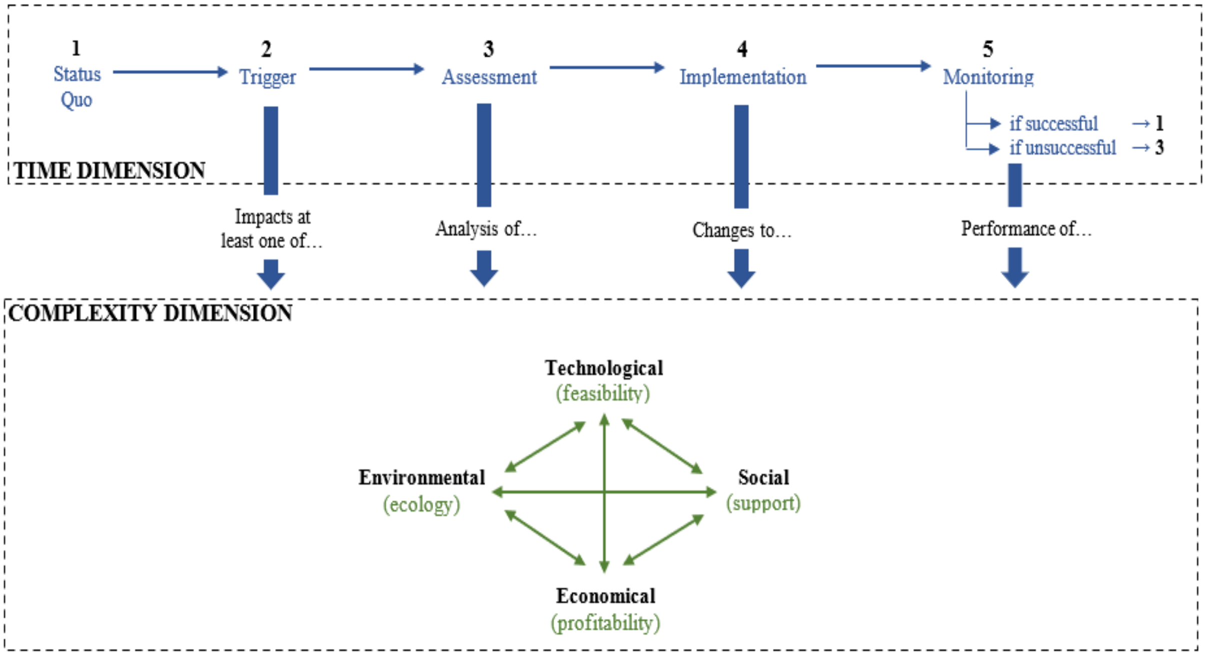

Figure 3.2 A summary of the time and complexity dimensions, and their interactions in the agricultural decision-making process

Source: Sutherland et al. (2012); Coteur et al. (2016)

Figure 3.2 is a culmination of various decision-making frameworks, highlighting the complications to agricultural management in response to time and complexity dimensions (Sutherland et al. 2012; Coteur et al. 2016). The role of time affects the system independent of the farm-specific problem; Sutherland et al. (2012) refer to this process as the "triggering change" cycle, wherein a shock (economic, physical, political, etc.) often initiates the discussion about when and where to improve upon or deviate from the status quo. In opposition to the assumption that risk averse farmers diversify off-farm, the likelihood of implementing on-farm risk management strategies increases following a triggering event (Meraner and Finger 2019). The degree to which a farmer is displaced by the shock or how comfortable a farmer is in deviating from their status quo position can be reduced by the presence of external support systems, which helps limit the risk associated with a project (Garbach and Morgan 2017). As a result, subsequent farm assessment can be impacted by the strength of operational support. transitioning to farm assessment can affect whether an individual subsequently assesses their operation at all. However, time effects continue trickling into the decision-making process as factors shift in response to external progressions; this affects how methodologies are assessed, added, and/or corrected, allowing successful long-term solutions to be injected into the mainstream rather than short-term or weak suggestions (Sutherland et al. 2012).

Presented in the complexity dimension (Figure 3.2) are the pillars of sustainability (environmental, economical, technological, and social), reflecting how the four broad categories can move with and against each other as standards and management priorities change (Ould-Sidi and Lescourret 2011; United Nations 2019). While literature usually focusses on the economic or the feasibility aspects of ICLS, factors such as the political climate, community interaction, and farmer experience (all falling within a classification of social considerations) may be as much a barrier to ICLS adoption as more traditionally reported factors (Zentner et al. 2002). This statement accentuates the complexity dimension of decision-making, where neglecting one facet of the (production) system limits long-term survivability of that system or, in a more extreme example, can undo progress made elsewhere (United Nations, 2019). The degrees of complexity, as well, are vast, such that considerations must not only be applied vertically to the supply chain (i.e. industry-wide vs. on-farm), but should also encompass the aforementioned individuality of quality depending on the decision-maker (Coteur et al. 2016; Nikoloski et al. 2017). The differences in priorities between types of producers and individual decisionmakers complicates universal ICLS transitioning but may also present an opportunity for extension to play a larger role in assessing each feasibility case (Batabyal and Biswas 2005; Deaton et al. 2017; Henderson et al. 2018; Meraner and Finger 2019).

3.3 Measuring Willingness to Accept in Integrated Systems

Much like novel processes, ICLS uncertainty within market, environmental, and managerial performances are barriers to the initial process of adoption (Kim et al. 2008; Ahmed et al. 2015; Masud et al. 2015). As a result, the decision to adopt appears to be segregated into a broader pair of contrasting goals: maximizing production value (profit) versus the more subjective, conservation value (Kim et al. 2008; Olynk et al. 2010; Bakker et al. 2018; Mooney et al. 2019). A brief conversation on the role of these values in the specific WTA question presented in this research is warranted here.

The increased interest of consumers in credence attributes, such as animal welfare, sustainability practices, and nutritional advantages, allows the marketplace for conservational methods to thrive (Igo et al. 2013; Danne and Mushoff 2017). When surveyed, 67% and 74% of farmers were willing to pay (various amounts) for access to a planned (climate change) adaptation program, suggesting that producers are invested in improving their operation for the sake of intangible externalities, regardless of the uncertainty (Masud et al. 2015). As input combinations and the production environment change, so too does the perceived value of the outcome and the reservation value of the land (van Houtven et al. 2014; Levers et al. 2018). To clarify, the number of average quality (productive) acres that can be enrolled in an integrated system should be used to determine the optimum land distribution, as good quality land should still, unquestionably, be occupied by cash crops (Levers et al. 2018). An investigation of the German dairy sector found that highly productive farmers with maximized land use were less likely to participate in grazing programs (Danne and Mushoff 2017), allowing for a similar inference of productive quality prioritizing any grazing program participation (integrated or otherwise) in the livestock sector.

According to Ahmed et al. (2015) and Masud et al. (2015), the most cited reasons for not buying into conservation methods were the feeling of government responsibility for environmental improvement and a lack of sufficient income to make the change. Kim et al. (2008) concluded similarly: reducing farmer contribution in a government cost-share conservation program does not guarantee a mainstream uptake of that program or its methods, as the operational and transition costs are still largely borne by the farmer. Results such as these complicate the decision-making process, as the significance of the price portion of system adoption in comparison to the entire bundle of operation characteristics can be contested (Danne and Mushoff 2017; Levers et al. 2018; Mooney et al. 2019). While it is possible to earn a profit from ICLS, especially when coupled with production and quality certification policies, the literature surrounding WTA for grazing-specific programs has focused on a comparison of private and public programs (Sun et al. 2009; Olynk et al. 2010; Mooney et al. 2019), which imperfectly substitute each other in modelling due to amenity differences (e.g. the strength of and accessibility to community supports).

This thesis has outlined integrated system uncertainty especially from the business angle, as the shadow costs of ICLS adoption (whatever they may be to the individual) directly impact farm economics (Boaitey et al. 2014). The specialization of ICLS, for instance, requires (physical, farm-specific) adjustments to production, and the decision to participate in integrated systems can lead to the commitment costs partially responsible for valuation ambiguity (Olynk et al. 2010; Kim et al. 2015). As such, WTA values are at risk of exaggeration, as the direct costs are easier to apply into the discrete choice framework than nonmarket (behavioural) costs (Holmes et al. 2017; Bakker et al. 2018). The full set of ICLS attributes can be standardized into the WTA process and accurately evaluated by converting nonmarket characteristics in the CV (Ahmed et al. 2015; Kim et al. 2015; Holmes et al. 2017).

3.3.1 The Econometrics of Discrete Choice Experiments

The use of WTA elicitation is justified for this research question, as it measures the perceived value of nonmarket benefits to the respondent in the wake of a welfare loss (Grutters et al. 2008; Whittington et al. 2017). The realisation of this loss is partially determined by the category of farmer, as ranchers and crop producers face different tradeoffs. In the case of ICLS, specifically, crop farmers forfeit some of their cash crop acres for cover crops but are better compensated for their participation; beef farmers (financially) compensate the program more than their partner but reap the benefit of a sustainable grazing source. Since it is assumed that the crop farmers are more financially displaced by the introduction and production of cover crops, cattle farmers pay for access to those cover crops, which presumably fill dietary requirements better than grass alone.

As implied by the RUM assumption that the personal utility is apparent to the respondent, the utility of transitioning to cover crop production (grazing using cover crops) must be greater to the farmer than the utility gained from producing the same way as usual (Mooney et al. 2019). This, coupled with the understanding that WTA is a static, income-independent valuation (Grutters et al. 2008; Kim et al. 2015), suggests that the variation captured in this modelling is reflective of the collection of program attributes, rather than a pure representation of payment acceptance.

The main WTA elicitation format used in this research is a DCE with randomized attribute levels, which asks farmers to participate in a binary evaluation between a status quo condition (growing their product the same as they have been – whatever that means to the individual) and an ICLS scenario (Watanabe 2010). The objective of this is to analyse the threshold of ICLS acceptance in prairie provinces (Figure 3.3) which, for this question, is the likelihood that the alternative will be perceived as more attractive than the baseline, or the likelihood that respondents will vote 'yes' to participating in the hypothetical program (Holmes et al. 2017).

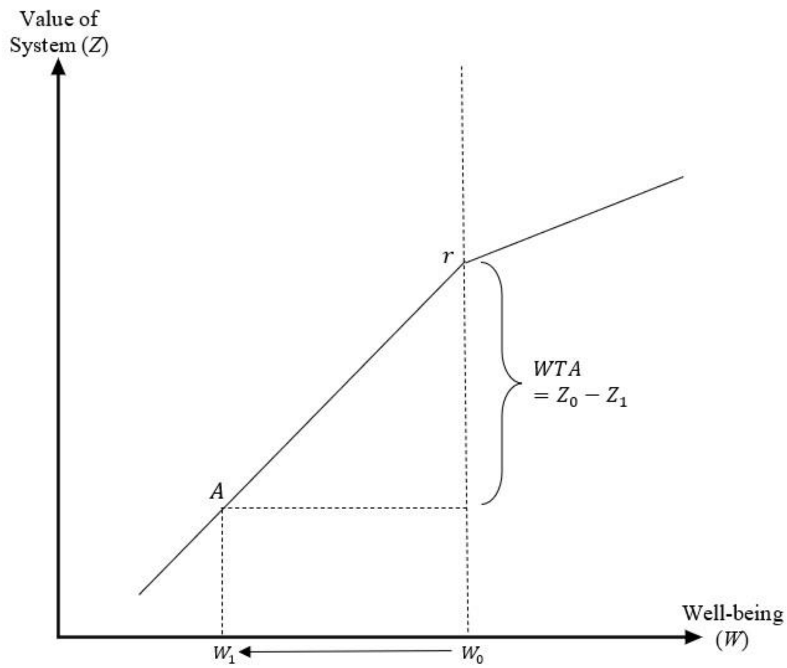

Figure 3.3 An illustration of the valuation mechanism of willingness to accept (WTA)

Source: Whittington et al. (2017) adaptation used with permission from the authors.

As illustrated in Figure 3.3 (and Whittington et al. 2017), when a program (A) exists that reduces one's well-being compared to the status quo ($W_0 \rightarrow W_1$), the individual values that alternative less. It should also be noted that the differences in indirect utility slopes (left and right of r) are reflective of how losses and gains are inversely valued, with farmers particularly sensitive to the losses of unconventional production shifts (Shalev 2000; Kim et al. 2015; Whittington et al. 2017). Point r is therefore the reference condition where the individual is indifferent between keeping production how it is and participating in an ICLS program. The minimum WTA is subsequently calculated as the difference in system values, but the alternative is weighed against the status quo (see **Error! Reference source not found.**).

To best incentivise truthful and accurate opinions toward adoption, the scenario must be compatible with the real world, which is illustrated in the discrete choice baseline condition (Holmes et al. 2017; Whittington et al. 2017). The survey, itself, should be written in such a way as to minimize unnecessary biases, as the questions that come before the DCE are designed to address any acceptability discrepancies or strategic behaviour (Grutters et al. 2008; Watanabe

2010; Holmes et al. 2017). By using a combination of literature-informed values and data calculations from field trials in Swift Current, the ICLS scenario presented in the survey is confidently realistic, regardless of which level is generated.

Chapter 4
Modelling and Attribute Selection

The primary purpose of the field data featured within this project is to simulate, within the DCE, the expected outcomes from an ICLS partnership. In doing so, the hypothetical uncertainty of ICLS is managed and respondents are able to analyse the details of the system. However, in controlling for the scenario (namely, a Canadian ICLS partnership with a neighbour in which each respondent is responsible for either the cover cropping or grazing portions, but not both), the considerations independent of the field data asks farmers to evaluate literature-specific factors of new process adoption, integrated systems, regenerative methods, and grazing programs.

Field trials began at the Swift Current Research and Development Centre in Saskatchewan (Figure 4.1 **A summary of cover crop grazing field trial results from the Swift Current Research and Development Centre and the estimated nutritive value of cover crops**), where three plots of each treatment (control, simple, and complex) were seeded spring 2019. The simple treatment refers plots using two forage species for cover crops, and the complex references the employment of an eight-species cover crop mix. The diverse mixes included in this research are realistic of prairie opportunities but are not the only way in which to include cover crops in an established operation. The subsequent economic analysis is also reflective of species diversity and may not be identical to what is observed in other, less complex ICLS.

Glyphosate was sprayed once in the spring to pre-treat the fields. Since there are no available herbicides for diverse mixtures (e.g. there are no commercially available chemicals safe for both perennial and annual species), no other chemical treatments were made. For consistency, the control also followed a similar spraying schedule. Subsequently, yearling steers grazed for approximately two months in the summer of 2019. In 2020, a monoculture barley crop was seeded over all treatments as a feedback year. This trial year was used to evaluate any land (soil) improvements following a forage cover crop and how they may translate to cash crop performance. The diverse annual forage crops were seeded again in 2021 as in the trial two years prior. One major difference, however, was in the performance of the forages and, as an unfortunate consequence, 2021 grazing only took place for approximately two weeks.

Swift Current Research and Development Centre (2019-2021)

Field Trial Data			2019	2020	2021
Control	Crop species		Peas	Forage barley	Canola
	Field size	*ac*	12.75	38.25	12.75
	Average cost	*/ac*	$74.10	$23.75	$117.35
Simple mix	Crop species		Oats, peas		
	Field size	*ac*	12.75	n/a	12.75
	Trial herd (maximum)	*hd*	24 steers		30 steers
	Grazing length	*days*	49		10
	Average start weight	*lbs*	968.38		901.20
	Average end weight	*lbs*	1,062.83		876.73
	Olympic average daily gain	*lbs*	1.07		-2.57
	Average cost	*/ac*	$51.51		$64.14
	Average cost	*/hd*	$27.37		$34.07
Complex mix	Crop species		Barley, brassica, hairy vetch, oats, peas, phacelia, radish		
	Field size	*ac*	12.75	n/a	12.75
	Trial herd (maximum)	*hd*	24 steers		30 steers
	Grazing length	*days*	51		10
	Average start weight	*lbs*	966.25		903.57
	Average end weight	*lbs*	1,012.50		877.63
	Olympic average daily gain	*lbs*	-0.26		-2.47
	Average cost	*/ac*	$144.83		$157.73
	Average cost	*/hd*	$76.94		$83.79

Cover Crop Nutritive Quality		Cereals			Legumes		Brassicas[2]		
Averages[1]		Barley	Oats	Golden German Millet[2]	Forage peas	Hairy vetch	Winfred brassica	Forage radish	Phacelia[2]
Dry matter (DM)	*% as fed*	25.0	87.9	29.7	15.6	20.3	17.4	30.3	23.8
Crude protein	*% DM*	11.0	11.0	16.0	17.7	23.0	22.0	14.8	16.9
Neutral detergent fibre	*% DM*	57.6	35.5	53.2	31.1	37.4	35.2	54.3	44.5
Acid detergent fibre	*% DM*	32.7	16.2	35.1	23.1	29.6	32.8	38.7	42.9
Calcium	*% DM*	0.49	0.11	0.48	1.86	1.33	2.29	1.09	2.80
Phosphorus	*% DM*	0.17	0.36	0.19	0.39	0.45	0.29	0.19	0.23
Average biomass contribution in **simple mix** (2019, 2021)	%		73.8		26.2				
Average biomass contribution in **complex mix** (2019, 2021)	%		75.3		6.5		32.7		2.5

Sources: [1] *Feedipedia (2022)*
[2] *Peace County Beef and Forage Association (2020)*

Figure 4.1 A summary of cover crop grazing field trial results from the Swift Current Research and Development Centre and the estimated nutritive value of cover crops

Throughout this paper, ICLS has been partnered with complexity, and the field trial results suggest that, even in practice, the system is perhaps an incomplete substitute for more conventional methods. Beyond the economic factors (more thoroughly discussed with Table 4.1), the ecological performance of the program may be its own barrier to adoption regardless of structure. Within the field trial data, for instance, herd numbers are represented as a maximum across the entire grazing period. In reality, stocking rate was temporarily modified for a short period of time in the 2019 grazing season in response to forage availability. What is available can differ nutritionally, as evidenced in the bottom table of Figure 4.1 where the inclusion of forage species (or additional species when comparing the complex to the simple mix) alters caloric and mineral diet composition. In beef production, these factors are important considerations for growth, health, and carcass characteristics (da Luz et al. 2019), and could be determinants of whether cover crops suitably address personal production goals and market standards.

Particularly when legume species are included, beef productivity, although conditional and varied, is expected to be somewhat superior to what is observed in monocrop or grass-dominant grazing (Toews et al. 2019; Christensen et al. 2022; McKenzie-Gopsill et al. 2022). The average herd weight of the Swift Current trials, although still market competitive, is slightly lower than what is expected of the additional protein provided by legume inclusion (Hillhouse et al. 2021), especially for those steers turned out to the complex mix. The trial size may have limited some of the productivity potential of the eight-species treatment (Thompson et al. 2021), although Swift Current farm managers suspect a more behavioural cause: yearling steers are preferential eaters. When provided an eight species polyculture mix, it is easier for animals to avoid certain species simply based on taste (in this specific case, brassica species).

It is difficult to conclude whether the negative average daily gain observed in 2021 can be attributable to the cover crop treatments due to unforeseen circumstances (i.e. growing conditions) and the length of the entire trial/grazing periods (Figure 4.1). Firstly, the 2021 grazing period is much shorter than its predecessor, more comparable to the beginning third of the 2019 trial than the entire season. If the 2019 trial in Figure 4.1 were broken down into its three grazing periods (a detail mainly relevant for stocking density), results would indicate a similar decline in average daily gain within the first week of grazing, albeit to a lesser degree than what is observed in the later year. Second, the final year of field trials saw extreme kochia pressures, resulting in at least a quintupled weed presence between grazing trial years (Figure 4.2). Although kochia can be nutritionally compared to alfalfa, the proportion at which it contributes to the diet may impact the performance and health of the animal if too high (Nair et al. 2021), which could partially explain the weight and gain differences observed across years and treatments.

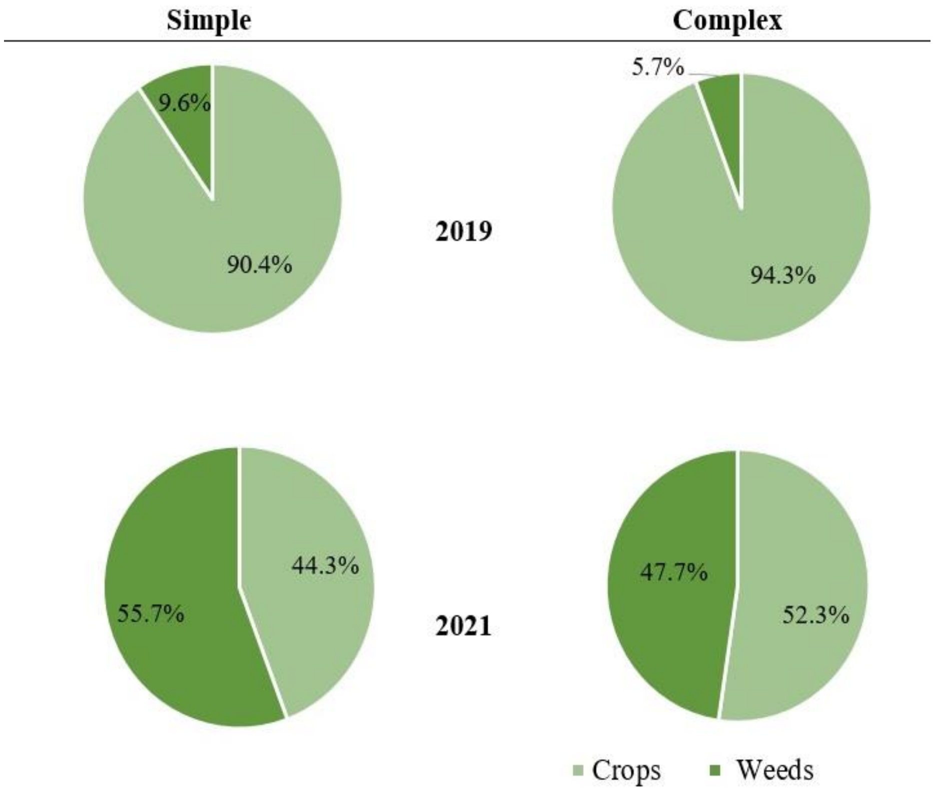

Figure 4.2 A comparison of weed contribution to total plant biomass (kg/ha) between grazing years

Kochia is a hardy broad leaf weed well-adapted to the Canadian prairies and, therefore, a challenge to terminate (Petrosino et al. 2015; Kumar et al. 2020). Integrated crop-livestock systems can potentially be a solution to kochia control, especially in instances where glyphosate is an unavailable option and the cover crop mixtures used are designed to out-compete kochia for space (Petrosino et al. 2015; Kumar et al. 2020; Nair et al. 2021), however growing conditions likely limited that potential in these trials. Regardless, inadequate research in the ICLS space contributes to the ambiguity of grazing effects on kochia populations, with the role of grazing on subsequent weed growth still one of the biggest unanswered questions from farmers surrounding both topics (Kumar et al. 2020). A more detailed analysis of the role of kochia in ICLS adoption is indeterminable due to the lack of research, however the fitness of the weed population and its prevalence in the area are strong determinants of adopting intensive weed management practices (Kumar et al. 2020).

In a typical crop production, herbicide treatment may be a possible solution to kochia should the weed still be susceptible (Nair et al. 2021). However, ICLS with the use of cover crops mixtures cannot include an in-crop spray due to the biodiversity and is one way in which the cost of production differs from annual crop production. The field trials from 2019 had similar pre-seed herbicide treatments, whereas, in response to weed pressures, the 2021 annual crop was able to include an in-crop spray that the ICLS treatments could not (Table 4.1).

Table 4.1 Comparison of field trial costs by treatment

	2019			**2020**	**2021**		
$	**Annual**	**Simple**	**Complex**	**Annual**	**Annual**	**Simple**	**Complex**
Seeding	510.00	329.23	1,532.41	690.41	828.75	329.23	1,534.95
Inoculant	124.92	17.77	5.33	0.00	0.00	17.77	5.33
Chemical	72.65	72.65	72.65	218.03	417.56	220.83	220.83
Fertilizer	237.15	237.15	237.15	0.00	249.90	249.90	249.90
Total cost	944.72	656.80	1,846.54	908.44	1,496.21	817.73	2,011.01
Cost per acre	74.10	51.51	144.83	23.75	117.35	64.14	157.73

Source: Swift Current Research and Development Centre

Inoculants were only applied to peas, which explains the high costs in the 2019 annual plots (yellow pea) and inclusion rate-based differences between the simple and complex treatments. When comparing the seeding costs associated with the control, it is important to note that the difference between 2019 and 2021 is the crop type and associated seeding rates, whereas 2020 also covered a much wider area. (The size of each field used to complete the total cost per acre estimates are displayed in Figure 4.1.) The seeding cost summary in Table 4.1 also recognises the impact of cover crop diversity (APPENDIX C – Trial seeding data for the simple and complex cover crop grazing treatments (*Top*) and the annual crop production control (*Bottom*)), which may require farmers to purchase expensive seeds to meet nutritional requirements for growth despite only being used in small quantities.

Timing is an additional consideration that can be affected by individual forage species, and therefore may have implications for cattle performance (Carrell 2022; McKenzie-Gopsill 2022). As noted by Carrell (2022), the management goal of extending the summer grazing period is rendered inefficient when stocking rate (as it should) is rearranged to meet forage availability. This sentiment is echoed by Hillhouse et al. (2021) who hypothesize that the number of grazing days can be at least as influential on beef gain as the forage mixtures in question. Although, to some degree, traits such as weight gain and especially preferential grazing are individual specific (Sim et al. 2020), an awareness of cattle type/characteristics or operation goal in combination with the best polyculture (whatever that may be) is advantageous to ensuring forage efficiency in ICLS.

4.1 Scenario Creation

One of the foundations of the DCE is informing farmers that their ICLS involvement includes a partnership with a neighbouring farmer. This condition is designed to partially alleviate the stresses of newness; a farmer would theoretically be more open to ICLS because they would only be responsible for the portion of the system with which they are most familiar. The inclusion of a neighbour would theoretically allow for transparency (via field checks) and a similar understanding of regional specific challenges (e.g. local politics, environmental trends, support availability, etc.) from both players. System logistics such as yardage, fencing, water costs, and the responsibility/frequency of herd checks were not explicitly used as attributes in the DCE because it was assumed such would be determined internally by participating farmers. However, by excluding those details, scenario realism was inadvertently sacrificed, as mentioned by a number of respondents when given the opportunity to freely comment on their acceptance/rejection decision (discussed further in Chapter 6).

To minimize the potential for hypothetical bias in the scenario creation, especially when asking farmers to imagine such a specific combination of integration characteristics, the features of ICLS displayed include both literature and data-based values. Five attributes of the program with randomized levels (from *low*, *medium*, and *high* options) were listed based on farmer type, along with a set trait that did not change across the dataset. Given the scope and organization of the survey, the DCE focuses more on the program’s technical and economic feasibility when compared to earlier sections. Justifications for the featured attributes are labelled as such, here.

4.1.1 Randomized Attributes

The only attribute to be presented to both farmer types is the program commitment length (in years), the range of which is based on the typical length of a cover cropping trial across multiple sources. As previously discussed, the performance of ICLS is uncertain, particularly with the climatic and environmental variability in prairie provinces, and the expected delay in ecological adaptation. Therefore, inclusion of this commitment factor asks if locking into ICLS, regardless of (unknown) annual performance and maybe an improvement to production after years of implementation, disincentivizes adoption.

I assume that the average crop farmer is unwilling to sacrifice a large percentage of their cash crop fields for unmarketable cover crops and cattle grazing. Therefore, the range of acres that could have been presented to respondents was very low. In Saskatchewan, for example, where the average farm size is less than 1,120 acres (Statistics Canada 2022), the potential area that crop producers were required to sow into polycultures (40, 80, or 160 acres) represented approximately four, seven, and 14 per cent of land, respectively.

Cattle ranchers were similarly presented with a production commitment, calculated by using the stocking rates of the acreage range for crop producers. While the field trials utilized a stocking rate of approximately 0.5 acres per animal, the survey used 0.6 acres per animal and rounded to the nearest five for visual simplicity. Although this prevents some question symmetry between farmer types, the minor difference in stocking rates is representative of availability inconsistencies across farms.

An extra consideration for cattle ranchers is the distance between their operation and the cover cropped field. Bakker et al. (2018) find that there is a negative relationship between field distance from the main operation and the price a farmer is willing to pay to have access to it. That trend is true regardless of farmer type but is far less elastic for cattle (Bakker et al. 2018). It is expected, in the kind of ICLS scenario established by the survey, that the largest cost (monetarily and labour-wise) is herd transport. Unfortunately, the use of the term ‘neighbour’ throughout the survey became looser than intended, more closely resembling farmers operating in the same rural municipality opposed to fields beside one another. Regardless, the *high* option for field distance is less than 50 kilometres away, such that cow checks are still relatively reasonable and transport still falls within short haul transport requirements (Beef Cattle Research Centre 2018).

The cost-share relationship of the grazing scenario is that crop producers incur the cost of cover crop implementation/upkeep, and cattle ranchers will compensate some of that by paying for land (grazing) access. The average costs presented to crop farmers ranged from $50/acre to $150/acre, which is representative of the range observed across field treatments, rounded to the nearest ten dollars per acre to be visually appealing (Table 4.1). The input savings trait ($20, $50, or $100 per acre) is largely determined by chemical savings from fewer sprays throughout the growth period. These values are similarly derived from the field data as the implementation costs, although not overtly observed in the previous figures. The costs of implementation and subsequent incurred savings (namely, feed and fertilizer) are comparable to external studies (Filbert et al. 2021; Rai et al. 2021).

The cattle payment for full grazing season use are based on the same values, although divided by the number of cattle expected per acre. Therefore, the direct payment between partners is designed to compensate cover crop establishment partially or completely, depending on which attribute level is displayed. The 2019 grazing period allows just under two months access, which would put the *high* cost of grazing amongst survey options at approximately $1.25/head/day. The level presented could impact decision making in a variety of ways, either looking overpriced when compared to alternative pastures (Association of Manitoba Community Pastures 2022), or unrealistic as in the case of Alberta, where the minimum grazing rent[5] required by the government exceeds the *high* option (Government of Alberta 2022). Given the randomization and combination of attribute levels, a rancher may be facing a scenario where the cost to participate in ICLS surpasses $7,100 on grazing rental, alone.

The economic foundations of forage rely on the costs and productive capacities of sown polycultures, with the latter being of particular concern to cattle ranchers seeking reliability and nutritive quality in said feed sources (Omokanye et al. 2019). The crop production estimates from the field data (Figure 4.1 **A summary of cover crop grazing field trial results from the Swift Current Research and Development Centre and the estimated nutritive value of cover crops**) exemplify the differences polycultures can have on nutritive potential. Within the last five years, Canada has faced historic drought conditions and, although programs such as *Hay West* have alleviated some of the sourcing concerns in the Prairie provinces, the availability of forage to meet local demands is extremely variable (Government of Canada 2021b; Canadian Federation of Agriculture 2022; Cordeiro et al. 2022). Given the variability of feed costs both in response to

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[5] Grazing rent is typically used to refer to the payment made for access to public grazing land, which is typically government-owned (Mooney et al. 2019). However, this thesis focuses on private fields that are subsequently rented, and therefore grazing rent is used to refer to the cost of herd access.

market conditions and to regional differences, cattle ranchers are asked to assess a difference in feed cost rather than an actual dollar value. Therefore, feed cost changes presented to cattle farmers represented no change or a 20 per cent deviation in either direction from their typical feed costs.

Given the foundations of the cost options, the payment reception range presented to crop producers could completely or partially compensate the cost of implementation. The best-case compensation scenario, which gives $50/acre surplus, was available for approximately 30% of crop respondents. Cattle producers, unfortunately, could face a worst-case scenario, with maximum costs on a maximum herd size. (The impacts of these hypothetical ICLS scenarios on income position are explored further in APPENDIX B – A comparison of income statements for the typical farm and the best/worst random attribute combinations from the DCE.) However, due to the unidirectional nature of program payments, evaluating the economic position in a best- and worst-case hypothetical is purely based on the attributes expressed in the DCE may yield a net gain for crop farmers, but will always be negative for cattle ranchers. Therefore, cattle ranchers may put more emphasis on agroecological performance if the economic component can be overlooked.

4.1.2 Performance Measures

An additional factor of the discrete choice scenario were locked performance measures, all of which feature field data as their defense. Given the scope of the field trials, cattle producers were told average herd weight would remain unchanged compared to pre-ICLS years. Although the herd subset that grazed throughout the entire season minorly underperformed those steers temporarily removed during period two (Figure 4.1), the average end weight is still within the expected range for September growing steers (Byrne 2020).

The barley growth in the feedback year yielded no significant differences between grazed and ungrazed fields on treatment plots. Therefore, one of the advantages presented to crop producers is an unchanged average yield of fields previously hosting cover crops. The inclusion of this statement was designed to assure producers with limited ICLS and/or cover crop experience (as was expected to be the case for the majority of respondents) that their productive capabilities would not be affected.

The statement “Observed weed reduction after two years” is defended largely by the complex treatment (2019-2020). Although 2021 saw extreme weed pressures, the year prior yielded more positive results. The control plots, for instance, saw a 50 percent weed reduction in the first two years and the complex mix, a 68 percent reduction. Although the small increase in weed growth on the simple treatment is unexpected, the stronger biodiversity of the complex mix could partially explain its resiliency.

Chapter 5
Results and Discussion

The overarching goal of the survey (APPENDIX A – Survey questions (excluding demographic questions)) is to determine prairie producer responses to ICLS and its components, to assess the likelihood of program adoption in Canada. There were broad filtering requirements, such as attempting an even distribution of responses across prairie provinces and striving for 250 responses each from the crop and cattle sectors. As questions are designed to have the respondent consider the on-farm decision-making process, the respondent pool, here, was also restricted to self-identified "key decision makers."

Some questions are tailored based on farm type (including the DCE) and, therefore, it is important to segregate the dataset accordingly (Table 5.1). Throughout the remainder of this discussion, the full dataset of 503 responses is used unless specified.

Table 5.1 Survey respondents classified by enterprise, the set of questions presented to them, and their response to the scenario hypotheticals

Total number of participants		503
	Crop	**Cattle**
Farm type (farmer identified)	486	234
Assigned question set	363	140
"Yes" responses to DCE	78	42

To clarify the values given above, *Farm type* refers to how the respondent identified their farm: primarily producing crops, primarily producing cattle, or both. The *Assigned question set*, however, refers to the set of questions (either cattle- or crop-specific) that were shown and answered. As observed, the number of mixed farmers dominated survey responses, and only 17 respondents declared themselves as a purely crop operation.

Further, with such vague restrictions, it is worth comparing how representative the pool is to the average provincial farmer (Table 5.2). If our dataset is representative of the typical farmer, it may give credibility to ICLS adoption likelihood in Canadian prairie provinces.

Table 5.2 A comparison of the average farmer in this survey with the average farmer reported in the 2021 Canadian Census of Agriculture, separated provincially

		Alberta		Saskatchewan		Manitoba	
		Census	**Survey**	**Census**	**Survey**	**Census**	**Survey**
Total producers		57,200	107	44,140	315	19,465	36
Average age		56.5	(55-64)	55.8	(55-64)	54.4	(55-64)
Average annual income		$558,055	>$100,000	$505,853	>$100,000	$582,557	>$100,000
Farms w/ access to off-farm income		49.1%	34.6%	43.6%	50.2%	46.1%	54.3%
Average acres		<400	>2,000	<1,120	>2,000	<1,120	>2,000
Total oilseed/grain farms		13,942	107	20,438	298	6,749	81
Farm type	**Oilseeds**	6,078		8,481		1,966	
	Soybeans	0		27		513	
	Dry peas/beans	347		1,305		96	
Total cattle farms		14,994	51	7,732	147	3,812	36
Per farm	**Average steers**	132.5		46.7		35.1	
	Average heifers	132.6	<100	45.2	<100	32.4	<100
	Average cows	89.4		86.9		74.2	

Source: Statistics Canada (2022)

Overall, our dataset is characteristic of the prairie provinces from a demographic standpoint. The strong representation from mixed farmers (Table 5.1) may partially explain the sampling of farmers with a slightly elevated income compared to the provincial average, although the values recorded by Statistics Canada are a broad average calculated by dividing the net provincial income by the number of producers (Statistics Canada 2022). Similarly, the survey farm type is not equivalent to the number of completed question sets; mixed producers dominate cattle opinions throughout this project and may be an overlooked necessity for ICLS accommodation. This further highlights the importance of determining farm suitability to the method when approaching on-farm sustainability improvement.

Producers are mostly familiar with ICLS and with cover cropping (Figure 5.1) although mixed farmers, unsurprisingly, claim to be more familiar with each.

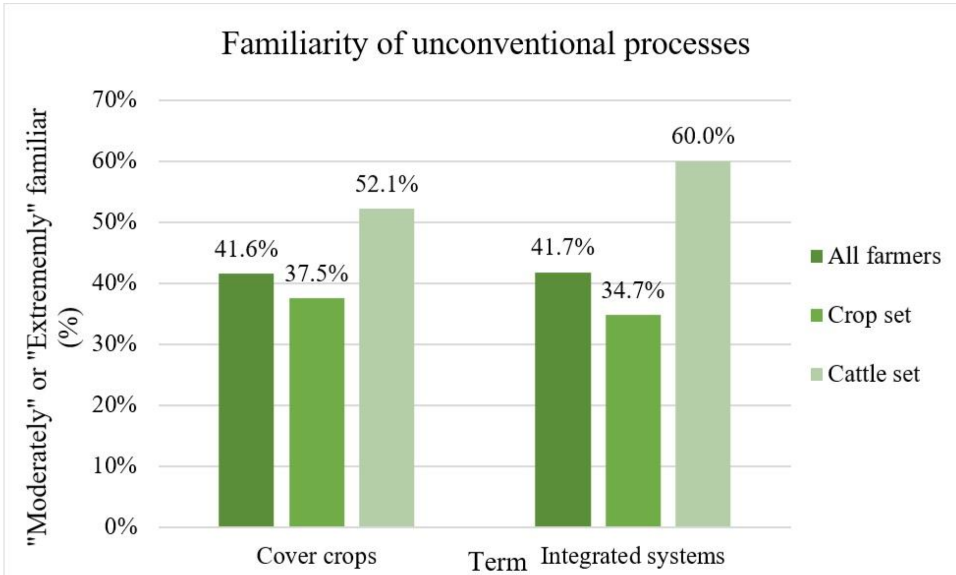


Figure 5.1 Percentage of each farmer type (based on question set) who are familiar with integrated systems and cover crops

Note: participants were provided with a brief definition of each term before being asked their familiarity

When these values are calculated to be representative of the entire dataset, just under 42% are moderately or extremely familiar with each term. However, what makes this interesting is that 42% is less than the 50% of farmers who claim to have experience with some type of integrated system within the last 15 years. This suggests that experience with complex, unconventional systems may not be enough to combat the learning curve of adopting something new. As discussed throughout the literature review, there is a delay to the performance benefits of ICLS, and a temporary use of these or similar methods may not be sufficient to provide farmers with sustained confidence.

By contrast, just under 32% of crop farmers admitted to using cover crops either currently or in the past, and only 24% of cattle ranchers to participating in grazing programs, which could suggest that producers are aware of farming alternatives, but the logistics do not fit their operation. In the case of all three types of programs presented (integrated system, cover crops, and grazing program) a lack of experience triggers a lack of confidence, and the more likely they are to reject the scenario.

Before introducing respondents to the choice experiment, gauging farmer perceptions of the scenario attributes, separately, contributes to understanding the thought behind integrated system acceptance. The order of questions increased in program specificity, starting with generic farm opinions, and transitioning to ICLS-based considerations. It should also be noted that discussed values are reflective of the entire dataset unless otherwise specified as a subset. The first content-related question presented asks respondents their level of agreement with various situational statements (Table 5.3).

Table 5.3 Percentage of the sample who *Somewhat Agree*, *Agree*, or *Strongly Agree* with preliminary (motivational) questions

	(Somewhat; strongly) agree
"Maintaining and improving soil quality on my farm is a priority"	95.4%
"I am willing to work with other farmers if it can improve my own farm"	87.7%
"I am satisfied with my farm's productivity"	78.7%
"Sustainability is of growing concern on my farm"	78.3%
"When it comes to farm decisions, I tend to choose methods similar to what was done the year before"	74.8%
"Regenerative farming practices are a good solution to many agricultural issues"	73.4%
"The market competitiveness of my farm needs to be improved"	70.8%
"Environmental changes are a growing concern on my farm"	67.0%

Given the overwhelming prioritization of soil quality in this sample (95%), better layperson vocalization of the ecological benefits in ICLS may be the exact encouragement farmers need to truly consider such programs. However, majority opinions such as already being satisfied with farm productivity (79%) and a desire to improve enterprise competitiveness (71%) may suggest that unconventional processes like ICLS will not be adopted so long as performance changes, let alone declines. These opinions may act as a non-starter to some producers however, for those producers who can and do successfully implement integrated systems, sustained efficiency minimizes the perceived loss of the program and may solidify, at least anecdotally, the physical competitiveness of the system.

The performance of the system is an especially important motivator if environmental altruism is not a prioritised consideration of farmers, and one that needs to be explored further in Canada, especially as only 30% of surveyed farmers state they personally know someone who has found success with an integrated system.

A telling response from Table 5.3 is the preference for previously used methods (75%), which matches the previously reported values for those with grazing and cover crop experiences. This suggests that much like most farmers, the survey sample is risk averse, which largely refers to decision-making that prioritizes avoiding perceived risk or potential loss regardless of how realistic it is (Herweg et al. 2010; Boyce et al. 2013). Since sustainability adoption is dependent on perceived need and farm capabilities (Kansanga et al. 2021), a preference for familiarity contributes to the necessity for adequate agricultural function (Soubry and Sherren 2022). In the farm management landscape, when stress plays a more prominent role in outcome than it does in a survey hypothetical, farmers are more likely to choose the option that circumnavigates all loss (regardless of magnitude) than analysing the full set of features (Pabst et al. 2013). Therefore, in programs such as ICLS where yield and weight losses, despite minor, are still present, and the benefits largely exist in the long term, it is important that farmers approach the system with as little anxiety as possible.

These conclusions acknowledge that the specifics of the partnership proposed in this research is, as is, dysfunctional for prairie producers. Some farmer-to-farmer matching programs do exist such as the *Manitoba Grazing Exchange*, and may be a better understood and more realistic option for prairie farmers than the incentivized conditions in the DCE. (As this research has proved, this program is only a better option if there is interest in the benefits provided, farmers know the program exists, and the program is feasible for the individual farm.) An interesting challenge, however, will be in overcoming crop farmer hesitation, which is observed in both the results of this survey and the number of summer cover crop farmers looking for a herd to graze their field at the time of writing (Manitoba Grazing Exchange 2023).The mechanisms of ICLS such as cover cropping and rotational grazing can be government-subsidized, but the improvement of performance and opportunity awareness cannot be understated. Field days, conferences, and blog articles such as those scheduled by the Beef Cattle Research Centre and Saskatchewan Soil

Conservation Council represent a powerful set of word of mouth and network-building techniques to improve information sharing and performance feedback immediacy.

These networks can allow existing ICLS partnership opportunities, such as

Integrated agricultural systems tend to be seen as independent projects, which makes the adoption of livestock involved processes, like ICLS, a daunting undertaking. As was clarified by comments later given, approximately 8% of respondents (40 comments) directly referenced the lack of cattle on their farm as a determining factor in their willingness to accept the hypothetical ICLS arrangement. Answers such as these add value to determining the quality of DCE responses, as not raising cattle could be a barrier to ICLS adoption in and of itself, or it could reveal a misunderstanding of the experiment scenarios. Further, when asked, nearly 30% of crop farmers explicitly said they would not allow cattle to graze their land; responses to this question partially inform how producers respond to the discrete choice (i.e. someone unsure about including cattle is likely to be "Unsure" about scenario participation; those unwelcoming to cattle are more likely to reject the scenario; etc.). Encouraging partnerships between farms reduces some of the managerial and inexperience stresses if the right partner can be determined. Approximately 39% of cattle farmers could confidently say there are cover cropped fields within 60 kilometres of their farm, whereas only 5% of crop producers could claim the same awareness for livestock operations. Therefore, in order to optimally match farmers, there may need to be some external intervention, at least at the introduction stage, to both match and direct the program.

Nearly 88% of producers declared a willingness to work with others for personal gain except, unsurprisingly, that confidence comes with conditions. One such condition is whether the partnership conditions need to exist to alleviate concerns (Figure 5.2).

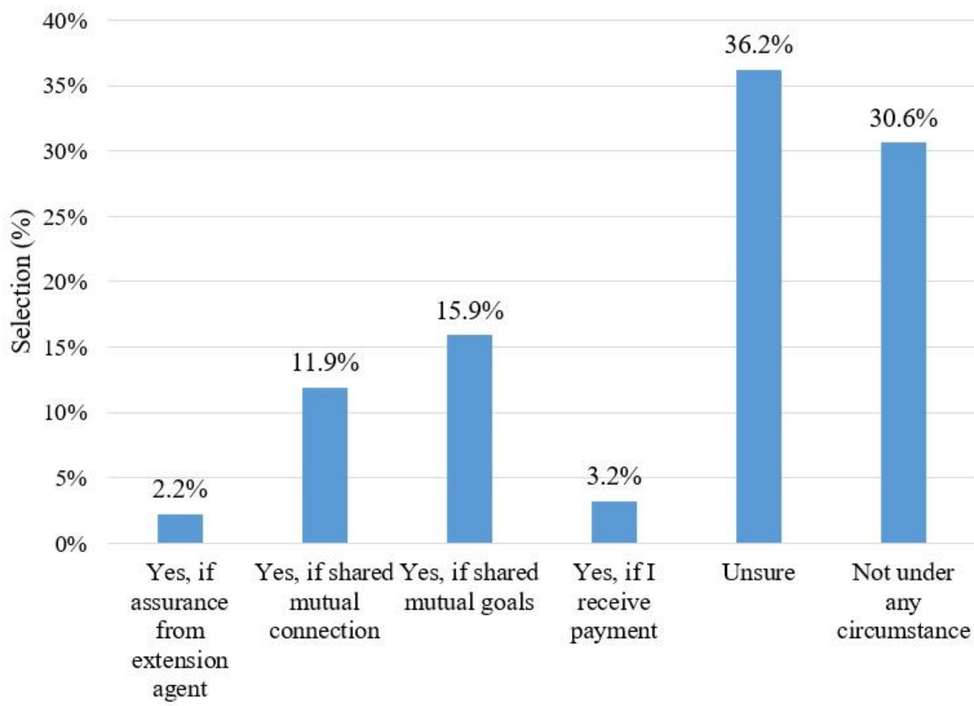
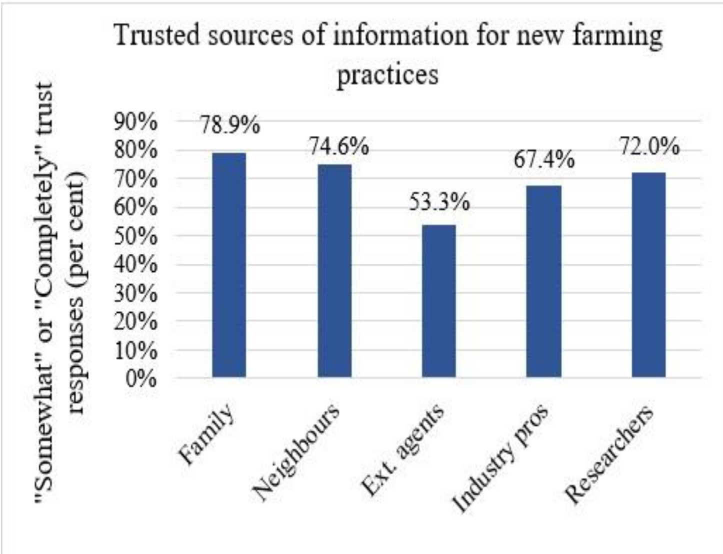


Figure 5.2 Conditional agreement to entering an integrated business partnership with a farmer not already personally known to them

The dominating responses when asked which conditions, if any, are required for participation in an integrated business partnership with a farmer not personally known to the respondent, are “Not under any circumstance” and “Unsure.” (These respondents have very similar opinions toward ICLS, as well, with the top discrete choice responses amongst those two groups being “No” and “Unsure”, respectively.) Although assurance from a mutual connection or the underlying foundation of mutual goals can be motivators for participation (for approximately 12% and 16% of the sample, respectively), the consensus in Figure 5.2 likely comes with intangible stipulations. (It is worth noting that a *No* response is not exclusive to the rejection of an unfamiliar business partner, as those fundamentally uninterested in integrated programs likely rejected this question, as well.)

Particularly in the Canadian prairies, the success of integrated systems is largely credited to the trust between farmers (Thiessen Martens et al. 2015), with some researchers further suggesting that the initial participation in these types of programs is contingent upon a stable and pre-established trust between partners (Files and Smith 2001). The responses given in this sample seem to follow the same principle (Figure 5.3), with nearly 79% putting trust in family members to share information about new farming processes.



Comment	Number of mentions
Lack of trust (in other farmers)	13
Personal connection dependence (i.e. family considerations, word of mouth)	12
Would participate if found the right partner	6
Control (decision-making) concern	3

Figure 5.3 Amount of trust placed in various relationships and the number of similar mentions in the comments when presented with the opportunity to name participation influences

Although neighbours are considerably better trusted than extension agents, the difference is more reflective of apathy than active distrust in extension agents or *Ext. agents*, above (39.2 per cent neutral towards extension agents compared to 7.6 per cent distrust). In a scenario such as the one presented by the discrete choice section of this survey, which explicitly asks producers to imagine a partnership with a neighbour, opinions on trust are likely deterministic of adoption. If there is neither trust for the partner nor the external supports designed to strengthen program trust, then an ICLS partnership is too niche for mainstream implementation. This underlying lack of trust that seemingly undercuts other considerations of adoption may partially explain opinions toward labour changes as a result of ICLS use (Figure 5.4). The overall discomfort at the idea of hiring external labour amongst both cattle and crop producers may be partially explained by the uncertainty over the quality of the worker.

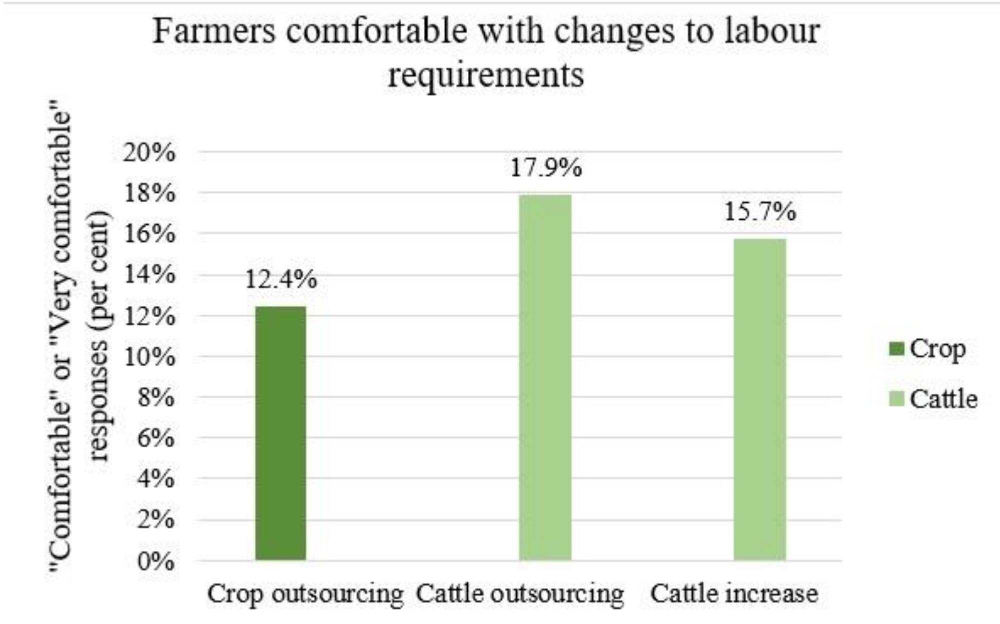


Figure 5.4 A visual representation of farmer comfort towards various changes to labour requirements (outsourcing crop and cattle labour, and increasing cattle labour)

Note: producers were only asked to comment on changes affecting their type of farm production

As observed, a potential increase in weekly work requirements is undesirable to the majority of cattle producers; the inevitability of increased workload in ICLS is explicitly mentioned as an influencing factor 22 separate times, and the amount of time (as associated time management) required for these systems is included 13 times. However, changes to labour requirements may be a factor of production cattle rancher are better able to adapt to, as it appears confidence meeting those labour changes translates into a higher acceptance of ICLS or, rather, the specific scenario presented.

Beyond perceptions of what the system will do to the established farms, the farm must be suitable for ICLS. Therefore, crop farmers were asked on which land bases they would be willing to try new systems, and cattle ranchers were asked their preferred forage type (Figure 5.5). To further justify the inclusion of these questions, if a crop producer is not comfortable using techniques with which they are inexperienced on any land base, then there is no adoption; it does not matter that the best possible partner is available or that the expected loss that year is negligible, this perception of managerial skills and land suitability act as a non-starter. The implications on the cattle side are more attune to the seeding mixes; for example, producers who tend to be legume averse in their forage selection would need to be paired with a producer who perhaps has no need for such a nitrogen-rich species in their cover crop mix.

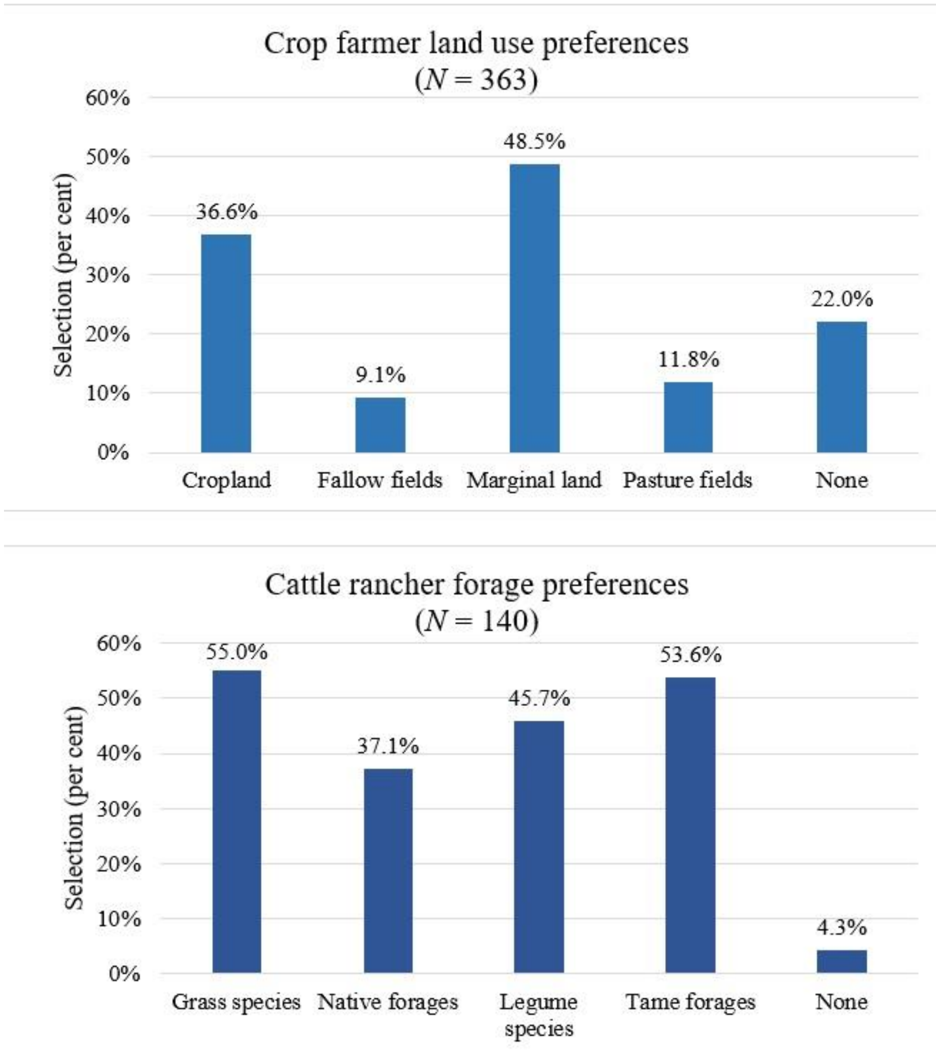


Figure 5.5 Openness to attempting new processes on various land bases amongst crop respondents (Top) and forage preferences amongst cattle respondents (Bottom)

Forty-eight percent of surveyed crop farmers feel comfortable experimenting, so to speak, with marginal lands, conducive to a farm business (economic) prioritization. Cropland, too, appears to be relatively open for new system introduction although, 22% feel as though none of the listed land types on their farm are suitable for anything other than their current processes. Those crop farmers unwilling to entertain the idea of new cropping systems regardless of land base are, unsurprisingly, less willing to entertain the ICLS scenario presented, which mimics the earlier sentiments of a necessary interest in integrated systems before their use.

Interestingly, tame forages are preferred by more respondents than native forages. Although a detailed discussion surrounding this trend extends beyond the scope of the project, tame species are generally perceived to be more reliable than native species, but less resilient in non-optimal growing conditions (Kilcher and Looman 1983; Kusler 2009; Peprah et al. 2018). The results shown in Figure 5.5 suggest that cattle ranchers overall are looking for diversity in their pasture mixes, as alluded by farmers opting for more than one type of forage. If these results are applicable to a much wider collection of farmers, then ICLS or, rather, the cover crop polycultures suggested in this research, is a stronger candidate to meet soil and grazing quality requirements for prairie agriculture than monocultures.

5.1 Scenario Results

The scenarios presented to farmers are generated to randomly assign each attribute value, however every respondent was tasked to answer the same question: given the information presented, are you interested in participating in an ICLS partnership with a neighbour? There is an even display of attribute levels across categories (i.e. *low* options were shown in approximately a third of the scenarios). Further, of the 243 possible scenarios that could have been created for each farmer type, there are observed 189 and 106 different combinations for crop and cattle producers, respectively. Therefore, although the pool of respondents is perhaps too low to adequately analyse every scenario, what is presented is representative of the average prairie farmer's perception toward the type of ICLS proposed throughout this project.

It may be worth noting that respondents did not have to definitively say 'Yes' or 'No' to participating in the hypothetical; an 'Unsure' option was also made available. However, this has sub-divided the dataset further past farm production types, into those confident and those still uncertain of personal ICLS practicality. A summary of these differences is displayed in Figure 5.6 and is indicative of the question set presented to each individual, not necessarily the type of farmer.

$$y = a_1 + b_1(area) + b_2(comm.) + b_3(savings) + b_4(est.costs) + b_5(payment_{in})$$

$$y = a_2 + b_6(herd) + b_2(comm.) + b_7(distance) + b_8(\Delta feed\ costs) + b_9(payment_{out})$$

CROP

Log Likelihood -186.6

$N = 363$	Coefficient	Standard Errors	
(Intercept)	-1.07	0.413	**
Area	0.0003	0.0015	
Commitment	-0.0066	0.0307	
Input savings	-0.0035	0.0022	
Establishment costs	0.0007	0.0018	
Payment received	0.0053	0.0036	

Certain

Log Likelihood -133.9

$N = 205$	Coefficient	Standard Errors
(Intercept)	-0.869	0.505
Area	0.0007	0.0018
Commitment	-0.0101	0.0378
Input savings	-0.0028	0.0028
Establishment costs	0.0004	0.0022
Payment received	0.0086	0.0044

Uncertain

Log Likelihood -246.8

$N = 363$	Coefficient	Standard Errors
(Intercept)	-0.408	0.365
Area	0.0001	0.0013
Commitment	0.0038	0.0273
Input savings	0.0034	0.0020
Establishment costs	-0.0007	0.0016
Payment received	0.0013	0.0032

CATTLE

Log Likelihood -81.9

$N = 140$	Coefficient	Standard Errors	
(Intercept)	0.641	0.559	
Herd size	-0.0055	0.0039	
Commitment	-0.0049	0.0460	
Field distance	0.0003	0.0060	
Feed cost change	-0.0123	0.0127	
Payment	-0.0137	0.0062	*

Certain

Log Likelihood -50.96

$N = 79$	Coefficient	Standard Errors	
(Intercept)	1.91	0.746	*
Herd size	-0.0083	0.0049	
Commitment	-0.0443	0.0584	
Field distance	-0.0066	0.0079	
Feed cost change	-0.0227	0.0164	
Payment	-0.0014	0.0078	

Uncertain

Log Likelihood -93.73

$N = 140$	Coefficient	Standard Errors
(Intercept)	-0.162	0.526
Herd size	0.0001	0.0036
Commitment	-0.0496	0.0442
Field distance	-0.0061	0.0057
Feed cost change	0.0006	0.0119
Payment	0.0068	0.0058

* $p \leq 0.10$
** $p \leq 0.05$

Figure 5.6 Summary of discrete choice experiment results

Note: from top to bottom, results represent the opinions of 'Yes' vs any other answer, 'Yes' vs. 'No' responses only, and 'Uncertain' vs any other answer. The regression equation for each farm type DCE is given at the top of the figure.

As observed, there is limited significance amongst any of the attributes, suggesting the most important determinants of ICLS participation lie outside of those presented to respondents. Given responses in the prior survey questions and the number of 'Unsure' answers, farmers likely rejected the scenario altogether. Rejection, here, does not only apply to the complexity and requirements of ICLS, but also to the specific relationships that farmers were asked to consider. Such a conclusion is strengthened by the number of

Further analysing the 120 respondents who accepted their scenario (Figure 5.6) reveals that 103 unique scenarios were accepted. The trends amongst these pools of producers are interesting, but ultimately insignificant, likely due to the sample size. Ideally, a more practical application of the ICLS program suggested in this thesis would allow producers to select their own attributes and establish their own partnership and performance contracts. Therefore, while the values presented here may be insignificant, it alludes to the necessity of farmer control for the implementation of novel production methods.

Throughout this survey, it is intended to convey that what is being asked is that farmers provide for the system either (cover) crop management or livestock management, but not both. Asking one farm to undertake responsibility for both pieces of the program contrasts the design of specialization, ultimately asking farmers to take over a system for which they are underprepared. For cattle producers, experience with cover cropping encourages ICLS adoption (de Souza Filho et al. 2021), although such does not appear to have the same degree of convincing for crop farmers with livestock experience. What became apparent in the comments, however, is that this intent was not adequately explained; forty comments explicitly said that their decision in the DCE was linked to them not owning cattle. The quantity of respondents with that opinion, however, perhaps hints towards an unspoken foundational requirement of ICLS which is a single operator for both aspects.

The trust factor may also play into this misunderstanding. In the scenario, farmers were forced to consider a neighbour business relationship, while responses to previous questions revealed such as a nonstarter. This hesitancy to work with others reveals a real gap in agricultural progress. By focussing investigative efforts on physical processes at the expense of socioeconomic factors, we miss these kinds of opportunities to strengthen the agricultural community. Building trust or, at the very least, working relationships between operations is paramount to opening the industry to unconventional innovations. For example, soil benefits and production stability means ICLS can be successfully competitive with more commercial processes. But, if operating ICLS alone is too onerous or daunting to implement, and farmers are unwilling to build the relationships necessary to take some of that management stress away, then there will be no mainstream adoption.

Chapter 6
Implications, Incentives, and Extensions

Arguably one of the major objectives of sustainability is the strive for network longevity, which sees flexibility in post-implementation support as needed as system independence strengthens (Bernet et al. 2006; McKenzie-Gopsill et al. 2022; Soubry and Sherren 2022). In Canada, a stereotypical farmer is one in a solo venture (Zimmerman et al. 2019), suggesting a level of productive and financial independence that is insurmountable in instances, as in grazing partnerships, where either the field or herd performances are impacted and the benefits are more indirect than marketable. The additional effort required (transaction costs) to ensure qualitive consistency with someone unfamiliar, the cost and responsibility of additional infrastructure (i.e. yardage, fencing, watering, reparations when necessary), inspecting field performance (especially if the field is of some distance away), the time and costs associated with cattle transportation, etc. may further signal that the 'integrated' component of ICLS is better equipped to be an intrapersonal one.

Institutional support broadly refers to the financial, social, and logistic resources from off-farm sources (i.e. banks, unions, insurance, extension etc.) that facilitate agricultural production and the specific goals of the farmer (Chapman et al. 2019). In regard to ICLS, wherein farmers are aware of the ecological and qualitative benefits often before implementation (and is likely a condition for ICLS adoption), the economic and market considerations can limit initial interest (Zimmerman et al. 2019; Liu and Brouwer 2022). Therefore, incentivization may improve the primary establishment (cost) hurdle if the required rate of compensation is determinable (Liu and Brouwer 2022).

Given the individualistic nature of program assessment (Pradhananga et al. 2017), subsidy determination relies on the complex network of market conditions and personal recognition of program features (Zimmerman et al. 2019). In cases where financial resources are needed for an extended period of time, promotion support is instrumental to successful innovation. An Ecuadorian paper exploring forest conservation trends in response to the institutional decision to freeze a five-year ecosystem service payment program found an additionality effect, and the degree of conservation relaxed (Etchart et al. 2020). Although these same farmers conserved Amazonian trees at a higher rate than farmers who had never received payments, the lack of incentive signalled the prioritization of landowner or business goals opposed to overall sustainability (Etchart et al. 2020).

A WTA valuation wherein the economic component is insufficient to convince participation, as is seen amongst the results presented in this thesis, perhaps signals an inappropriate scale at which the ICLS program was approached (Pradhananga et al. 2017). To clarify, Chapman et al. (2019) find that partial compensation is preferred to full compensation in instances where the conservation program infringes upon productive independence. In this sense, although support is a recognized requirement of adopting unconventional, lesser-known productive processes, the program design must also match where farmers believe intervention should be (Chapman et al. 2019). The DCE in this thesis may have had a similar design flaw, as the lack of significance amongst attributes suggests disinterest in the program and calculating a WTA estimate would subsequently be redundant. Therefore, one way to extend beyond a single economic value, in this case, is determining adoption hesitancy.

6.1 Zero Willingness to Accept

Recall Figure 3.3 and the discussion from Whittington et al. (2017) in 3.3 , which suggests a value kink at the reference point between alternatives. However, the kink point implies an instance where the status quo gives equal utility to the grazing program (i.e. where WTA is zero), instead of considering a set of acceptable and equivalent conditions (Villanueva et al. 2017; Whittington et al. 2017). When considering incentivization, a range of zero WTA conditions allows for the consideration of a range of compensation levels; the subsequent analysis of this lends itself to amassing the largest proportion of adoption (Villanueva et al. 2017). For example, there is a difference between a farmer who rejects ICLS because the payment is insufficient and a farmer who will always reject ICLS regardless of payment scheme (Kriström 1997; Villanueva et al. 2017).

Given the variability of production requirements, the theoretical solution to the productive maximization problem also varies. In this sense, there is no one defined vector of x_0 or x_1, and no promise of rational utility maximization (Villanueva et al. 2017), meaning it is possible for one of those input levels to be zero. Determining which responses are founded in rationality can subsequently be used to determine the minimum and maximum participation requirements (Kriström 1997). According to the spike model (summarized below from Kriström 1997), the inclusion of the post-experiment comment option, wherein respondents could indicate the strongest proponent of their *Yes*, *No*, or *Unsure* response, lends itself well to determining the marginal difference of acceptance (Kriström 1997).

Assume that the probability an individual will accept the compensation payment included within the DCE (j) is given by $h(j) = prob(WTA \leq j)$, where $prob(.)$ signals some probability function. Here, the value of compensation an individual is willing to accept is at most j, indicating that the payment is appropriately assigned, if not over-compensatory. The distribution of continuous probability function, $h(.)$, as adapted from Kriström (1997), is given in (2.7):

$$\begin{aligned} h(j) = F(j) \;\; & if\; j > 0 \\ k^{-} \;\; & if\; j \rightarrow 0^{-} \\ k^{+} \;\; & if\; j \rightarrow 0^{+} \\ G(j) \;\; & if\; j < 0 \end{aligned} \tag{2.7}$$

where $F(.)$ and $G(.)$ are WTA functions which, as j approaches zero, so, too, does the individual's likelihood of adoption. The limit for $h(j)$ is represented by $0 < k < 1$ such that each acceptance function approaches zero along with the compensation. It is important to note that j is a received monetary value, and therefore a negative j is indicative of an outgoing payment. The distribution of k therefore informs of the "spike" condition, or the range of payment values in which WTA is zero because of either indifference between scenarios or corner solutions in ICLS adoption (Kriström 1997). Zero acceptance only informs that the status quo is preferred, but it does not give insight into why preference exists nor whether that preference is based on internal or external state factors. The modelling considerations that would need tailoring are outlined in Villanueva et al. (2017) and applied here.

An additional consideration posited by Villanueva et al. (2017) is the inclusion of multiple error estimates in the generic, linear-in-parameters scenario utility function (2.8):

$$U_y = \boldsymbol{\beta z} + e_y + \vartheta_y \tag{2.8}$$

where $\boldsymbol{\beta}$ is the associated vector of parameters, $\boldsymbol{z}$ is the complete vector of attributes (both nonmonetary and monetary attributes), e is the random choice-independent error term, and ϑ is the normally distributed scenario error term. Although both error terms capture the unobserved reasons for ICLS rejection, ϑ is more representative of the specific errors that create inequality between ICLS and the status quo (i.e. production requirements).

However, the problem with this addition to the random utility theory is that determining WTA can only ever be approximate and achieved through repeated simulation (Villanueva et al. 2017). This is another reason why the DCE designed in this thesis is incompatible with more thorough rejection analyses; the lack of significance in attributes suggests DCE repetition to gain insight into decision-making and the acceptable range of attribute values (Kriström 1997). Without understanding where or why hesitation exists, everything outside of the specific attributes mentioned in the experiment are considered barriers to adoption (Villanueva et al. 2017).

As previously mentioned, the survey sent to farmers included the opportunity for respondents to state decision determinants, summarised in Table 6.1 below. Villanueva et al. (2017) recommend removing any responses that fall within the top four categories of Table 6.1 (labelled with an asterisk) to determine a true WTA. A true WTA response is one that rejects the ICLS partnership scenario itself based on the program criteria presented to that individual; the alternative response would be one of rejection simply in favor of higher payment than offered in the experiment (Villaneuva et al. 2017).

Table 6.1 Number of mentions for each category based on rejection response

	Crop mentions		**Cattle mentions**	
	No	**Unsure**	**No**	**Unsure**
Total responses	127	158	37	61
Lack of (scheme) believability*	5	2	1	1
Institutional (or partner) mis-/distrust*	2	4	1	3
Lack of information/understanding*	9	14	2	2
Lack of control*	0	0	1	0
Disinterest	5	7	0	0
Physical (land) concerns	13	30	12	14
Economic concerns	18	28	9	10
Managerial/workload concerns	8	20	0	3

**Source: Villanueva et al. (2017)*
Note: number of mentions does not refer to number of separate comments, as some participants listed more than one decision determinant.

It should be noted that the elicitation method used by Villanueva et al. (2017) presented respondents with multiple experiments, in order to segregate rejection into non-participants and high-value adopters. The sample size available in this DCE is incompatible with response removal partially due to the single incentive scenario presented to each respondent. In doing so, participants are indirectly giving a single WTA value rather than a (perhaps more realistic) range of acceptable values. To achieve a more accurate range, amassing responses to more if not all possible scenario combinations as well as individual repetition, this survey could be adapted to repeat the DCE with a different randomization of the attribute values. The resulting WTA estimate may indicate how involved policy can be used in ICLS adoption and implementation whereas this research concludes, at least through the use of an incentivised partnership between two assured but unacquainted farmers, policy inclusion would be redundant.

More extensive spike test analyses could be possible with an extension of the ICLS DCE (e.g. farmers could be presented with scenarios of varying attribute extremes in order to determine if the program is rejected or just the attribute levels presented). A major assumption of the question presented in this thesis is that a "No" response rejects the program whereas an "Unsure" response rejects the (internal or external) program attributes; Kriström (1997) suggests this is an overestimation of acceptance. To clarify, just because an individual feels constrained by "Yes", "No", or "Unsure", does not mean their response is representative of their true feelings (Kriström 1997). The financial and incentive system must therefore be complementary of the social and institutional structures already available, since it is the combination of the two that creates system confidence.

6.2 Realism in Government Incentivization

While adoption is relatively low in the Prairies, the recognition of cover cropping as a beneficial management practice has improved agronomic and government involvement on farm (Morrison 2021). In early 2022, the recipients of the combined $183 million from the *On-Farm Climate Action Fund* were announced to encourage the implementation of three target best management practices (Government of Canada 2022a). Of those, approximately a quarter of the programs explicitly mention the education or adoption of cover crops, and two of those are applicable to Saskatchewan (Government of Canada 2022a). While this cluster of grants is a positive improvement to the years of absence following the expiration of similar federal programs such as *Greencover Canada* in 2009 and *Cover Crop Protection Program* in 2011 (Government of Canada

2022b), the majority of government involvement in cover crop compensation is done so provincially with farm stewardship programs (Government of Alberta 2022b; Government of Manitoba 2022a; Government of Saskatchewan 2022a).

Cattle ranchers are able to rely on external means of financial aid, as well. Ducks Unlimited Canada, for instance, offers support to Prairie farmers wishing to convert land into forage resources (Ducks Unlimited Canada 2022). Across public and private resources, it appears as though converting grassland to be grazing compatible (which may include cover crop information but does not directly prioritize cover crops) is a much easier venture for beef ranchers than crop farmers. Of the producers who do implement cover crops in Canada, over half also raise beef cattle, and slightly less than that use direct grazing for termination (Morrison 2021; Morrison and Lawley 2021). As is corroborated by the portion of cattle responses completed by mixed farmers, such may be the reality of ICLS adoption: cattle ranchers are more inclined to adopt cover crops as a forage source than crop producers are to use cover crops for soil improvements.

However, physical investigation of cover crop grazing and subsequent annual crop growth is a relatively novel area of research. Programs such as *Living Laboratories Initiatives* and *Results Driven Agriculture Research* utilize government funding to directly test and communicate the agri-environmental performance of various agricultural practices (Government of Canada 2021b; Government of Canada 2022a). However, there needs to also be interest from farmers such that available resources can be realised. The sporadicity of funding and support availability represents both a challenge for ICLS mainstreaming and an opportunity to improve the overarching communication and information channels in the agriculture network.

6.3 Agricultural Support Systems

The decision to adopt unconventional methods is founded on a combination of objective and personal reasonings, representing logistic and behavioural facets, respectively (Abagandura et al. 2017). Similarly, intrapersonal identification of altruistic responsibility and productive goals signal which methods can be feasibly implemented; the decision-making process, therefore, is more indicative of value prioritization opposed to the system (Pradhananga et al. 2017). As this thesis suggests, and as corroborated by literature, the surrounding operational environment (i.e.

institutional, financial, and social supports) can influence ICLS confidence as strongly as performance measures (Files and Smith 2001; de Souza Filho et al. 2021). Without these structural encouragements to adoption, the decision to apply integrated systems is entirely individualistic, culminating in pockets of interested communities rather than more mainstreamed implementation (Thiessen Martens et al. 2015).

It is suggested that a serious player in the innovation landscape (opposed to an interested player) is one with "exploitable" and "explorable" opportunities (Quintero et al. 2022), but how can these types of players be identified and welcomed into the discussion when the opportunities are unknown? The title *innovative* assumes knowledge intake from technical (extension) and social (stakeholder) sources, the culmination ultimately strengthening the relationship between local and commercial markets (Garbach and Morgan 2017). The open-ended opportunity to express where decision-making concerns or determinants lie (Table 6.2) reveals that technical and social reasons dominate scenario adoption acceptance.

Table 6.2 Common themes present throughout respondent comments

	Crop farmer	**Cattle rancher**
Total number of comments	320	117
– scenario accepted	66	35
– scenario rejected	110	34
– unsure of scenario	144	48

"Please indicate which attribute(s), if any, has the greatest influence on your decision to (not) adopt integrated systems"

Category	**Key terms**	**Number of mentions**	
		Crop set	***Cattle set***
ICLS (and mechanism) experience	currently use; have used; tried in the past	23	10
Lack of ICLS familiarity	'don't understand'; 'never heard of it'; no awareness; no information; no experience	41	6
No livestock	don't have cattle; no cattle nearby;	46	-
Environmental Pillar			
ICLS (and mechanism) praise or interest	complimentary comments; 'good idea'; 'makes sense'; solution	22	6
Performance doubt	results objection; feed quality concerns; yield concerns	11	13
Production efficiency	efficient; input allocation; land allocation/use; productivity; system sustainability	59	35
Economical Pillar			
Economic concerns	cost; economics; profit(ability)	41	23

Economic praise	economics; revenue; savings;	10	8
Social Pillar			
Partnership concern	inequality; neighbour problem; neighbour willingness; trust; [lost control/decision making]	16	5 [+3]
Social circle dependence	family; friends; know someone who has used ICLS; word of mouth	6	4
Technological Pillar			
(Human) capital concerns	age; equipment; labour; machinery; [cattle infrastructure]	30 [+6]	7
On-farm objection (individualized)	'currently productive'; 'bad area'; 'doesn't work for us'; 'not a good fit'	28	2

Note: since respondents were able to list multiple attributes to justify their scenario response, the values representing 'Mentions' is not equal to the number of comments.

Values in square brackets correspond to the keyword in square brackets, which highlight interesting farm-type specific concerns that were not mentioned by the other group.

What is clear from the comments is that factors of decision-making were not confined to the few given in the hypothetical scenario. It should also be noted that just because a farmer rejected their DCE does not guarantee their comments expressed negative opinions towards ICLS (and vice versa). Therefore, the discussion surrounding ICLS acceptance or rejection throughout this thesis is fragile, and perhaps more indicative of the way in which the ICLS partnership is presented rather than true feelings towards the system. This partnership rejection can be further evidenced by the number of crop farmers who listed the absence of cattle and associated infrastructure (i.e. fencing) on their farm and in the surrounding area, a portion of whom accepted their DCE.

Across both producer types, concerns over productive and economic performance dominate, which made up the majority of DCE hypothetical attributes. Particularly in reference to the capital and efficiency issues, cattle ranchers appear more comfortable with changes to both, likely a consequence of mixed farmers making up the majority of cattle responses. Cattle ranchers also introduced a novel subset of partnership concerns: the feeling of losing some decision-making capacity. The comments overall, however, suggest little consideration of the social facets of an ICLS partnership; while this could be interpreted as comfort towards sharing the workload with neighbour, the number of crop producers using the lack of cattle on farm or in the area as a reason for ICLS decision making suggests that the partnership was not a real or clear condition to participants.

The sociology of adoption communication is such that the most successful innovators – the early-adopting farmers – have a larger, more diverse network of established social resources than those who adopt later in the commercial life cycle (Garbach and Morgan 2017). As technology and market capacity evolves in the agricultural innovation plane, the necessity for smoothly operating communication channels cannot be understated (Pigford et al. 2018). When ecosystem services are involved, it is frequently recommended that the insertion of new processes be evaluated with a broad range of players involved, in the pursuit of balancing economic and environmental trade-offs (Kołoszko-Chomentowska 2016; Pigford et al. 2018). Integrated considerations traditionally overlooked in solo planning like structural limitations and responsibility jurisdiction, are now more informative pieces of system viability and, in later stages of adoption, market readiness (Iiyama et al. 2018; Pigford et al. 2018). Therefore, these types of holistic frameworks focus less on reaching a target (i.e. mainstream adoption) and instead strive to improve the way in which information and technology is transferred (Quintero et al. 2022).

This thesis has discussed in length the implications of uncertainty in innovation risk perception and unfortunately, that uncertainty also applies to the operational environment. Especially in the case of ICLS, which tends to follow regenerative principles of production such as the prioritization of soil advancements opposed to those for yield, the variability of outcomes further deters participation in favour of reliability (Brandt et al. 2010; LaCanne and Lundgren 2018). Demonstration plots may improve uptake, as they provide peer-learning as well as observed regional success (Cook 2018). Theoretical results can be advantageous in the planning phases of implementation, but accessibility to examples may clarify operational success, particularly given the variation of (ecological and technological) efficiency (Iiyama et al. 2018; Chavas and Nauges 2020). Further, in an investigation of input changes in Tanzanian agro-communities, demonstration plots provide tangible outcomes of suggested processes and facilitate community building (Sseguya et al. 2021). Farmer knowledge is ultimately a culmination of various innovations that help inform production, tasking new techniques and relationships to compliment pre-existing skills and standards (Quintero et al. 2022). Demonstrations can clearly exhibit complementary traits of the process while also reducing the gap between knowledge and implementation (Jaeck et al. 2014; Garbach and Morgan 2017; Iiyama et al. 2018; Zimmerman et al. 2019).

However, the surrounding social conditions of farm decision making have been minimally explored, which has allowed firm rooting of these social hurdles in the innovation landscape (Abagandura et al. 2017). Network restructuring, as suggested in Roesch-Mcnally et al. (2018), is important for improving innovation adoption and one such way is through establishing participatory market chain foundations. A participatory market chain approach is a tool that stimulates information sharing and agency feedback, as well as the conversations necessary to progress from interest to implementation (Bernet et al. 2006; Wisudayati et al. 2021). Kansanga et al. (2021) posit something similar on a more local scale, which would rely on horizontal peer-learning to provide instant system performance feedback. Opting for these types of information networks, wherein farmers are involved with neighbours and their operations, allows farmers to locally drive agricultural trends (Krah et al. 2019; Zheng et al. 2021). It is a framework for complete discussion, in that all players in the market, including those with traditionally minor influence, can improve the environment in which future innovations will enter (Wisudayati et al. 2021).

Using this research as an example, the investigation of producer opinions (interest determination) of ICLS would precede the planning phase of a project, as it would determine whether ICLS is viable for that individual. The planning phase, itself, would use more of the farm specific data, assessing what conditions of ICLS would need to be implemented for successful operation. The grazing program scenario subsequently presented could serve as both the execution and performance monitoring steps of management since the hypothetical includes details of the end product despite farmers not actually participating. The missing component – the relationship building – is vital for innovative success, as it links theoretical interest with evolving program requirements. By expediting the introduction phase between farmer and system or farmer and farmer, the social environment becomes a tool for input lending, market innovation, trust-building, and information symmetry (Roesch-Mcnally et al. 2018; Chavas and Nauges 2020; Sseguya et al. 2021). Consequently, without system harmonisation or communication, unconventional processes simply cannot compete with the current agricultural environment (Jaeck et al. 2014; Liu and Brouwer 2022).

6.4 Concluding Remarks

The practical landscape for integrated systems in Canadian prairie rotations is encouraging for sustainability goals. The field trials suggest physical ICLS plausibility in prairie conditions, however recreation of similar multi-discipline trials is vital for establishing performance certainty and associated confidence in the system as a whole. Complementary, survey results suggest that there is an interest in integrated systems among producers, although this interest is conditional. Beyond the observation that cover crops are opportunistically perceived and used by cattle ranchers whereas crop producers are hesitant to livestock inclusion, aspects of and motivations for integrated systems are embraced by farmers even though ICLS, specifically, is not. (A reminder that the promotion of ICLS is in and of itself conditional, given that the suitability of the system to the farm is independent of the farmer's decision to adopt.)

The survey also suggests that the indirect benefits of implementing ICLS with a neighbour opposed to alone (i.e. surpassing the learning curve; maintained technical efficiency; resource proximity) do not adequately compensate personal concerns. The social structure of Canadian agriculture, specifically, appears to impact the innovation environment much more strongly than originally hypothesized, which affects the ways ICLS is supported. Therefore, the introduction of robust communication networks will improve the social environment into which integrated innovations enter for the sake of feasibility assessments and, potentially, adoption. If integrated systems are to be the market-competitive sustainability solutions for agricultural problems implied by research and early-adopters, then trust between stakeholders and external information sources needs to be structurally sound enough to support commercial progression and adoption.

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APPENDIX A – Survey questions (excluding demographic questions)

Filtering questions

1. When it comes to crop-livestock production decisions on your farm/ranch, are you one of the primary decision-makers?

[YES / NO]

2. In which province are you located?

[ALBERTA / SASKATCHEWAN / MANITOBA / OTHER]

3. Do you grow crops, raise livestock, or both? (*select all that apply*)

[GROW CROPS / RAISE LIVESTOCK / NEITHER]

4. ***If*** *response to Q3 is "Grow crops"*: How many acres is your farm operation?

[LESS THAN 500 ACRES / 500 TO JUST UNDER 1,000 ACRES / 1,000 TO JUST UNDER 1,500 ACRES / 1,500 TO JUST UNDER 2,000 ACRES / 2,000 ACRES OR MORE]

5. ***If*** *response to Q3 is "Raise livestock"*: How many heads of cattle do you have?

[LESS THAN 100 / 100 TO JUST UNDER 200 / 200 TO JUST UNDER 300 / 300 TO JUST UNDER 500 / 500 OR MORE]

Thank and terminate IF:	- Response to Q1 is "*No*" - Response to Q2 is "*Other*" - Response to Q3 is "*Neither*" - Q3 is only *"Grow crops"* AND Q4 is *"Less than 500 acres"* - Q3 is only *"Raise livestock"* AND Q5 is *"Less than 100 head"* - Response to Q3 is both *"Grow crops"* and *"Raise livestock"* AND Q4 is *"Less than 500 acres"* AND Q5 is *"Less than 100 head"*

Farm practices and information

6. Please rate how much you agree or disagree with the following statements:

[STRONGLY DISAGREE / DISAGREE / SOMEWHAT DISAGREE / NEUTRAL / SOMEWHAT AGREE / AGREE / STRONGLY AGREE]

a) Sustainability is of growing concern on my farm
b) The market competitiveness of my farm needs to be improved
c) I am satisfied with my farm's productivity
d) I am willing to work with other farmers if it can improve my own farm
e) Environmental changes are a growing concern on my farm
f) When it comes to farm decisions, I tend to choose methods similar to what was done the year before

e) Regenerative farming practices are a good solution to many agricultural issues
f) Maintaining and improving soil quality on my farm is a priority

7. When it comes to farming practices that are new to your farm, how much do you trust the following sources of information?

[COMPLETELY TRUST / SOMEWHAT TRUST / NEUTRAL /
SOMEWHAT DISTRUST / COMPLETELY DISTRUST]

a) Family/friends
b) Neighbouring farmers
c) Extension agents
d) Industry professionals
e) University researchers

An integrated crop-livestock system refers to a farm that incorporates both crop and livestock production on the same land. For example: grazing annual forage crops, use of crop residues for feed, manure application to cropland, land swapping with other farmers, etc.

8. How familiar are you with integrated farming?

[NOT AT ALL FAMILIAR / SLIGHTLY FAMILIAR / SOMEWHAT FAMILIAR /
MODERATELY FAMILIAR / EXTREMELY FAMILIAR]

9. Within the last 15 years, has your farm ever used integrated methods?

[NO, AND HAVE NOT CONSIDERED / NO, BUT WE HAVE CONSIDERED
INTEGRATED SYSTEMS / YES, IN THE PAST / YES, CURRENTLY]

10. Do you have a personal connection (i.e. family member, friend, neighbour) to anyone who has found success with integrated systems?

[YES / NO / NOT SURE]

11. Would you be willing to enter a business partnership for integrated farming with a farmer you don't personally know?

[NOT UNDER ANY CIRCUMSTANCE / YES, IF THEY HAVE ASSURANCE FROM AN EXTENSION
AGENT / YES, IF WE SHARE A MUTUAL CONNECTION (i.e. FAMILY,
NEIGHBOUR, FRIEND, FAMILY) / YES, IF WE SHARE MUTUAL GOALS /
YES, IF I RECEIVE PAYMENT FOR THE PARTNERSHIP / NOT SURE]

Cover cropping refers to the planting of non-market crops (i.e. ryegrass, radish, vetch, clover, field peas, etc.) between cash crop growing periods. These crops are largely employed to improve soil health but can additionally be used as a forage resource for cattle.

12. How familiar are you with cover cropping?

[NOT AT ALL FAMILIAR / SLIGHTLY FAMILIAR / SOMEWHAT FAMILIAR /
MODERATELY FAMILIAR / EXTREMELY FAMILIAR]

“Primarily crops” [Q3] Stream

13. Within the last 15 years, has your farm ever grown cover crops?

[NO, AND HAVE NOT CONSIDERED / NO, BUT WE HAVE CONSIDERED COVER CROPS / YES, IN THE PAST / YES, CURRENTLY]

14. On which of the following land base, if any, would you be willing to try a new cropping system? *Please select all that apply*

[CROPLAND / FALLOW FIELDS / MARGINAL LAND / PASTURE FIELDS / NONE OF THE ABOVE]

15. How comfortable would you be with outsourcing labour requirements for your farm?

[VERY COMFORTABLE / COMFORTABLE / NEUTRAL / UNCOMFORTABLE / VERY UNCOMFORTABLE]

16. How open are you to allowing cattle to graze on your farm? (not including your own cattle *if mixed farm*) [WOULD NOT CONSIDER / MIGHT CONSIDER / WILL CONSIDER]

17. Are you aware of any livestock operations within 60km of your farm? (not including your own *if mixed farm*) [YES / NO / UNSURE]

Discrete Choice Experiment (crop farmers)

18. Would you be interested in seeding cover crops to facilitate a crop-livestock integrated grazing program with the following benefits and required commitments?

a) Area of your cover crops that a neighbour’s cattle would graze in	*(40 acres / 80 acres / 160 acres)*
b) Program commitment	*(2 years / 4 years / 8 years)*
c) Input cost savings from grazed cover crops	*($20 per acre / $50 per acre / $100 per acre)*
d) Cost of cover crop implementation	*($50 per acre / $100 per acre / $150 per acre)*
e) Payment received	*($50 per acre / $75 per acre / $100 per acre)*
f) *Your average yield per acre on the crop seeded after the cover crop remains unchanged* *Observable weed reduction will occur within two years*	

[YES / NO / NOT SURE]

“Primarily cattle” [Q3] Stream

13. Are you aware of any farms using cover crops within 60km of your farm?

[YES / NO / UNSURE]

14. Which of the following, if any, is your preferred forage type? *Please select all that apply*

[GRASS SPECIES / NATIVE FORAGES / LEGUME SPECIES /
TAME FORAGES / NONE OF THE ABOVE]

15. How comfortable would you be engaging in a project that increases your weekly labour requirements?

[VERY COMFORTABLE / COMFORTABLE / NEUTRAL /
UNCOMFORTABLE / VERY UNCOMFORTABLE]

16. How comfortable are you with hiring outside labour for your farm?

[VERY COMFORTABLE / COMFORTABLE / NEUTRAL /
UNCOMFORTABLE / VERY UNCOMFORTABLE]

17. Within the last 15 years, has your farm ever participated in a grazing program with another farmer?

[NO, AND HAVE NOT CONSIDERED / NO, BUT WE HAVE CONSIDERED GRAZING PROGRAMS / YES, IN THE PAST / YES, CURRENTLY]

Discrete Choice Experiment (cattle ranchers)

18. Would you be interested in a crop-livestock integrated grazing program with the following benefits and required commitments?

a) Head of cattle to commit to graze in a neighbour's cover cropped field	*(25 head / 50 head / 95 head)*
b) Distance to grazing field	*(5 km or less / 20 km or less / 50 km or less)*
c) Program commitment	*(2 years / 4 years / 8 years)*
d) Change in feed costs	*(20% lower than before the program / Same as before the program / 20% more than before the program)*
e) Required payment to landowner for full grazing season	*($30 per head / $50 per head / $75 per head)*
f) *Average herd weight remains unchanged*	

[YES / NO / UNSURE]

APPENDIX B – A comparison of income statements for the typical farm and the best/worst random attribute combinations from the DCE

Crop Farmers – Canola production

($/ac unless otherwise specified)			**Baseline scenario**		**Worst-case scenario**		**Best-case scenario**
Target yield	*bu/ac*		42.33		42.33		42.33
Est. farm gate price		$	17.01	$	17.01	$	17.01
Pasture rental income		$	-	$	50.00	$	100.00
Est. gross revenue		$	20.03	$	770.03	$	820.03
Seed (and treatments)		$	84.73	$	150.00	$	50.00
Fertilizer (N, P, S)		$	167.33	$	147.33	$	67.33
Chemicals		$	60.70	$	60.70	$	60.70
Machinery – fuel		$	12.97	$	12.97	$	12.97
Machinery – repair		$	8.85	$	8.85	$	8.85
Crop insurance premium		$	13.09	$	13.09	$	13.09
Utilities/miscellaneous		$	3.23	$	3.23	$	3.23
Labour		$	21.05	$	21.05	$	21.05
Interest expense		$	7.71	$	7.71	$	7.71
Total variable expenses		$	379.66	$	424.93	$	244.93
Total other expenses		$	92.92	$	92.92	$	92.92
Total expenses		$	472.58	$	517.85	$	337.85
Production size	*ac*		100		40		160
Program income position	*profit (loss)*	$	24,745.33	$	10,087.33	$	77,149.33

ASSUMPTIONS

Baseline (Government of Saskatchewan 2022b)	Worst-case (DCE attributes)	Best-case (DCE attributes)
– Brown soil zone – 5lbs/ac seeding rate – 89 lbs/ac N – 48 lbs/ac P_2O_5 – 15 lbs/ac S – Management costs are not included in *Labour*	– $150/ac to establish cover crops – Save $20/ac on fertilizer – Must commit 40 acres – Receive $50/ac for rent	– $50/ac to establish cover crops – Save $100/ac on fertilizer – Must commit 160 acres – Receive $100/ac for rent

Cattle ranchers – Grassing steers

($/hd unless otherwise specified)		**Baseline scenario**	**Worst-case scenario**	**Best-case scenario**
Target weight	*lbs*	1,000	1,000	1,000
Feeder selling price		$ 220.00	$ 220.00	$ 220.00
Est. gross revenue		$ 2,200.00	$ 2,200.00	$ 2,200.00
Total feed costs (feedlot)		$ 108.40	$ 130.08	$ 86.72
Feeder cost (800lb steer @ $230/cwt)		$ 1,858.34	$ 1,852.54	$ 1,849.72
Yardage		$ 44.00	$ 44.00	$ 44.00
Rented pasture		$ 51.00	$ 75.00	$ 30.00
Pasture checking		$ 8.00	$ 8.42	$ 32.00
Veterinary (supplies)		$ 16.25	$ 16.25	$ 16.25
Cattle insurance		$ 4.39	$ 4.41	$ 5.84
Selling cost		$ 89.24	$ 83.44	$ 80.62
Death loss		$ 30.24	$ 30.20	$ 30.18
Interest expenses		$ 36.78	$ 37.04	$ 36.39
Total operating costs		$ 2,246.65	$ 2,281.38	$ 2,211.73
Labour		$ 21.00	$ 22.11	$ 84.00
Total expenses		$ 2,267.65	$ 2,303.48	$ 2,295.73
Production size	*hd*	100	95	25
Program income position	*profit (loss)*	($ 6,764.81)	($ 9,830.95)	($ 2,393.13)

ASSUMPTIONS

Baseline (Government of Manitoba 2022b)	Worst-case (DCE attributes)	Best-case (DCE attributes)
– 120 days fed → 60 days on feedlot; 60 days on pasture – Pasture is 120km away from farm/feedlot – Purchase 800 lbs steers at $230/cwt – Sell 1,000 lbs steers at $220/cwt – Net average 1.67 lbs/hd daily gain – 1.5% mortality rate – $5.75/cwt livestock price insurance premium – 54,000 lbs/load truck capacity – $25/hr wage (Management costs are not included in *Labour*)	– Additional 20% in feed costs – Pasture is 50km away from farm/feedlot – Pasture rent is $75/hd for the full 60 days – Must commit 95 steers	– Save 20% in feed costs – Pasture is 5km away from farm/feedlot – Pasture rent is $30/hd for the full 60 days – Must commit 25 steers

APPENDIX C – Trial seeding data for the simple and complex cover crop grazing treatments (*Top*) and the annual crop production control (*Bottom*)

Treatment Seeding	**2019**						**2021**					
	Simple mix			**Complex mix**			**Simple mix**			**Complex mix**		
	Seeding rate *lbs/ac*	Seeding costs *$/ac*	Post-graze biomass *kg/ha*	Seeding rate *lbs/ac*	Seeding costs *$/ac*	Post-graze biomass *kg/ha*	Seeding rate *lbs/ac*	Seeding costs *$/ac*	Post-graze biomass *kg/ha*	Seeding rate *lbs/ac*	Seeding costs *$/ac*	Post-graze biomass *kg/ha*
Treatment total	-	$25.82	41,046.0	-	$120.11	42,478.8	-	$25.82	24,717.8	-	$120.39	28,012.5
Barley				13.89	$2.50					13.89	$2.78	
Millet				1.12	$2.07	28,182.5				1.12	$2.07	8,789.5
Oats	33.68	$9.09	31,633.2	10.11	$88.42		33.68	$9.09	6,832.3	10.11	$88.42	
Peas	69.70	$16.73	5,474.2	20.91	$5.02	1,904.0	69.70	$16.73	4,110.7	20.91	$5.02	893.9
Hairy vetch				3.75	$13.13					3.75	$13.13	
Brassica				0.62	$3.40	9,544.7				0.62	$3.40	4,552.4
Radish				1.60	$4.79					1.60	$4.79	
Phacelia				0.20	$0.79	422.2				0.20	$0.79	423.7

Annual Crop Production (Experimental Control)		**2019**	**2020**	**2021**
Annual crop species		Yellow peas	Forage barley	Canola
Seeding rate	*lbs/ac*	200.0	95.0	5.0
Seeding costs	*$/ac*	$40.00	$18.05	$65.00
Average yield	*kg/ha*	2,105.1	n/a	401.6
Average 250 kernel weight	*g*	47.1	n/a	0.9
Total crop biomass on previously ungrazed field	*kg/ha*	18,945.9	221,578.7	n/a
Total crop biomass on previously grazed field	*kg/ha*	n/a	129,421.3	22,574.6