AGRICULTURAL BEST MANAGEMENT PRACTICES

A summary of adoption behaviour

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Background Information

Agricultural productivity is essential to meet food demands as the global population increases. Conversely, intensive farming and unsustainable agricultural practices including excessive fertilizer and irrigation use, over-grazing, and monoculture production used to increase agricultural productivity are resource-intensive and contribute to global environmental problems (Harrison & Hester, 2012). These problems include climate variability and change from greenhouse gas emissions, deforestation and biodiversity loss from converting forests to crop and pasture land, soil degradation from the loss of organic matter and soil fertility due to erosion, and water pollution from the overapplication of pesticides and fertilizers causing eutrophication (German et al., 2017). The global continuation of unsustainable agricultural practices will damage natural ecosystems impairing the ability to produce food and obtain essential ecosystem services vital to the future functioning of society (German et al., 2017). Therefore, to achieve long-term food security and maintain the economic and social viability of agricultural production it is necessary to consider the environmental sustainability of agriculture. Best management practices (BMPs) are an approach to improve agricultural sustainability by encouraging producers to conserve soil and water resources, protect agricultural land and mitigate the release of agricultural pollutants without sacrificing productivity (Ontario Ministry of Agriculture, Food and Rural Affairs [OMAFRA], 2020). BMPs are developed by researchers and professionals in agricultural business for producers to voluntarily adopt.

Globally, agricultural operations are diverse across different climates, countries, and cultures making it difficult to develop universal BMPs and enforce adoption. The voluntary adoption of BMPs supports the unique conditions that exist across agricultural operations allowing producers to take responsibility towards adopting the appropriate BMPs. To support producers in the voluntary adoption of BMPs, policymakers have developed various financial incentives and education programs. For example, the Canadian Agricultural Partnership is a federal-provincial-territorial government investment to support cost-share funding, business risk management programs, and educational activities such as workshops and online learning (Government of Canada, 2019). Specifically, the Canada-Ontario Environmental Farm Plan encourages the adoption of BMPs by providing voluntary environmental education and awareness programs (OMAFRA, 2019). Regardless of the BMP awareness initiatives, educational programs, and financial incentives, the decision to adopt a BMP is ultimately up to the producer. Therefore, achieving widespread BMP adoption depends on the collective action of individual producer's management decisions. To determine the extent of BMP adoption in Canada, MacKay et al. (2010) develop a BMP adoption index that calculates a score based on the number of BMPs implemented ranked according to

the level of environmental benefit. The average BMP adoption score for producers across Canada is between 25-40% (MacKay et al., 2010). This score indicates that Canadian producers are achieving a good level of BMP adoption with the highest individual BMP score being 71% across all producers in Canada (MacKay et al., 2010). However, there is still an opportunity for Canadian producers to increase the adoption of BMPs. The study of preferences and decision-making can provide insight to understand and improve the adoption of BMPs. Furthermore, the application of behavioural economics to study BMP adoption behaviour is a valuable approach towards improving policy and effectively increasing the adoption of BMPs.

The challenge with addressing environmental issues in agriculture is producers have conflicting interests towards environmental sustainability and often behave in their self-interest creating a collective action problem that limits social efficiency (Palm-Forster et al., 2019). The voluntary adoption of BMPs, decentralizes decision-making giving producers the authority to make decisions about BMP adoption and determine what is best for their operations based on local conditions (Clement, 2009). A producer behaving in self-interest will seek to enhance productivity and increase profit without accounting the negative externalities that impact society from unsustainable agricultural production (Lefebvre, 2015). The adoption of BMPs supports the provision of environmental benefits such as improving air, soil, and water quality as a positive externality (Lefebvre, 2015). In general, positive externalities lead to the under-provision of a public good because adoption is suboptimal when the benefit to society is not considered (Palm-Forster et al., 2019). Given the positive externalities BMP adoption has for society, the authority producers have to make decentralized decisions about BMP adoption has implications beyond outcomes at the farm operation level (Clement, 2009). Therefore, it is important to understand the behavioural factors that influence producer decision-making. Experimental and behavioural economics are useful tools for studying BMP adoption because they can directly measure individual preferences and establish a causal link between behavioural factors and decision-making (Dessart, 2019). The majority of existing BMP adoption research uses empirical approaches analyzing producer data from surveys or interviews and report correlational evidence that can be subject to biases including self-reported measures for adoption behaviour (Dessart, 2019). Lab experiments with producers have better control, reducing biases with the use of randomized controlled trials to identify causal relationships between behavioural factors and decision-making (Dessart, 2019). Therefore, experimental, and behavioural economics can add value to the existing body of research on BMP adoption with the ability to experimentally manipulate behavioural factors identified in the literature (Palm-Forster et al., 2019). Behavioural experiments use approaches such as nudges, social norms, and framing to adapt policy scenarios and determine outcomes

for adoption behaviour (Dessart, 2019). The application of behavioural and experimental economics offers a valuable approach to motivate behavioural change supporting the adoption of BMPs and the provision of environmental benefits as a public good for society.

The following summary includes six sections that review the BMP adoption literature including the theoretical framework, major themes, BMP characteristics, industry trends, policy implications, and research opportunities. The first section will introduce behavioural theories relevant to the study of BMP adoption used to understand producer decision-making. The objective of section one is to outline the theoretical foundation used to establish data collection and empirical analysis methods applied in the BMP adoption literature. Section two will introduce variables that influence producer decision-making used to empirically estimate and predict the adoption of BMPs. To summarize positive and negative determinants for BMP adoption and identify themes and inconsistencies in the literature. The third section will introduce BMP characteristics that influence the frequency of adoption including differences in BMP profitability, observability, and complexity. The objective of section three is to summarize producer preferences for BMP characteristics as determinants for BMP adoption. Section four will summarize trends in BMP adoption specific to livestock, crops, and aquaculture industries. To identify similarities and differences in BMP adoption behaviour across three major agricultural industries. The fifth section will outline policy implications for the adoption of BMPs based on the advantages and challenges for implementing relevant strategies. The objective of section five is to promote strategies that guide policy towards facilitating the voluntary adoption of BMPs. Finally, section six will identify the primary knowledge gaps in the BMP adoption literature and outline opportunities for future research. Overall, this summary examines multiple publications from 1982 to 2020 establishing a broad overview of the current issues and research initiatives in the BMP adoption literature.

Section 1: Theory

The following section introduces the theoretical foundation for BMP adoption behaviour. Theories relevant to the BMP adoption literature provide a conceptual framework to understand the producer's

decision-making process. This section reviews utility, prospect theory, the theory of planned behaviour, and diffusion of innovation theory. The BMP literature applies a variety of methods to study behavioural theories and model producer BMP adoption behaviour. The objective is to describe the application of behavioural theories in the BMP adoption literature and outline the data collection methods used to study BMP adoption behaviour.

1.1   *Expected Utility Theory*

The value, worth, satisfaction, or usefulness received from a good or service is referred to as utility (Aleskerov et al., 2007). When deciding amongst various options, a rational individual chooses to maximize their utility based on preferences over an alternative (Aleskerov et al., 2007). A utility function is used to graphically represent individual preferences for a good or service (Aleskerov et al., 2007). Individual preferences for a set of alternatives can be modeled using a random utility model (McFadden, 1974). A random utility model applies the utility function with an additional error term that considers random factors influencing decisions resulting in behaviours unexplained by observable individual preferences (McFadden, 1974). To study BMP adoption behaviour, random utility models are used to understand producer preferences for BMPs. For example, a producer will choose to adopt a BMP that maximizes their utility over a set of alternative BMPs based on individual preferences for a BMP such as profitability or time-savings (Manski, 1977). Possible random factors that could influence a producer's decision to adopt a BMP include the lack of information, knowledge, or compatibility (Manski, 1977).

Situations, where individuals are required to make decisions under uncertainty, are explained using expected utility theory (Von Neumann & Morgenstern, 1944). Expected utility theory assumes that individuals will choose the option that yields the highest expected utility by weighing the probability of utility over all possible outcomes and the final decision depends on the individual's risk preference (Chavas, 2004). In the context of BMP adoption, producers can risk yield loss, increased labour requirements, and profit loss causing uncertain operation outcomes. A producer's decision to adopt a BMP given various uncertainties is based on the expected utility derived from the adoption of BMPs. In the BMP adoption literature, expected utility theory introduces a foundation for modeling behaviour and understanding producer decision-making under risk and uncertainty (Chavas, 2004). One limitation is that producers might not behave according to the underlying assumptions of expected utility theory because risk aversion is the sole parameter and depending on if the outcome results in a gain or loss producers might behave differently.

1.2 *Prospect theory*

Developed from the foundation of expected utility theory, prospect theory describes expected utility relative to a reference point rather than an absolute outcome (Kahneman & Tversky, 1979). Individuals value gains and losses differently, where gains and losses are valued against a reference point that represents an individual's expectation or current state (Kahneman & Tversky, 1979). Losses that contribute a stronger influence on an individual's utility than an equal gain is known as loss aversion (Kahneman & Tversky, 1979). For BMP adoption, a producer acknowledges possible losses in utility such as yield loss, increased maintenance costs, time costs or profit loss; and possible benefits in utility such as improved water quality, reduced soil erosion, or savings from decreased input costs from the adoption of a BMP. Loss aversion renders producers less likely to adopt a BMP, despite benefits, due to the strong influence of loss impacting the decision to adopt. Furthermore, an individual can have an emotional bias that increases the value of ownership known as the endowment effect (Kahneman et al, 1990). For BMP adoption, the endowment effect influences the decision to adopt when a producer values current agricultural practices and is reluctant to give up a familiar practice. Finally, prospect theory explains risk-seeking and risk-averse behaviour. Risk-averse individuals are more likely to choose an option with a guaranteed gain over a riskier alternative gain even if both options have the same expected value (Kahneman & Tversky, 1979). However, when avoiding a loss, an individual is more likely to choose the riskier option to avoid loss rather than the alternative guaranteed loss with the same expected value exhibiting risk-seeking behaviour (Kahneman & Tversky, 1979). Prospect theory is incorporated into the BMP adoption literature with the use of framing, an approach used to present positive or negative aspects of the same decision, to highlight certain BMP characteristics and examine changes in adoption. This approach provides an understanding of how producer risk-seeking and risk-averse behaviour affects the probability of adopting a BMP.

1.3 *Theory of planned behaviour*

The theory of planned behaviour consists of three main conditions including attitudes, subjective norms, and perceived behavioural control that predict a behavioural intention and lead to a displayed behaviour (Ajzen, 1991). First, attitude toward the behaviour considers the individual's belief that the behaviour will create a positive or negative contribution to the individual's life (Ajzen, 1991). For BMP adoption, a producer either believes the BMP will positively or negatively impact their operations. Second, subjective norm considers social factors that influence individuals including social networks, cultural norms, and group beliefs (Ajzen, 1991). For BMP adoption, this is a producer's perceived social pressure to adopt or

not adopt a BMP based on the behaviours of other nearby producers. Third, perceived behavioural control considers how easy or hard is it for an individual to perform the behaviour (Ajzen, 1991). For BMP adoption, this is a producer's perception of the difficulty or ease to implement a BMP. The theory can predict a behavioural intention when favourable conditions for each of the three conditions are met leading to an expected behavioural outcome (Ajzen, 1991). If one or more of the three conditions are unfavourable, it is less likely the individual will display the expected behaviour. In the context of BMP adoption, the theory of planned behaviour introduces producer attitudes, BMP complexity, and social factors as influences on producer decision-making that are not achieved in expected utility theory or prospect theory. Understanding the role of attitudes, social norms, and perceived behavioural control in producer decision-making is important to explain and predict BMP adoption.

1.4   *Diffusion of Innovation Theory*

The previous behavioural theories outlined consider general behavioural predictions, diffusion of innovation theory focuses specifically on innovation adoption behaviour. Diffusion provides an understanding of innovation adoption rate over time, through communication channels and members of the social system (Rogers, 1995). The decision to adopt an innovation is characterized by knowledge about the innovation and the attitude towards the innovation (Rogers, 1995). The diffusion of innovations theory considers five categories on a normal distribution that explain when an individual will adopt an innovation. The five categories include innovators, early adopters, early majority, late majority, and laggards (Rogers, 1995). The innovators are 2.5% of individuals that are the first to learn about and adopt an innovation (Rogers, 1995). Innovators are characterized as risk-takers and are important for introducing innovations to others. The early adopters are 13.5% of individuals that are respected as opinion leaders (Rogers, 1995). Potential adopters look to these individuals for information about the innovation and advice on if they should also adopt. The early majority are 34% of individuals that observe other's experiences and will only adopt an innovation once they are convinced the innovation will provide them with actual benefits (Rogers, 1995). The other 34% of individuals are the late majority characterized as resistant to change but are influenced by peer pressure to adopt an innovation (Rogers, 1995). Finally, the remaining 16% of individuals are known as laggards and are highly resistant to change and might not ever adopt an innovation (Rogers, 1995). The largest proportion of individuals are either part of the early or late majority category. In the context of BMP adoption, the diffusion of innovation theory is important to understand how to target producers in each of the five categories to achieve wide-spread adoption of a BMP.

Furthermore, the diffusion of innovation theory provides a measurement to determine the rate of BMP adoption.

1.5   *Methods*

Behavioural theories provide general statements explaining human decision-making that can be applied to the study of BMP adoption using models. A variety of models are developed in the BMP adoption literature to represent the reality of producer decision-making. The study of BMP adoption behaviour mainly relies on collecting and understanding real-world data using an empirical evidence-based approach. The BMP adoption literature applies both qualitative and quantitative methods of observation (Amemiya, 1981). The majority of data are collected using transcribed interviews with producers conducted face to face or by telephone and using surveys distributed to producers by mail, telephone, or online. Otherwise, data are collected using existing data sets that often include farm-level demographic, income, agricultural practices, and production data. Given that the literature primarily utilizes surveys to collect data, it is important to consider the difference between stated and revealed preferences. Stated preferences are individual choices made based on a hypothetical scenario, whereas revealed preferences are observations of actual choices made by individuals in the real world. Surveys using stated preference methods including contingent valuation, conjoint analysis, contingent ranking, and choice experiments. Revealed preference methods examine actual adoption rates of BMPs and often involve the use of experiments. Recently the literature has seen the application of economic experiments to study BMP adoption behaviour. Experimental methods include laboratory experiments, field experiments, artefactual experiments, framed field experiments, and randomized control trials. Laboratory experiments are used to test theories offering control over behavioural factors to determine causality and are usually conducted with students (Higgins et al., 2017). Artefactual experiments are similar to laboratory experiments, however, provide more context by recruiting people from a target group or environment such as producers to perform experiments in a laboratory environment. Field experiments are conducted with people in a real-life environment offering a better representation of the population of interest however are less controlled (Higgins et al., 2017). Finally, randomized control trials randomly assign participants to either a control or treatment group to compare outcomes. For BMP adoption differences could be observed in adoption rates and isolate causality.

The empirical analysis of collected BMP adoption data includes non-parametric approaches and regression modeling. Non-parametric approaches include mean comparison, rank-order correlation, chi-square analysis, and correlation analysis (Frölich, 2008). Regression modeling applies a variety of

techniques to investigate relationships between dependent and independent variables. An ordinary least square regression is used to determine BMP adoption rates as a continuous dependent variable. Duration analysis is used to model adoption over time. Dichotomous models including logit and probit regressions are used to determine adoption as a discrete dependent variable (Cox, 1958). Principle component factor analysis is used to determine correlation patterns between attitudinal variables and BMP adoption. Spatial models examine the spatial integration of adoption between neighbouring producers. Monte Carlo simulations are used to model the probability of adoption due to random variables that impact risk and uncertainty. Finally, Bayesian models are used to determine a probability-based rank of BMP adoption. Overall, the data collection and analysis approaches outlined, provide an overview of empirical research methods used to study the adoption of BMPs.

Section 2: Adoption Behaviour Major Themes

The following section summarizes major themes in the BMP adoption literature. The literature explores diverse variables to understand relationships that influence a producer's decision to adopt BMPs. For the purposes of this summary, variables frequently studied in the literature are condensed into four categories including socioeconomic variables, risk and uncertainty, information and awareness, and financial variables. The objective is to summarize the variables within each of these four categories identifying significant positive and negative determinants of BMP adoption and insignificant debatable effects on BMP adoption. With the goal of identifying inconsistencies in the literature and identify universal variables that predict the adoption of BMPs.

2.1   *Socioeconomic Variables*

In the literature, frequently studied socioeconomic variables include producer age, producer farming experience, level of education, and producer attitude towards the environment. A positive relation between producer age and BMP adoption is consistent in the literature however, this positive relationship has bee documented with both significant, and insignificant effects. Usually, producer age, measured in years, has a positive significant effect on the adoption of BMPs (Baumgart-Getz et al., 2012; Ervin & Ervin, 1982; Lee, 2005; Mishra et al., 2018; Prokopy et al., 2008; Soule et al., 2000). Generally, older producers have a shorter planning horizon and are unable to realize long-term benefits from the adoption of BMPs. However, other results indicate that the relationship is insignificant arguing that producer age is an ineffective predictor of adoption behaviour (Knowler & Bradshaw, 2007; Liu et al., 2018). Therefore, producer experience, measured in years farming, is another commonly used variable to predict adoption behaviour. It is expected that more experienced producers are more informed about BMPs to make

appropriate decisions about adoption. However, in the literature, the results are most often insignificant indicating that there is no clear relationship between producer farming experience and adoption (Baumgart-Getz et al., 2012; Boyer et al., 2018; Ervin & Ervin, 1982; Knowler & Bradshaw, 2007; Lee, 2005; Liu et al., 2018; Prokopy et al., 2008).

A producer's ability to understand BMPs and make informed decisions to adopt is often measured by a producer's level of education. A significant positive relationship between education and BMP adoption is regularly documented in the BMP adoption literature (Boyer et al., 2018; Cooper, 1997; Ervin & Ervin, 1982; Knowler & Bradshaw, 2007; Lee, 2005; Liu et al., 2018; Mishra et al., 2018; Prokopy et al., 2008; Rosenberg & Margerum, 2008; Soule et al., 2000). Producers with a higher level of education can access information and understand the environmental consequences of unsustainable agricultural practices increasing the adoption of BMPs. Furthermore, the literature introduces a distinction between formal education and extension training. In general, the literature considers education variables as attaining a formal high school, college, or university level education. However, extension education provides technical information about BMPs that are not achieved from formal education. Baumgart-Getz et al. (2012) use a meta-analysis to examine education as a general variable and include two separate subcategories for formal education and extension training to determine if extension education is distinct from formal education. Results indicate that general education and formal education variables had an insignificant effect on BMP adoption and extension education has a significant positive effect on the adoption of BMPs (Baumgart-Getz et al., 2012). Overall, education, general or specific, influences the adoption of BMPs from the ability to process information effectively with formal education or the knowledge of technical information about BMPs with extension education.

An attitude is described as a positive or negative belief that explains an intention used to predict behaviour. In the BMP adoption literature various attitudes have been studied, most often attitudes towards the environment are examined since a major component of BMP adoption is to reduce environmental degradation from using unsustainable agricultural practices. Producer attitude towards the environment is usually found to have a significant positive effect on BMP adoption in the literature (Armstrong et al., 2011; Baumgart-Getz et al., 2012; Boyer et al., 2018; Knowler & Bradshaw, 2007; Lee, 2005; Prokopy et al., 2008). For example, producers who value conserving the land, and protecting flora, fauna, and water quality are significantly more likely to adopt BMPs (Boyer et al., 2018). However, producers' attitudes towards the environment have also shown insignificant results (Ervin & Ervin, 1982; Mishra et al., 2018). An explanation is that regardless of producer attitudes towards the environment,

traditional values for managing the land from previous generations create a barrier to the adoption of BMPs (Armstrong et al., 2011). Overall, producer attitudes indicate producer intention to understand and predict adoption behaviour.

2.2   *Risk and Uncertainty*

Producer land ownership status, producer risk aversion, farm diversity and heritage, a measure of if a family member is planning to take over the farm, are frequently studied risk and uncertainty variables that affect adoption decisions. Producer land ownership status differentiates between operations with producers that rent the land and producers that own the land. To determine producer land ownership status, a tenure variable is used as a measure of the proportion of land owned to land operated. In the literature, the relationship between land tenure and the adoption of BMPs is often found to be insignificant (Baumgart-Getz et al., 2012; Boyer et al., 2018; Knowler & Bradshaw, 2007; Liu et al., 2018; Mishra et al., 2018; Prokopy et al., 2008). However, measuring ownership status using land tenure does not differentiate between owner-operators, share-renters, and cash-renters or account for the investment requirements for the adoption of BMPs. Soule et al. (2000) use farm-level corn producer data to perform a logit regression and examine the relationship between ownership type and the adoption of BMPs with short, medium, and long-term benefits. Results indicate that renters are significantly less likely than owner-operators to adopt BMPs that provide benefits over the long-term (Soule et al., 2000); suggesting producers who rent the land generally, only operate on the land for a short time frame diminishing the benefits of adopting BMPs with long-run benefits. Furthermore, share-renters and owner-operators are equally likely to adopt BMPs while cash-renters are significantly less likely to adopt BMPs (Soule et al., 2000). Overall, there are more studies that indicate land ownership status has an insignificant relationship with BMP adoption, however, these studies do not consider the nuances that exist between different ownership types that impact the adoption of BMPs.

Producer risk aversion is measured as a producer's willingness to take risks and is used to determine a producer's attitude towards risk. A risk-averse producer is expected to be reluctant to take risks and less likely than a risk-seeking producer to adopt BMPs. However, in the literature, the relationship between producer risk aversion and the adoption of BMPs has been observed as positive (Rahelizatovo & Gillespie, 2004; Savage & Ribaudo, 2013), negative (Gillespie et al., 2007; Holley et al., 2020; Kim et al., 2005; Kim et al., 2008; Liu et al., 2018), and insignificant (Baumgart-Getz et al., 2012; Lee, 2005; Prokopy et al., 2008). The overall impact of producer risk aversion on the adoption of BMPs is unclear. Risk has also been associated with farm diversity and heritage. Farm diversity is measured by the

number of cultivated crops or agricultural enterprises and is often used as a risk management strategy. Producers with more diverse farming operations are significantly more likely to adopt BMPs because more practices are applicable to diverse operations (Liu et al., 2018; Mishra et al., 2018; Prokopy et al., 2008). Heritage measured by if a family member is planning to take over the farm usually results in a significant positive effect on BMP adoption in the adoption literature (Ervin & Ervin, 1982; Liu et al., 2018; Prokopy et al., 2008). Investments in BMPs are perceived as less risky by farmers with family members planning to take over the farm since the long-term benefits can be maintained within the family for future generations.

2.2.1 *Experimental Evidence for the Role of Risk Attitude in the Adoption of BMPs*

Risk preference is not easily assessed using survey data since they often use stated preference methods that can introduce hypothetical bias. Furthermore, there is mixed evidence in the literature to clearly understand the relationship between risk aversion and BMP adoption. This introduces an area of the BMP adoption literature where experimental and behavioural economics can be applied to elicit actual producer risk preferences. The following paragraphs provide examples of studies that use behavioural experiments to determine how risk attitude affects BMP adoption.

To determine the role of risk attitudes in technology adoption decisions Liu (2013) examines the adoption of *Bacillus thuringiensis* (Bt) cotton amongst Chinese cotton producers. The field experiment had producers choose between two lotteries each with two possible outcomes, the lotteries were differentiated by safe and risky options. The experiment consisted of three different series of lottery rounds where producers were only allowed to switch between lotteries once during each series. Results indicate that producers are risk-averse and overvalue low probabilities indicated by the switching point in the experiment. Furthermore, producers who are risk-averse and experience loss aversion adopt Bt cotton later than producers who are less risk and loss averse adopt Bt cotton earlier. Evidence form this experiment suggests that producer risk and loss perceptions does influence producer decisions to adopt new technology.

Bocquého et al. (2014) follow similar methods to elicit the risk preference of randomly selected producers from Bourgogne, France. The field experiment had producers choose between pairs of lotteries differentiated by a safe and risky option. The expectation is that a risk-averse producer will always choose the safe option and a risk-seeking producer will always choose the risky option. Risk-neutral producers will switch between the two options depending on the expected value. Results indicate that producers

are risk-averse valuing losses twice as much as gains of the same magnitude exhibiting loss aversion. Evidence from this study suggests that producers value gain and loss outcomes differently. Additionally, Reynaud & Couture (2012) find that producers in France have different risk preferences in different contexts. After completing a lottery task during a field experiment, producers were asked to complete a domain-specific risk-taking questionnaire to determine risk attitudes for different domains. Results indicate that producers are significantly risk-averse in ethical, financial, and recreational domains. However, context domains for social, health, and safety revealed insignificant results for producer risk preferences. Overall, this study provides some evidence that risk preferences are context dependent.

In the context of risks to producers, Rommel et al. (2018) frame lottery tasks using two different varieties of wheat and the probability of good or bad weather. German producers were randomly selected to complete contextually framed lottery tasks and complete a questionnaire about the purchase of hail, harvest, or weather insurance. To determine if the framed lottery tasks could predict real-world risk preferences and management decisions indicated by the purchase of hail, harvest, or weather insurance. Results from the experiment do not correlate with the purchase of insurance and could not predict the producer's insurance purchases. The authors concluding that other methods of experimental design such as randomized control trial would offer more external validity than framed field experiments for predicting producer risk preferences.

2.3   *Information and Awareness*

In the literature, frequently studied information and awareness variables include producers' access to quality information, networking capacity, and producer environmental awareness. The BMP adoption literature frequently reports access to information as resulting in a significant positive effect on BMP adoption (Armstrong et al., 2011; Baumgart-Getz et al., 2012; Prokopy et al., 2008; Boyer et al., 2018; Knowler & Bradshaw, 2007; Lee, 2005), suggesting producers are more likely to adopt when exposed to knowledge about BMPs. Furthermore, inadequate information or lack of access to quality information about BMPs is a significant barrier for adoption (Liu et al., 2018; Mishra et al., 2018). Producer networking can improve access to quality information by connecting with government agencies, businesses, and local groups. Producers with greater networking capacity usually result in a significant positive effect on BMP adoption in the literature (Baumgart-Getz et al., 2012; Lee, 2005; Lui et al., 2018; Prokopy et al., 2008). For example, Cambell et al. (2011) compare adoption rates of BMPs in two different watersheds, one with a farmer-initiated local partnership and one without. Results indicate that there is no significant difference in the BMP adoption rates for the two watersheds. However, producers that participate in a farmer-

initiated collaborative local partnership are significantly more likely to adopt BMPs than producers that do not participate (Campbell et al., 2011), suggesting that traditional sources of information such as government agencies and businesses are primarily responsible for delivering information about BMPs. While friends, family, and neighbours have an important role in diffusing information across a variety of communication networks (Rosenberg & Margerum, 2008). This evidence suggests that the producer's access to quality information and networking capacity mutually benefit the adoption of BMPs.

Access to quality information isn't limited to understanding BMPs. Other examples include information about unsustainable agricultural practices that improve producer environmental awareness. Environmental awareness includes understanding how agriculture impacts the environment and the consequences of damaging agricultural landscapes. A significant positive relationship between environmental awareness and BMP adoption has been frequently documented in the BMP adoption literature (Baumgart-Getz et al., 2012; Ervin & Ervin, 1982; Lee, 2005; Liu et al., 2018; Prokopy et al., 2008). For example, producers with highly erodible soils due to uneven and hilly land are more likely to adopt BMPs (Knowler & Bradshaw, 2007). Similarly, producers with a stream running through their property are more likely to adopt BMPs to protect water quality (Knowler & Bradshaw, 2007). This evidence suggests that producers who observe soil and water damages from unsustainable practices on their property raise environmental awareness and increases the adoption of BMPs.

To examine the role of information and awareness for the adoption of hybrid maize technology, Kathage et al (2015) randomly survey producers in the north and east regions of Tanzania. Kathage et al (2015) use an average treatment effect framework to control for awareness and determine adoption rates. Results reveal that adoption rates are significantly different between the two regions. Producers in the northern region have widespread awareness of hybrid maize technology and if all producers were aware the adoption rate would increase from 49% to 57%. Awareness of hybrid maize technology is not as widespread in the east region and if all producers were aware the adoption rate would increase from 12% to 35%. Therefore, information and awareness can improve the adoption of hybrid maize technology however, there remains a proportion of informed and aware producers that are non-adopters. Kathage et al (2015) conclude that the hybrid maize seeds are better suited for the higher altitudes in the north explaining the difference in adoption rates for the north and east regions. Hence, improving seed varieties for different local conditions could bridge the adoption gap for hybrid maize technology in different regions in Tanzania. Overall, information exchange, social networks, and extension services can improve producer awareness of hybrid seed technology.

2.4   *Financial Variables*

Producer income from farm operations, access to capital, and farm size are frequently studied financial variables that affect adoption decisions. The BMP adoption literature frequently reports income as resulting in a significant positive effect on BMP adoption (Baumgart-Getz et al., 2012; Boyer et al., 2018; Cooper, 1997; Knowler & Bradshaw, 2007; Liu et al., 2018; Rosenberg & Margerum, 2008). Producers with higher incomes from farming operations are more likely to adopt because they can afford to invest in BMPs and take advantage of the benefits. However, Prokopy et al. (2008) find insignificant results suggesting, the ability to afford BMPs is not an indicator of a producer's willingness to adopt BMPs (Prokopy et al., 2008). The relationship between capital and BMP adoption is unclear since results are most often insignificant (Ervin & Ervin, 1982; Prokopy et al., 2008). Some results have shown that access to capital has a significant positive effect on the adoption of BMPs (Baumgart-Getz et al., 2012; Liu et al., 2018). For example, financial constraints from lower levels of capital and increased debt are a significant barrier to the adoption of BMPs (Knowler & Bradshaw, 2007; Rosenberg & Margerum, 2008). Finally, farm size usually results in a significant positive effect on BMP adoption in the literature (Armstrong et al., 2011; Baumgart-Getz et al., 2012; Liu et al., 2018; Prokopy et al., 2008; Soule et al., 2000). Larger farms are associated with greater economies of scale to benefit from the adoption of BMPs. For example, large farms are influenced by financial incentives to adopt early while late adopters are pressured by the community and peers (Liu et al., 2018).

2.5   *Literature Themes*

It is difficult to identify universal variables that predict the adoption of BMPs since there is a variety of factors that affect BMP adoption behaviour. For example, not all variables are equally measured across the BMP adoption literature. Age and education are frequently studied since these variables are easily measured (Prokopy et al., 2008), while variables such as risk and attitude are more difficult to measure and as a result are seldom studied (Baumgart-Getz et al., 2012). Furthermore, there are correlations between variables such as producer age and risk aversion, or years of farming experience and knowledge about BMPs. A systematic review examining variable frequency in the literature and the resulting relationship on BMP adoption could be valuable towards further identifying where future research is needed and determine universal variables that predict BMP adoption.

Recognizing that there is conflicting evidence in the literature, the following summary of general themes includes consistent and contradicting relationships that influence BMP adoption. Certain variables such as environmental awareness, education, access to information, networking capacity, heritage, and

crop diversity show a clear and positive effect on BMP adoption. However, other variables such as farming experience, land ownership status, risk aversion, capital, farm size, age, and attitude towards the environment show unclear or debatable effects on BMP adoption. The general findings for variables discussed in this section are summarized in Table 1. There are various factors at multiple scales that influence the adoption of BMPs. The categories of variables discussed in this section mainly highlight producer characteristics to identify general trends from the BMP adoption literature. However, the literature examines two other influential categories considering BMP characteristics and farm characteristics that provide further insight into BMP adoption behaviour. Details about the role of BMP characteristics and farm characteristics in the adoption literature are discussed in sections three and four.

<u>Section 3:</u> Characteristics of Best Management Practices

The following section summarizes BMP characteristics that influence the adoption rate. Voluntary adoption of BMPs allows individual producers to decide which BMPs to adopt and consequently not all BMPs are adopted equally. Variability in farm characteristics, producer demographics, and socioeconomic factors make it difficult to achieve widespread voluntary BMP adoption. Differences in BMP characteristics such as profitability, observability, and complexity also influence adoption decisions. Furthermore, individual producers' preferences for environmental, social, and economic BMP characteristics impact the frequency of adoption. The objective is to summarize producer preferences for BMP characteristics and identify the main determinants of BMP adoption including profitability, observability, and complexity.

3.1   *Profitability*

According to the literature, profitability is one of the main determinants of BMP adoption (Amacher & Feather, 1997; Boyer et al., 2018; Cooper, 1997; Dickson et al., 2016; Hennessey & Heanue, 2012; Hyland et al., 2018; Mitchell, 2004; Reimer et al., 2012; Stanley, 2000; Valentin et al., 2016; Wade et al., 2016). Intuitively, BMPs that decrease profitability reduce a producer's willingness to adopt (Boyer et al., 2018; Hennessey & Heanue, 2012; Valentin et al., 2016; Wade et al., 2016). Changes in profitability could be due to a decrease in income from yield loss or an increase in expenses from investments in new machinery or increased labour requirements (Amacher & Feather, 1997). Therefore, profitability incentives are a significant motivator for the voluntary adoption of BMPs (Cooper, 1997). For example, Amacher & Feather (1997) found that legume crediting and split application are jointly beneficial when adopted together. BMPs that are jointly beneficial maximize producer utility when used together by lowering costs and increasing profits than if they were used singly (Amacher & Feather, 1997). This provides evidence to suggest that bundling BMPs to increase profitability motivates the adoption of multiple BMPs.

To determine the relationship between farm income and BMP adoption, Valentin et al. (2004) use farm-level economic and BMP adoption data to analyze the effect of three different BMPs on-farm profitability. First, results indicate that the adoption of soil conservation practices does not have a significant impact on farm profitability. Second, the reduction in nutrient input from the adoption of nutrient management practices significantly increased farm profitability. Third, the adoption of reduced herbicide uses significantly decreased farm profitability due to a decrease in crop yields and an increase in costs from switching to herbicide substitutes. Overall, evidence from this study suggests that there is a significant positive correlation between nutrient management practices and farm profitability which should strengthen producer's confidence in the economic outcome of nutrient management practices and thereby increase adoption rates.

Wade et al. (2016) examine the impact of crop rotations on conservation tillage adoption. Conservation tillage leaves crop residue on the soil surface to improve soil structure, reduce soil erosion, and nutrient run-off. Results indicate that producers who rotate corn and soybean crops are significantly more likely to adopt conservation tillage compared to producers who only plant corn. For producers who only plant corn, the cost to implement conservation tillage is $43/acre compared to $14/acre for producers who rotate crops. The increased costs of implementing conservation tillage for nonrotated corn significantly reduces the profitability and adoption of this BMP. Overall, the threefold increase in the cost of conservation tillage adoption for corn compared to soybean reduces the adoption of this BMP due to impacts on profitability.

Andrews et al. (2013) use a survey-based experiment with crop producers across the United States to determine if decisions about conservation tillage practices change based on framing effects. The sample of crop producers was randomly divided equally into six different frame treatments. The control frame only received basic information about conservation tillage. Two other treatment frames received additional information about either carbon offset payments or payments for environmental services in general. The remaining three treatments received the same information as control, offset payment, and environmental services as previously mentioned, with additional information about how conservation tillage could increase profits by increasing crop yields or by lowering labour and fuel costs. Results indicate that producers who received the control frame were equally likely as those who received the profitability frames to express interest in the practice. Furthermore, the two payment frames; carbon offsets and environmental services were equally likely to develop producer interest for conservation tillage. Evidence from this experiment suggests that portraying conservation tillage as profitable doesn't increase interest

in the practice more than presenting basic information about conservation tillage. For the remaining non-adopters of conservation tillage, exploring alternative frames describing social benefits to the public or community could increase interest in the practice.

3.2 *Observability and Complexity*

A producer's ability to acquire information and comprehend a BMP determines the level of observability and complexity of a BMP. The ability to try a BMP, such as a new variety of corn, allows producers to observe the outcomes and overall effectiveness, before deciding to adopt (McCann et al., 2015). BMPs that are not easily trialed due to high initial costs or are preventative and difficult to observe create barriers for adoption (McCann et al., 2006). Additionally, the difficulty to understand a BMP increases information costs to overcome uncertainties reducing the adoption of complex BMPs (Mishra et al., 2018; Valentin et al., 2004). Quantifying producer comprehension and information acquisition is more challenging than determining profitability. Therefore, observability and complexity are not analyzed as often in the BMP adoption literature. The following paragraphs summarize the literature regarding the observability and complexity characteristics of BMPs as determinants for adoption.

Reimer et al. (2012) conduct a qualitative analysis of interviews with producers located in Indiana to identify determinants of BMP adoption. Results indicate that the ability for producers to try out a BMP before fully investing reduces the perceived risk and increases the adoption of BMPs. Furthermore, the compatibility with the producer's current farming system and relative advantage from reduced inputs and time saving increased the adoption of BMPs. Analysis of barriers for BMP adoption revealed that more complex BMPs are less likely to be adopted. Results from this study are consistent with the literature, concluding that, relative advantage, compatibility, observability, and complexity have the largest influence on a producer's decision to adopt BMPs.

To examine the effects of observability and complexity on BMP adoption McCann et al. (2015) consider two BMPs, manure testing, and manure application setbacks. The profitability of the two BMPs is similar, resulting in a significant positive effect on adoption. However, the BMP manure application setback was adopted more often than manure testing. The observability of setbacks by avoiding water bodies when applying manure is associated with an immediate improvement in water quality. Compared to manure testing that is more time consuming and complex requiring producers to manipulate nutrient applications based on test results which has a less obvious impact on improving water quality. Overall,

promoting observable impacts of BMPs to producers and providing prompt observable feedback to overcome complexities with educational efforts can increase the adoption of BMPs.

Abate et al., (2018) conduct a randomized control trial to determine changes in wheat yields for producers in Ethiopia. Producers are randomly assigned to either the control, a promotional treatment, or a marketing treatment. The promotional treatment receives a wheat initiative package that includes certified wheat seeds, fertilizers, training to improve farming techniques, and a guaranteed market to sell wheat. The marketing treatment only received marketing assistance to sell wheat after the harvest. Results indicate that producers in the promotional treatment had a 14% increase in wheat yields compared to the control group. Producers who received the promotional treatment were significantly more likely to plant certified seeds and apply fertilizer. However, producers in the promotional treatment did not follow all the recommended farming techniques. This result indicates that changing input rates is simple for producers to adopt while understanding and applying new farming techniques is more challenging. Evidence from this randomized control trial supports that complex farming techniques or practices are not easily adopted by producers.

Efforts to improve water quality from non-point source pollution requires collective action, which often discourages individual producers from adopting complex BMPs with low observability. To overcome this, Joelsson & Kyllmar (2002) monitor agricultural catchments providing information and guidelines to producers for BMPs that improve water quality. Information provided to producers based on leaching levels in agricultural catchments allows individual producers to understand their contribution to non-point source pollution. The recommendations based on monitoring results gave producers feedback to decrease soil cultivation and change crop rotation to lower nitrogen loss. The adoption of recommended BMPs reduced nitrogen leaching from 53 kg N/ha to 50 kg N/ha. Despite complex monitoring models used to estimate leaching levels, the prompt observable feedback given to producers successfully reduced nitrogen leaching.

Barreiro-Hurlé et al. (2010) randomly select producers in Spain to complete an interview and survey questionnaire to determine the factors that influence the adoption of intense or complex BMPs. Results indicate that intense BMPs, that require demanding implementation measures, are significantly influenced by farm structure and management. Less demanding BMPs are not significantly influenced by farm technical factors or changes in marginal profit. Furthermore, the decision to adopt intense BMPs is determined by transaction costs and utility derived from providing environmental services. Results from

this study suggest that in addition to the economic factors, producer attitudes towards the environment have a strong role in the decision to adopt complex BMPs.

3.3   *Environmental, Economic and Social Factors*

Producer perceptions for benefits and costs of BMPs do not equally value environmental, economic, and social factors (Reimer et al., 2012). For example, producers who are concerned about environmental factors, the decision to adopt is motivated by the sustainability of a BMP. Producers who value economic factors, the decision to adopt is motivated by the profitability of a BMP (Reimer et al., 2012). Since the economic factor of profitability is previously discussed in section 3.1, the following paragraphs focus on the role of environmental and social factors in the adoption of BMPs.

To assess trade-offs and rank BMPs, Giri & Nejadhashemi (2014) evaluate the environmental, economic, and social factors of five BMPs using an analytical hierarchy process. Considering all three factors weighted equally, results indicate strip cropping as the preferred BMP. Strip cropping is preferred due to the low cost of alternating crop type by row with high pollution reduction by preventing soil erosion. When only considering environmental factors, results indicate native grass as the preferred BMP. This removes agricultural land from production and replaces land with native grass which has greater pollution reduction capacity. However, native grass has a significantly higher cost compared to strip cropping. Socially, producers are unwilling to forego farming opportunities from planting native grass and economically, native grass has the highest installation cost and annual maintenance costs. When only considering the social component, results indicate residue management as the preferred BMP. Producers prefer residue management as it requires less labour and area than strip cropping to implement. Overall, BMPs have different environmental, economic, and social trade-offs that affect preference for adoption which is why all three factors need to be evaluated. Generally, BMPs that reduce less pollution at a lower cost are often preferred over BMPs that reduce more pollution at a higher cost.

Filter strips are an example of a BMP with heavily weighted environmental factors. Filter strips are dense areas of permanent vegetation used to control agricultural runoff into waterways. This BMP removes land from agricultural production and has high initial costs. Yeboah et al. (2015) survey producers to understand the motivation to adopt filter strips. Results indicate that producers who value aesthetics, land stewardship, and the environment are significantly more likely to adopt filter strips. However, producers indicate financial pressures as a large concern influencing their decision to adopt. Emphasizing that financial factors have an important role in producer decision-making regardless of environmental

improvements from the adoption of BMPs. Similarly, Wachenheim et al. (2018) investigate a wetlands program that encourages producers to keep small wetlands on their property instead of draining them. Producers who value protecting wetlands agree that they are important and have benefits for their operations. However, producers who view wetlands as an area that could be used for agricultural production are more likely to drain wetlands. Despite positive attitudes towards water quality and protecting wetlands, financial incentives influence producer decision making. This supports that environmental, economic, and social factors need to be equally considered for producers to adopt a BMP.

Quantifying social capital and social networks is challenging therefore, social factors are analyzed less frequently in the BMP adoption literature. Usman & Ahmad, (2018) consider the effect of social capital on the adoption of BMPs. Results indicate that producers who interact in social networks that provide support and relevant information significantly increase the adoption of BMPs (Usman & Ahmad, 2018). Similarly, Floress et al. (2011) compare three watersheds with varying access to social capital using interviews to determine the impact on the adoption of BMPs. Results suggest that producers in the watershed with the greatest access to human capital and social networks were more likely to adopt BMPs (Floress et al., 2011). The human capital and social network create a social structure that allows producers to have greater access to information and resources from different organizations. Compared to producers in the other two watersheds with less producer participation in meetings and missing links in social structures to coordinate and access information from different organizations (Floress et al., 2011). Furthermore, social norms can impact BMPs for example, Yang & Sharp (2017) found that livestock producers are significantly more likely to adopt BMPs if their neighbours are also BMP adopters. Kuhfuss et al. (2016) conduct a national online survey of producers in France with three randomized treatment groups to test the effect of social norms on the adoption and continuation of agri-environmental schemes. Results indicate that producers are conditional cooperators and informing producers about the choices of others significantly influences their decision to adopt (Kuhfuss et al., 2016). Rewarding the collective success of producers adopting BMPs could be an effective policy tool to encourage conformity and signal social norms to producers.

Crane-Droesch (2017) randomly selected producers in Bungoma, Kenya to participated in a field experiment to improve crop yields using biochar demonstration plots. Biochar helps to amend soils by retaining nutrients, water, and improve soil pH. Producers who received the demonstration plot allowed then to determine if the biochar was effective at improving crop yields. Overall, biochar plots performed better than non-biochar plots and a social network survey was used to determine if producers transmit

information about the benefits of biochar. Results indicate that producers who observed the success of biochar in their networks were more likely to adopt. However, information about biochar was not routinely discussed with other producers suggesting information dissemination through social networks is imperfect towards delivering information about agricultural technologies. Results from this study suggest that in addition to social networks, extension services have an important role in disseminating information to producers. To determine the effectiveness of extension services Krishnan & Patnam (2013) examine longitudinal household data from Ethiopia to determine the adoption of hybrid seeds and fertilizers. The results suggest that neighbours have a significant influence on the decision to adopt. Furthermore, extension services significantly impact the initial decision to adopt however, over time the effect of extension services on adoption become insignificant. Authors conclude that extension services introduce new agricultural technologies and have an important role in raising awareness while learning from neighbours supports information diffusion over time. Overall, social learning has an important role in the adoption of agricultural technologies

Section 4: Industry trends

The following section summarizes BMP adoption literature associated with three major agricultural productions: livestock, crops, and aquaculture. For the purposes of this summary, livestock production focuses on BMP adoption literature specific to beef cattle, dairy, swine, and broiler producers. Crop production focuses on BMP adoption literature specific to potato, corn, fruit, cotton, soybean, rice, and vegetable producers. Aquaculture is discussed in general since there is significantly less BMP adoption literature related to aquaculture. The objective is to identify similarities and differences within each of the major agricultural productions outlined. With the goal of identifying trends and inconsistencies in the BMP adoption literature for aquaculture, livestock production, and crop production.

4.1   *Livestock Production*

Livestock production raises domesticated animals in an agricultural setting to produce commodities such as meat, eggs, and milk. As livestock production expands to meet increasing demands, expansion increases environmental degradation. Livestock production has been associated with problems such as non-point source pollution, land and water degradation, and greenhouse gas emissions. Livestock producers adopting BMPs such as manure management, grassed waterways, livestock exclusion, riparian forest buffers, shoreline protection, fencing, rotational grazing, prescribed grazing, nutrient management, mortality management, soil compaction prevention, animal nutrition management, and waste storage reduce the negative externalities associated with livestock production. The following paragraphs

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summarize the barriers and incentives for livestock producers to adopt BMPs, identifying similarities and differences in the literature.

4.1.1   Literature Consistencies

Similarities within the BMP adoption literature related to livestock production include factors such as farm size, being a male producer, level of education, amount of income and debt, willingness to adopt BMPs, land characteristics, and participation in government programs affecting the adoption of BMPs. Farm size is measured by the number of livestock animals, the literature has primarily documented the relationship between farm size and BMP adoption as positive with both significant and insignificant results. Most frequently results indicate that livestock producers with a larger farm size are significantly more likely to adopt BMPs (Hennessy & Heanue, 2012; Hyland et al., 2018; Johnson et al., 2010; Paudel et al., 2016; Rahelizatovo & Gillespie., 2004). The more animals a livestock producer has, means better access to information and economies of scale to effectively implement BMPs. This positive relationship is consistent throughout the literature however, results have reported the relationship as insignificant (Gillespie et al., 2007; Kim et al., 2005) since some BMPs are not applicable to larger operations.

The relationship between being a male producer and BMP adoption is consistently positive with significant and insignificant results in the literature. Primarily, livestock producers who are male are significantly more likely than females to adopt BMPs (Gillespie et al., 2007; Hadrich & Van Winkle, 2013), as male producers are more familiar with BMPs increasing the likelihood of adoption. Other results have reported this positive relationship as insignificant (Hyland et al., 2018), suggesting that the gender of livestock producers is not an effective predictor of BMP adoption since the majority of livestock producers are male.

Another socioeconomic factor is education, measured on a scale of receiving a high school diploma to a bachelor's degree. Primarily, the literature has documented education as having a positive effect on BMP adoption with both significant and insignificant results. Most often, educated livestock producers are significantly more likely to adopt BMPs (Glenk et al., 2014; Gillespie et al., 2007; Hyland et al., 2018; Johnson et al., 2010; Kim et al., 2005; Kim et al., 2008; Paudel et al., 2008; Savage & Ribaudo, 2013; Yang & Sharp, 2017). Livestock producers with a higher level of education can access and process information more effectively and are aware of the negative impacts of unsustainable livestock production increasing the adoption of BMPs. This positive relationship is consistent in the literature however, results have also reported the relationship as insignificant (Hadrich & Van Winkle, 2013; Holley et al., 2020;

Paudel et al., 2016; Rahelizatovo & Gillespie., 2004), suggesting that formal education alone does not provide technical information about BMPs that is an important component in the decision-making process for BMP adoption.

Income is measured by the revenue earned from livestock production, results in the literature have documented both positive significant and insignificant relationships between income and BMP adoption. Most frequently literature results indicate that livestock producers with higher incomes are significantly more likely to adopt BMPs (Gillespie et al., 2007; Holley et al., 2020; Johnson et al., 2010; Paudel et al., 2008; Yang & Sharp, 2017). Higher income increases financial flexibility and reduces capital constraints allowing livestock producers to afford an investment in BMPs and take advantage of the benefits. Similarly, debt measured by a livestock producers debt to asset ratio has a significant negative relationship with the adoption of BMPs (Hadrich & Van Winkle, 2013; Kim et al., 2005; Kim et al., 2008; Paudel et al., 2008; Yang & Sharp, 2017). This further supports that financial problems such as high-debt and capital constraints are barriers to the adoption of BMPs. However, insignificant results have been documented in the literature for the positive relationship between income and BMP adoption (Kim et al., 2008; Paudel et al., 2016), suggesting that livestock producer's ability to afford the adoption of BMPs is not an indicator of the willingness or intent to actually invest in BMPs. For example, Glenk et al. (2014) hypothesized that BMPs with a financial gain would be adopted by profit-maximizing livestock producers without requiring any incentive as they reduce the cost burden of production. However, results reveal a lack of BMPs with negative costs were adopted (Glenk et al., 2014), suggesting that adoption behaviour is driven by a more complex set of motivating factors.

Livestock producers' intention or willingness to adopt BMPs is measured by attitude, awareness, and beliefs about BMPs. Positive attitudes and beliefs towards BMPs consistently result in a significant increase in the adoption of BMPs (Hyland et al., 2018; Holley et al., 2020; Paudel et al., 2008; Rahelizatovo & Gillespie., 2004), suggesting that awareness of BMPs and concern for the environment explain the behavioural intention to adopt BMPs. For example, livestock producers with hilly land are more likely to be concerned about soil erodibility significantly increasing the adoption of BMPs (Gillespie et al., 2007; Kim et al., 2005; Yang & Sharp, 2017). Furthermore, livestock producers with a stream running through their property are significantly more likely to adopt BMPs (Gillespie et al., 2007; Kim et al., 2005; Rahelizatovo & Gillespie., 2004). Streams are often used as a source of drinking water motivating livestock producers to reduce erosion and control sedimentation by adopting BMPs.

Participation in government programs is measured by the membership of involvement with cost-sharing programs, extension programs, agricultural outreach programs, or discussion groups. The literature results consistently indicate that livestock producers who participate in these kinds of programs are significantly more likely to adopt BMPs (Gillespie et al., 2007; Hadrich & Van Winkle, 2013; Hennessy & Heanue, 2012; Holley et al., 2020; Hyland et al., 2018; Kim et al., 2005; Paudel et al., 2008; Paudel et al., 2016; Rahelizatovo & Gillespie., 2004; Savage & Ribaudo, 2013; Yang & Sharp, 2017). Livestock producers who are more familiar with BMPs from receiving one-on-one advice, technical information, training, and support increase the adoption of BMPs. For example, Gillespie et al. (2007) found that livestock producers who were unfamiliar with BMPs thought that they were not applicable to their farms creating a barrier for the adoption of BMPs. Participation in government programs can overcome this information barrier and increase the adoption of BMPs.

4.1.2   *Literature Inconsistencies*

Differences within the BMP adoption literature related to livestock production include factors such as pasture acres, level of experience, producer age, risk aversion, land ownership, farm diversification, producer retirement, and internet affecting the adoption of BMPs. When farm size is measured by pasture acres there are inconsistent results in the literature. Some studies find that livestock producers with more acres of farmland allocated as pasture significantly reduced the adoption of BMPs (Hadrich & Van Winkle, 2013; Kim et al., 2008; Savage & Ribaudo, 2013). Increasing pasture acres means that livestock producers have higher costs and labour requirements preventing the adoption of BMPs. This negative relationship has also been documented in the literature as insignificant (Holley et al., 2020). However, Yang & Sharp (2017) find that an increase in pasture acres significantly increases the adoption of BMPs arguing that larger pasture areas require better management increasing the adoption of BMPs.

Experience is measured by the number of years a producer has been farming, there is mixed evidence in the literature documenting both positive and negative significant results. Usually, results indicate that livestock producers with more years of farming experience are significantly more likely to adopt BMPs (Glenk et al., 2014; Hadrich & Van Winkle, 2013; Paudel et al., 2008; Savage & Ribaudo, 2013). Experience increases the livestock producer's knowledge and ability to recognize the importance of BMP adoption. However, Paudel et al. (2016) find that livestock producers with more years of farming experience are significantly less likely to adopt BMPs arguing that more experienced livestock producers wait longer to adopt BMP as they are less motivated to adjust existing systems. Similar to experience, producer age, measured in years, is another factor with inconsistent results in the literature, reporting

positive, negative, significant, and insignificant effects on BMP adoption. Often results indicate that older livestock producers are significantly less likely to adopt BMPs (Gillespie et al., 2007; Glenk et al., 2014; Hennessy & Heanue, 2012; Johnson et al., 2010; Kim et al., 2008; Rahelizatovo & Gillespie., 2004; Yang & Sharp, 2017), suggesting that older producers are more reluctant to adopting BMPs since they likely won't be able to realize long-run net benefits. In contrast, other Results suggest that older livestock producers are significantly more likely to adopt BMPs (Kim et al., 2005; Paudel et al., 2016; Savage & Ribaudo, 2013), arguing that producers often raise livestock in their retirement as a hobby and consider maintaining the land as a high priority. However, this positive relationship has also been documented in the literature as insignificant (Holley et al., 2020; Hyland et al., 2018), suggesting that BMPs have been developed and promoted for decades allowing older producers to be more familiar with BMPs and have various opportunities to adopt.

Risk aversion is often measured using a proxy for risk attitude self-indicated by livestock producers, there is mixed evidence in the literature documenting both positive and negative significant results. Usually, results indicate that risk-averse livestock producers are significantly less likely to adopt BMPs (Gillespie et al., 2007; Holley et al., 2020; Kim et al., 2005; Kim et al., 2008). However, other results have shown that risk-averse livestock producers are significantly more likely to adopt BMPs (Rahelizatovo & Gillespie, 2004), arguing that risk-averse livestock producers view BMP adoption as a strategy to reduce risk especially if there is a regulation that could shut down operations by not complying. For example, Savage & Ribaudo (2013) compare states where the Environmental Protection Agency (EPA) established regulation that restricts total maximum daily load to avoid non-point pollution to states without this regulation. Results indicate that EPA regulation increases adoption rates for risk-averse livestock producers.

Land ownership is measured by ownership status as an employee, renter, or primary owner with inconsistent results in the literature, reporting positive, negative, significant, and insignificant effects on BMP adoption. Some studies find that livestock producers that own their land are significantly more likely to adopt BMPs (Gillespie et al., 2007; Hadrich & Van Winkle, 2013; Kim et al., 2005). BMP adoption is perceived by livestock producers as an effective way to enhance and maintain the value of land increasing the adoption of BMPs. However, other results suggest that ownership significantly decreases the adoption of BMPs (Rahelizatovo & Gillespie., 2004), arguing that landowners are not required to adopt BMPs in comparison to landlords that require the use of BMPs in rental agreements reducing the adoption of BMPs for owners. For example, Hoban et al. (1997) found that land application of manure was twice as likely

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done by producers under contract than independent producers, suggesting that livestock producers who are not required to maintain BMPs are less likely to adopt BMPs. However, Kim et al. (2008) and Paudel et al. (2016) find insignificant results for the negative relationship between land ownership and BMP adoption. Additionally, farm diversification is measured by the number of different enterprises included on the farm property and is another factor with mixed evidence in the literature. Usually, more diverse farms are significantly more likely to adopt BMPs (Gillespie et al., 2007; Kim et al., 2005; Rahelizatovo & Gillespie., 2004), suggesting that livestock producers can take advantage of economies of scope and adopt more BMPs. However, Kim et al. (2008) find that more diverse farms are significantly less likely to adopt BMPs, arguing that livestock producers are limited in the span of control and unfamiliar with BMPs of other enterprises reducing the adoption of BMPs due to non-applicability.

Heritage is a factor that measures if a family member will take over the land and farm operations after the livestock producers' retirement. In the literature a positive relationship between heritage and BMP adoption is frequently observed however, this relationship has shown to have both significant and insignificant results. It is often expected that livestock producers with the intention of passing on the land to the next generation are significantly more likely to adopt BMPs (Kim et al., 2008) since the adoption of BMPs will maintain interfamily social capital. However, the literature has more frequently documented the positive relationship between heritage and BMP adoption as insignificant (Hadrich & Van Winkle, 2013; Holley et al., 2020; Kim et al., 2005; Paudel et al., 2016). These insignificant results suggest that livestock producers are not investing in BMPs beyond their own time horizon (Paudel et al., 2008), and sustaining foraging productivity for future generations is not a significant motivation to adopt BMPs. Furthermore, livestock producers are not expecting or encouraging their family members to continue livestock operations. Finally, an interesting factor that has received limited attention in the literature is access to the internet. Livestock producers that use the internet to inform farm management decisions are significantly more likely to adopt BMPs (Holley et al., 2020; Liu et al., 2018).

4.2   *Crop Production*

Crop production involves growing a variety of crops to produce food and fiber commodities. As crop production expands, increasing harvest to meet demands has introduced problems with persistent negative externalities. Crop production has been associated with problems such as deforestation, soil erosion, and pollution from fertilizer and nutrient run-off. Crop producers adopting BMPs such as conservation tillage, intercropping, cover crops, mulches, crop rotation, integrated pest management, recommended fertilizer and nitrogen application rates, soil testing, irrigation system scheduling, filter

strips, and recommended pesticide and herbicide application rates reduce negative externalities associated with crop production. The following paragraphs summarize the barriers and incentives for crop producers to adopt BMPs, identifying similarities and differences in the literature.

4.2.1 Literature Consistencies

Similarities within the BMP adoption literature related to crop production include factors such as level of education, land ownership, BMP awareness, participation in government programs, and environmental concern or perception affecting the adoption of BMPs. Education is measured on a scale of no high school diploma to advanced post-secondary degrees. Consistently in the literature, results show that crop producers with a higher level of education are significantly more likely to adopt BMPs (Denny et al., 2019; Dong et al., 2016; Li et al., 2018; Tey et al., 2014; Traoré et al., 1998). Educated crop producers have a greater ability to understand the importance of BMPs and manage more complex production systems with accompanying risks and benefits from the adoption of BMPs. Additionally, Land ownership is often measured by ownership status on a scale of employee, renter, or primary owner. Crop producers that own their land have shown a consistent positive but not significant relationship with the adoption of BMPs in the literature (Denny et al., 2019; Dong et al., 2016; Tey et al., 2014; Traoré et al., 1998). Landowners suffer the consequences of damages to the land and therefore are more likely to manage the land sustainably for long-term productivity and value. However, this ownership status is not relevant in the crop producer's decision to adopt BMPs reflected in the insignificant relationship documented in the literature.

The level of awareness and willingness to adopt BMPs is measured by the producer's level of knowledge about a BMP and the level of intention to implement a BMP. Most often results indicate that, crop producers who are more aware of BMPs and have stronger intentions and are significantly more likely to adopt BMPs (Denny et al., 2019; Li et al., 2018; Lubell & Fulton, 2008; Tey et al., 2014; Traoré et al., 1998). Awareness of BMPs decreases uncertainty about innovations and supports a willingness to adopt. Similarly, environmental concern is measured using producers' beliefs, attitudes, and perceptions towards land stewardship. In the literature, results frequently indicate that crop producers with greater concern for the environment are significantly more likely to adopt BMPs (Denny et al., 2019; Dong et al., 2016; Lubell & Fulton, 2008). Environmental concerns are consistent with BMP adoption to preserve the land and long-term crop production for future generations. Finally, participation in government programs is measured by the membership of involvement with cost-share programs, agricultural outreach programs, or conservation stewardship programs. Government programs are associated with delivering

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information to crop producers and providing access to trained personnel offering practical experience using BMPs. Usually, the literature reports that crop producers who participate in government programs are significantly more likely to adopt BMPs (Boland et al., 2006; Denny et al., 2019; Li et al., 2018; Lubell & Fulton, 2008; Tey et al., 2014; Traoré et al., 1998).

4.2.2   Literature Inconsistencies

Differences within the BMP adoption literature related to crop production include variables such as level of experience, producer age, risk aversion, farm size, and income. Experience is measured by the number of years a producer has been farming and has been reported in the literature as having both a positive and negative insignificant effect on BMP adoption. Some studies find that a crop producer's experience has a positive and not significant relationship on the adoption of BMPs (Dong et al., 2016; Lubell & Fulton, 2008). One explanation for this result is that more experienced producers have a greater opportunity for innovation. However, other results have shown a negative and not significant relationship between crop producer's experience and the adoption of BMPs (Denny et al., 2019; Li et al., 2018; Tey et al., 2014; Traoré et al., 1998), arguing that the number of years a producer has been farming doesn't indicate the knowledge or awareness about BMPs to predict adoption behaviour. Overall, the insignificance of these positive and negative results indicates that experienced producers are no more likely than inexperienced producers to adopt BMPs.

Producer age is another factor, measured in years, with inconsistent results in the literature. Some studies find that crop producer's age has a significant negative impact on the adoption of BMPs (Boyer et al., 2016; Denny et al., 2019), suggesting older crop producers are less likely to adopt BMPs, due to an unwillingness to learn or the ability to take on new risk as an older producer compared to younger producers. However, Tey et al. (2014) found that crop producer's age has a positive and not significant impact on the adoption of BMPs, indicating that older producers are more willing to adopting BMPs to ensure land stewardship for future generations. Overall, it is difficult to interpret the effect of producer age on the adoption of BMPs when it is associated with the producer's risk aversion since age does not directly indicate a crop producer's risk preference. Risk preference is measured using a measure of risk aversion self-indicated by crop producers. Results have shown that risk-taking crop producers are significantly more likely to adopt BMPs (Asci et al., 2015; Denny et al., 2019). For example, risk-averse producers prefer fertilizer application rates above the recommended BMP to avoid low yields while risk-neutral producers prefer a medium fertilizer application rate to avoid high fertilizer expense (Asci et al., 2015) Overall, the adoption of BMPs depends on the producers level of risk aversion.

Farm size is measured in acres of farmed cropland and has mixed evidence in the literature documenting positive, negative, significant, and insignificant effects on BMP adoption. Dong et al. (2016) find that crop producer's farm size has a significant negative relationship with the adoption of BMPs, as larger farms face greater time constraints that prevent the adoption of BMPs since many BMPs require additional labour. However, this negative relationship has also been reported in the literature without significance (Li et al., 2018; Lubell & Fulton, 2008; Traoré et al., 1998). Other results, in a study by Boyer et al. (2016), indicate that farm size has a significant positive effect on BMP adoption, arguing that producers of larger farms perceive the BMP adoption benefits to exceed adoption costs. However, this positive relationship has also been reported in the literature without significance (Denny et al., 2019; Tey et al., 2014). Similar to farm size is farm income, measured by gross farm revenue has shown a positive effect on BMP adoption with both significant and insignificant effects. Usually, crop producers with higher farm incomes are significantly more likely to adopt BMPs (Boyer et al., 2016; Tey et al., 2014). Higher farm incomes allow greater economies of scale and productivity to allow crop producers to invest in BMPs and undertake the risks of adopting BMPs. However, Lubell & Fulton (2008) find the positive relationship between farm income and BMP adoption to be insignificant.

4.3   *Aquaculture*

Aquaculture is often overlooked in the BMP adoption literature. Aquaculture is the largest supplier of fishery products such as crustaceans, molluscs and farmed fish producing large volumes of waste run-offs that pollute surface waters. Expansion of aquaculture has been associated with increasing problems such as non-point source pollution, mangrove deforestation, and unintended by-catch. Producers adopting aquiculture BMPs such as sludge removal, feed management, fertilizer management, reduced water exchange, closed water recycling systems, effluent treatment plants, reduced stocking rates, conservation cover, nutrient management, irrigation water management, and shoreline protection reduce the negative externalities associated with aquaculture. The following paragraphs summarize barriers and incentives for the adoption of aquaculture BMPs from the literature.

Nyaupane et al. (2012) mailed questionnaire surveys to crawfish producers in Louisiana and used a probit model to analyze results. Factors such as farm size, education, the presence of a stream, farm diversification, and land ownership significantly impacted the adoption of BMPs. Crawfish producers with larger operations, measured in acres, were significantly more likely to adopt BMPs. Larger operations can spread an initial investment required to implement a BMP over a greater quantity of output reducing the cost of production. Similarly, crawfish producers with a college education were significantly more likely to

adopt BMPs due to increased awareness and ability to process information. Crawfish operations in proximity to a stream were significantly more likely to adopt BMP to avoid polluting the waterway and use for irrigation. Crawfish producers that also produce rice or rotate production with soybean and rice are significantly more likely to adopt BMP. Diverse farms use the land more intensively requiring BMPs to operate effectively with the advantage that benefits can be seen across multiple enterprises. Crawfish producers who rent land for operations are significantly less likely to adopt BMP. Renters are discouraged from adopting BMPs due to large investments and long-run benefits that are received by the owner rather than the renter. Factors such as age, income, leasing land for operations, and off-farm income had no significant impact on the adoption of BMPs. The Adoption of BMPs such as conservation cover, nutrient management, and pumping plants significantly increased profits. Conversely, the adoption of filter strips significantly reduced profitability, suggesting that the profitability of BMPs is an important incentive to increase adoption.

Dickson et al. (2016) further investigate profitability as an incentive for the adoption of aquaculture BMPs by randomly selecting Egyptian fish producers to receive BMP training. The field experiment compared farm performance, production, and profitability with a control group that did not receive BMP training. Results show no significant difference between the average number of ponds, average pond size, or years of experience in the two groups. Farm characteristics including the age of a producer in years and average family size were significantly different between the two groups. This means that fish producers who received training and implemented BMPs were younger and had smaller average family sizes than producers who did not implement BMPs. Producers who received BMP training effectively applied the recommended fertilizer rate, used more organic fertilizers, and less feed. There was no significant difference between stocking rates or the average protein level of feed between the two groups, indicating that producers who improved feed management practices had a more efficient conversion of feed into fish growth. This significantly increased the average size of thin-lip mullet and catfish at harvest compared to the control group. The average yields of other fish types were not significantly different between the two groups. Total operating costs were significantly less for producers who received BMP training compared to the control group. There was no significant difference between the average fixed costs of the two groups. Overall, producers who implement BMPs use less feed reducing operating costs, grow larger fish increasing sales and are more profitable.

Evidence from these two studies focuses on aquaculture BMPs that improve inputs effectively introducing cost savings and increased profits. Compared to BMPs that require large investments that

don't increase profitability such as filter strips, effluent treatment plants, and sludge removal. These waste reducing BMPs create barriers to adoption due to perceived risk and reduced profitability (Stanley, 2000). Stanley (2000) argues that the benefits of BMPs that don't increase profitability are often disregarded in aquaculture because they are difficult to quantify and value. Incomplete information about ecological and long-run private benefits creates barriers for the adoption of aquaculture BMPs (Stanley, 2000). Furthermore, producer risk aversion due to production uncertainties and income risks are magnified due to inadequate cost-sharing programs reducing the adoption of aquaculture BMP (Stanley, 2000). Overall, aquaculture faces considerable barriers for the adoption of BMPs with few incentives to overcome these barriers. Despite the lack of adoption literature for aquaculture BMPs, aquaculture is an expanding industry with a large environmental footprint creating major opportunities for future research.

4.4   *Trends in Agriculture*

Aquaculture, livestock production, and crop production contribute to global environmental problems including biodiversity loss, non-point source pollution, and climate change. Each of these three major agricultural productions has specific BMPs that can reduce these negative externalities through voluntary adoption. There are various barriers and incentives for the adoption of BMPs. The variable findings discussed for each of the three agricultural productions in this section are summarized in Table 1. Key similarities across the three agricultural sectors include the level of education, BMP awareness, intention, or willingness to adopt, and participation in government programs as significant factors that increase the adoption of BMPs. Inconsistencies across the three agricultural sectors include years of farming experience, risk aversion, and producer age, suggesting that these factors are not universally effective predictors for the adoption of BMPs.

In conclusion, the socioeconomic variables across all the agricultural sectors are found to have different effects on adoption behaviour. Given the differences between aquaculture, crop, and livestock production, it is reasonable to see inconsistencies across these agricultural productions. Alternatively, the consistencies observed across all agricultural sectors are associated with interventions such as education, awareness, and participation in government programs. Considering this, interventions offer more value towards changing producer behaviour to voluntarily adopt BMPs than individual socioeconomic factors or farm characteristics. While these individual characteristics are very important towards understanding factors that affect BMP adoption, on a large scale these factors have inconsistencies that challenge the feasibly of achieving widespread BMP adoption. When designing behavioural and policy interventions, it is important to consider the different effects individual socioeconomic factors and farm characteristics

have on adoption behaviour and determine how these variables interact with specific interventions. Behavioural interventions with education, awareness, and participation in government programs have shown consistency in the literature to effectively change producer behaviour on a large scale and expand BMP adoption. Thus, applying behavioural interventions through extension education and outreach programs is an important policy consideration to effectively achieve widespread BMP adoption.

Section 5: Policy Implications

The following section identifies different policy implications for the adoption of BMPs. Previous sections summarized determinants for BMP adoption providing insight for incentives and barriers that influence a producer's decision to adopt BMPs. This information is helpful to guide policy and facilitate the voluntary adoption of BMPs. Policy approaches that improve adoption rates are associated with three categories including authority, incentives, and barrier removal. The objective is to summarize strategies relevant to each of the three policy approaches identifying advantages and challenges for implementing the proposed strategies. Overall, the goal of this section is to summarize effective and ineffective policy implications from the literature.

5.1 *Authority*

Enforcing the adoption of BMPs using authority prohibits environmental degradation and requires producers to act sustainably through regulation. Since BMPs are adopted voluntarily, regulations don't specifically require the adoption of BMPs to achieve compliance. However, environmental laws can influence the management of agricultural production. For example, total maximum daily loads regulate the amount of pollutants that can enter a water body requiring producers to manage agricultural production accordingly to meet water quality standards. To determine the effect of regulation on the adoption of BMPs, Kara et al. (2008) examine the influence of local interactions with urban populations and state-level environmental regulation on the adoption of BMPs. Kara et al., (2008) use farm-level economic and agricultural data from corn producers and geographic data of population-interaction zones for agriculture to determine areas where urban activities affect agriculture. The population-interaction indexes are used to measure the potential interaction between urban population and agricultural production based on a continuous measure of proximity to nearby population concentrations. The level of environmental stringency for each state is determined by the presence or absence of seven regulations related to environmental pollution. Kara et al. (2008) expect that producers with agricultural land located in proximity to urban residents will create pressures for producers to increase the adoption of BMPs to avoid conflicts. For example, the use of manure can be scrutinized by citizens causing producers to adopt

manure management plans to avoid complaints from citizens. However, results reveal that the proximity to urban areas did not have a significant influence on the adoption of BMPs. State-level environmental stringency significantly increased the adoption of two BMPs, grassed waterways, and erosion plans while the remaining six BMPs tested were not significant. The authors conclude that environmental stringency could influence the adoption of some BMPs however, this might not effectively increase adoption without additional incentives. Overall, regulation is not an effective method for achieving widespread BMP adoption because agricultural pollution is primarily a non-point source that is not easily monitored making it difficult to regulate and enforce (Joelsson & Kyllmar, 2002).

The polluter-pays tax-based policy encounters similar opposition because monitoring can only identify pollution at the watershed scale and not identify an individual producer's pollution level. Therefore, a tax-based policy would penalize producers who adopt BMPs and reduce emissions when other producers in the same watershed continue to pollute (Bowden, 2006). In Canada, agricultural land is primarily privately owned, and rather than intervene with rural property interests, the federal and provincial governments work with industry and producers to suggest guidelines that support the adoption of BMPs (Bowden, 2006). To achieve BMP adoption without regulation, a policy aims to remove barriers and incentivise producers supporting behavioural change towards voluntary BMP adoption.

5.2   *Incentives*

Policies that encourage the voluntary adoption of BMPs using financial benefits are known as incentives. Since BMP profitability is a significant motivator for adoption, incentives allow producers to maximize utility when there is an insufficient perceived financial benefit to encourage voluntary adoption (Beckie et al., 2019; DeVuyst & Ipe, 1999; Duflo et al., 2011; Helling et al., 2015; Larue et al., 2014; Mitchell, 2004; Talberth et al., 2015). Reduced insurance premiums and cost-share programs are the two main financial incentives used in policy to support the adoption of BMPs. In Canada, production insurance and cost-share programs are available under the Canadian Agricultural Partnership (CAP). Production insurance protects producers from losses due to yield reduction from factors such as weather and disease that are beyond the producer's control (Agricorp, 2020). Within the CAP framework, federal and provincial governments fund 60% of production insurance with producers paying the remaining 40% of the insurance premium cost (Agricorp, 2020). Cost-share programs are available for application depending on producer eligibility and include projects related to protection and assurance, economic development, and environmental stewardship (CAP, 2019). The framework for cost-share programs depends on the specific project but can offer up to 65% cost-share funding with a specified project cap (CAP, 2019). Given the Canadian context

for policy incentives, the following paragraphs will discuss the literature related to the use of reduced insurance premiums and cost-share programs to support the adoption of BMPs.

5.2.1   Reduced Insurance Premiums

Canadian production insurance currently does not offer any incentive for producers to adopt BMPs. In the United States, eligibility for federal crop insurance requires compliance with wetland conservation and management requirements for highly erodible land to receive subsidized crop insurance (Shields, 2015). Conservation compliance does not directly incentivise producers to adopt BMPs, however, does require producers to meet a minimum environmental standard to receive reduced insurance premiums (Shields, 2015). Expanding conservation compliance to include the adoption of BMPs to receive further reductions in insurance premiums could effectively increase adoption. To study the expansion of conservation compliance, Ribaudo et al. (2017) examine the effectiveness of including nutrient management practices to reduce excess nitrogen application. Using farm-level data on nitrogen application and insurance premiums, results from hypothetical nitrogen compliance subsidized insurance policy indicate that requiring nitrogen compliance would reduce nitrogen runoff by 60%. Overall, this study provides some evidence to suggest that reduced insurance premiums could provide an incentive to adopt nutrient management and reduce nitrogen runoff.

Rather than requiring conservation compliance to receive subsidized crop insurance, Beckie et al. (2019) suggest offering additional insurance discounts to producers who implement BMPs. Using crop rotation as an example, Beckie et al. (2019) explain that audits can verify and record that crops are effectively rotated each year and reward producers with lower insurance premiums for adopting BMPs. However, this requires the adoption to be verifiable and equally feasible in any location, suggesting that insurance premiums would only be feasible for practices such as crop rotation, cover crops, tillage, pesticide application, and sanitation practices. Mitchell (2004) considers another approach that requires insured farmers to plant a check strip that receives status quo management while the remaining land is managed using an approved BMP. Then at harvest, if there are yield differences between the check strip and the BMP managed area, the producer will receive payments for the yield loss if the value exceeds the deductible. However, this can introduce a moral hazard for producers to maximize the yield of the check strip to receive greater insurance payments. To avoid this, Mitchell (2004) suggests requiring documentation and monitoring from a certified consultant. Empirical results of an insurance pilot project indicate that insurance causes a significant increase in the adoption of BMP when producers receive 50-

85% coverage (Mitchell, 2004). Overall, there is evidence that reduced insurance premiums are an effective incentive to encourage voluntary adoption of BMPs.

5.2.2   Cost-share programs

Cost-share programs are subsidies funded by the government based on public budgeting for producers to receive financial support from payments or discounts for the adoption of qualified BMPs. Different cost-share program structures use different methods for calculating incentive payments or determining discounts for different types of BMPs with varying adoption outcomes. For example, Duflo et al. (2011) found that in Kenya, reducing the cost of fertilizer at harvest significantly increases producer's adoption of fertilizer BMPs. Without discounting the cost of fertilizer, producers procrastinate purchasing fertilizer failing to adopt fertilizer BMPs as a profitable investment (Duflo et al., 2011). Determining that producer is in Kenya prefer an immediate payoff relative to a larger payoff in the future (Duflo et al., 2011). Alternatively, incentive payments that compensate producers for risks and costs associated with the adoption of BMPs need to effectively compensate producers for the adoption of BMPs, not losses related to mismanagement or weather (Larue et al., 2014). This creates discrepancies between the costs of maintaining BMPs and compensation received. For example, Helling et al. (2015) determine the costs of two BMPs, cover crops and rotational grazing for producers in Vermont. Twelve participating farms were asked to document daily labour, inputs, fuel costs, and equipment used for the two BMPs for the entire growing season. Nine farms were already maintaining cover crop and rotational grazing while the other three farms adopted these practices at the start of the study to identify the different costs associated with establishing and maintaining the two BMPs. Data were only collected to determine the cost of activities, materials, and equipment for the adoption and maintenance of the two BMPs. The average cost per acre was then calculated for each of the BMPs aggregated for the entire growing season and analysis compared data for the average incentive payment received in the same year. Results indicate that the average cost to maintain cover crops is $126.23/acre. However, an assessment of incentive payments revealed that producers who maintain cover crops only received $79.45/acre as compensation (Helling et al., 2015). Similarly, results indicate that the average cost to maintain rotational grazing is 70% higher than the incentive payments received. Concluding that incentive payments do not adequately compensate producers for the costs of implementing BMPs.

To overcome incentive payment discrepancies, DeVuyst & Ipe (1999) suggest a group incentive program that results in a Pareto-improvement by comparing nearby participating and nonparticipating producers. The group incentive program consists of two groups of producers that operate in the same

region with similar soil and climatic condition. The average long-run profit is calculated for nonparticipating producers to act as a baseline. Participating producers adopt the recommended BMPs and receive incentive payments based on the percent deviation in average profits from the baseline for nonparticipating producers. Determining a baseline using nonparticipating producers in the same region avoids over and underestimating incentive payments and prevents a moral hazard problem since the baseline is separate from participating producers. To test the effectiveness of a group incentive program Ipe et al. (2001) simulate the program across different scenarios. Results indicate that reducing nitrogen application rates by 25% reduces nitrogen emissions by 23% and compensation payments are between $0.34-1.40/acre. Ipe et al. (2001) conclude that producers over-applying fertilizers can reduce application rates by 35 pounds and maintain profits. This group incentive program does address some of the issues with calculating incentive payments however, it only encourages producers to reduce nitrogen application rates at a level that is profit-maximizing. Allowing risk-averse producers to experiment with new BMPs without the risk of losing profit and effectively increase the adoption of BMPs. However, this limits the group incentive program to BMPs that are triable and have observable profit-maximizing outcomes.

An alternative method known as pay for performance allows the producer to decide the appropriate BMP adopt and receive incentive payments based on the amount of pollution reduction achieved. This motivates producers to reduce pollution to a larger degree compared to the private profit-maximizing rate since incentive payments are calculated based on the benefit to the public by providing an environmental service. Talberth et al. (2015) model pay for performance system in the Chesapeake Bay watershed. Results indicate that applying pay for performance policy scenario, BMP adoption achieves a 32% reduction in total nitrogen pollution and a 29% reduction in total phosphorus each year. Furthermore, the pay for performance policy scenario is more cost-effective and efficient at reducing pollution than the previous subsidy program in the Chesapeake Bay watershed. Overall, the literature examines different methods to calculate incentive payments with various strengths and limitations. Regardless of the method used, evidence suggests incentive payments increase the adoption of BMPs.

5.2.3   *Experimental Evidence for the use of Incentives*

In a laboratory experiment with undergraduate students, Palm-Forster et al. (2018) use framing to determine if subsidies are an effective strategy to achieve water quality goals. Participants were asked to make management decisions based on ten different input levels and management decisions based on either conventional or conservation technology. Choosing conservation technology has an additional cost and reduces emission based on the level of input and conventional technology has no additional cost but

has greater emissions based on the level of input. Participants were randomly assigned to a group of six and earned money based on production income earned and the amount of pollution emitted from the decision during five rounds across four treatments. The treatments included a control with no policy, a tax-based policy, a subsidy reduction policy, and a subsidy reduction policy with no penalty for participants who chose to adopt the conservation technology. Results indicate that the tax-based policy and subsidy reduction policy equally reduced pollution below the control of no policy and approached the socially optimal pollution level. Furthermore, when participants were assured that they would not be penalized by the subsidy reduction if they adopted the conservation technology, participants were significantly more likely to adopt the conservation technology. Without assurance, participants chose the conventional management option with lower input levels to reduce emissions rather than choosing to adopt conservation technology. Overall, evidence from this experiment suggests that incentives to avoid penalties with subsidy reductions introduce a cost-effective way to reduce pollution and overcome problems with financial penalties of tax-based policies by assuring producers who invest in conservation technology will not be penalized by producers who pollute within the same watershed.

Similar results were found by Holst et al. (2014) using a business simulation game where producers at an agricultural exhibition in Germany were randomly selected to manage a virtual farm making cultivation decisions based on the cost of cultivation, type of crop and stochastic variables including market price and weather impact on yield. Crop type options include biogas plants such as silage maize, sorghum, and flowering cover crops. Flowering cover crops are considered an alternative to unsustainable biogas plants as they provide habitat for wildlife and a source of food for pollinators. Producers make decisions for twelve production periods, during the last six periods the conditions change to introduce one of three randomized policy scenarios including a reference scenario that remains unchanged, a reward scenario, and a penalty scenario. The reward scenario introduces a premium for growing flowering cover crops and subsidizes the price for cultivation. The penalty scenario introduces a financial penalty for growing flowering cover crops on less than 10% of cropland. The income effect for the reward and penalty scenario is the same only the framework is different. Results indicate that the reward and penalty scenario increased the cultivation of flowering cover crops. Further supporting that producers are influenced by incentives and the opportunity cost effect.

Kuhfuss et al. (2015) use a choice experiment to determine preferences of wine producers in Languedoc-Roussillon, France for an herbicide-reduction payment with a bonus conditional on the number of other producers in the area who enroll in the program. Therefore, the greater number of

participating producers, the greater chance of receiving the bonus. This framework attempts to encourage more producers to enroll and contribute to the public good by reducing herbicide use contributing to the contamination of water. Determining a producer's willingness to accept different attributes of a program with a conditional bonus. Results indicate that the introduction of a conditional bonus has a significant and positive effect on the decision to enroll in a program with a collective incentive. Furthermore, producers who believe that other producers will also enroll in the program are significantly more likely to participate in the collective incentive program. Producers enrolled a larger area of land in the program with the conditional bonus compared to the program option without a conditional bonus suggesting that producers enroll more land to increase the probability of receiving the bonus. Therefore, the conditional bonus has a significant positive effect on the amount of land enrolled in the program. Overall, this study provides evidence that a collective incentive effectively increases the participation and commitment of land to programs with a conditional bonus.

5.3 *Barrier Removal*

Financial incentives assume that producers are motivated by economic factors however, nonfinancial motivators are also important for voluntary BMP adoption. Delivering resources such as education and BMP training enable producers to overcome information, time and incompatibility barriers and support behavioural change towards voluntary BMP adoption (Arbuckle, 2013; Boland et al., 2006; DeAngelo & Nielsen-Pincus, 2017; Kalcic et al., 2014; Lubell & Fulton, 2008; Perry-Hill & Prokopy, 2015; Tamini, 2011). For example, DeAngelo & Nielsen-Pincus (2017) analyze how producer attitudes influence the adoption of BMPs to evaluate the effectiveness of different policy tools. Results reveal that financial incentives have an insignificant effect on the adoption of BMPs and the belief that producers don't have enough time to implement BMPs is a significant barrier for adoption BMPs. To overcome this barrier, providing producers with a dedicated staff member to implement BMPs significantly increased the adoption of BMPs. This suggests that providing an additional staff member is the appropriate compensation to effectively remove time constraint barriers increasing the adoption of BMPs compared to simply providing financial compensation.

Insufficient knowledge and information about BMPs are a significant barrier to adoption. Extension activities overcome this information barrier by providing formal and informal BMP training with demonstrations and information sessions through education programs offered by the government. Tamini (2011) found that producers who participate in extension activities are significantly more likely to adopt BMPs that require advanced technical knowledge. Extension activities are critical in disseminating

information, providing support and advice from experts, and raising awareness for BMP adoption (Tamini, 2011). Extension educators are essential to overcome information barriers, Perry-Hill & Prokopy (2015) interview extension educators to understand their perspective on the adoption of BMPs. Results indicate that BMP adoption is not a simple linear process of learning and implementing, each farm is unique requiring support through trial and error to successfully implement a BMP (Perry-Hill & Prokopy, 2015). For example, BMPs are often designed for large scale operations making it difficult to apply the same recommendations on a small operation (Perry-Hill & Prokopy, 2015). Individualized support from an extension educator helps to overcome these challenges and successfully implement BMPs.

A New Zealand study monitored stream health of deer producers who receive information about BMPs and compared results with deer producers who did not receive BMP information (Rhodes et al., 2007). Rhodes et al. (2007) predict that deer producers who received BMP information would have healthier streams than deer producers who did not receive the same information. However, results indicate that there was no significant change in stream health between the two groups, suggesting that a one-time delivery of information failed to increase the adoption of BMPs. Furthermore, Boland et al. (2006) evaluate the effectiveness of extension activities to increase the adoption of BMPs. Extension activities that include demonstrations, support with technical issues and provide regular feedback with an appropriate management response significantly increase the adoption of BMPs (Boland et al., 2006). Indicating successful extension activities are resource-intensive requiring one-on-one input and on-going monitoring. Overall, extension activities successfully overcome information barriers however, successful adoption of BMPs depends on the quality of education services.

Bold et al. (2017) use a field experiment to identify a barrier to access for high-quality fertilizer and hybrid seed for producers in Uganda. Low adoption rates for fertilizers and hybrids seed results from the ineffectiveness of these technologies due to low quality. Producers are unable to identify low quality hybrid seeds and diluted fertilizers from those that are authentic high-quality products. Overall, without access to the quality inputs producers are not adopting agricultural technologies. Overcoming this access barrier could improve the adoption of hybrid seeds and fertilizers in Uganda.

Government agencies provide a variety of services that support producers and the adoption of BMPs however, these services are constrained by limited resources. Providing services equally to all producers is not an effective use of resources since not all producers contribute equally to environmental degradation. An alternative strategy known as targeted BMP aims to identify vulnerable lands and assist in improving the damage thereby efficiently achieving the greatest environmental benefit (Arbuckle,

2013; Kalcic et al., 2014). Targeted BMP recognizes the disproportion of producers who contribute to environmental issues and prioritizes BMP support on vulnerable lands where unsustainable agricultural practices are occurring (Arbuckle, 2013; Kalcic et al., 2014). A survey of producer perceptions for targeted BMP reveals that producers support a targeted strategy that minimizes negative environmental impacts with efficient use of government funding (Arbuckle, 2013). Furthermore, respondents who support a targeted approach believe that producers who contribute more to environmental degradation are less likely to seek assistance. Results also reveal that producers perceive targeted BMP as excessive regulation that singles out producers forming concerns about government intrusion (Arbuckle, 2013). Government distrust is only expressed by a small proportion of producers and is a reflection of frequent negative interactions with conservation agencies disregarding producer knowledge of their land (Kalcic et al., 2014). Without communication and trust between agency officials and producers, a policy cannot be implemented effectively (Lubell & Fulton, 2008). Overall, targeted BMP is an effective strategy when producers have supportive and trustworthy relationships with government officials.

5.4   *Implications*

Unsustainable agricultural practices contribute to global environmental problems including biodiversity loss, non-point source pollution, and climate change. These issues cannot be solved by a single strategy. Each policy approach is relevant for different producer motivations, beliefs, operations, and types of BMPs. The combination of different policy approaches is important to achieve successful BMP adoption at multiple scales. Overall, effective policy removes barriers, provides quality educational services, targets vulnerable land, and incentivises producers to voluntarily adopt BMPs. Furthermore, policy strategies need to consider the feasibility, verifiability, monitoring, auditing, and adequate compensation to achieve widespread BMP adoption. Collaboration between policymakers, the scientific community, and individual producers can further improve policy to achieve widespread voluntary BMP adoption.

Section 6: Future Research Opportunities

The following section provides an overview of the BMP adoption literature based on the information in this report. Review of the consistencies and inconsistencies in the BMP adoption literature reveals knowledge gaps that are not fully understood. The objective is to identify the knowledge gaps in the BMP adoption literature and suggest opportunities for future research to overcome the necessary knowledge gaps.

The BMP adoption literature included in this review can be summarized as inconsistent and consistent factors that influence the adoption of BMPs. Consistent factors include education, attitude towards the environment, environmental awareness, heritage, and income frequently resulting in a positive significant effect on BMP adoption across the literature. Additionally, debt consistently results in a significant negative effect on the adoption of BMPs. Inconsistent factors include age, experience, tenure, risk aversion, farm diversification, and farm size and have shown mixed results in the literature and debatable effects on BMP adoption. These inconsistent factors are associated with individual socioeconomic factors and farm characteristics. Since socioeconomic factors and farm characteristics have been found to have different effects on BMP adoption without a clear understanding of the role in the adoption of BMPs, future research is needed to develop this understanding. One aspect that has not been explored in the BMP adoption literature is the application of a gender-based analysis plus (GBA+). GBA+ is an analytical process that not only examines gender but other identities including religion, race, ethnicity, and disability to determine how people experience policies, programs, and initiatives (Government of Canada, 2018). Few studies have examined how gender and cultural factors affect the adoption of BMPs, a GBA+ could provide important information on how diverse groups experience BMP adoption programs. The use of GBA+ to study BMP adoption could introduce an opportunity to expand the understanding of socioeconomic variables beyond what has already been studied in the literature. Furthermore, GBA+ can assess the inclusivity of BMP adoption policies that have not otherwise been explored in the literature to ensure BMP adoption programs are accessible to everyone.

To address the consistencies and inconsistencies in the BMP adoption literature a systematic review examining the variable frequency and the resulting relationship with BMP adoption could be valuable towards understanding nuances that affect BMP adoption. Since some variables have been studied more frequently than others, a systematic review could provide a better understanding of why there are inconsistencies in the literature and identify universal variables that predict adoption. For example, producer access to the internet is an emerging factor impacting BMP adoption as more individuals use the internet to access information. Future research could identify if producers are using the internet to access information about BMPs and determine the accessibility and quality of BMP information online increases BMP adoption. Additionally, understanding the nuances related to the consistent variables mentioned can develop a complete understanding of their role in BMP adoption behaviour. For example, education variables can be further differentiated as formal education and technical BMP education and information variables can be further differentiated as information from

extension services and information from neighbours, friends, and family, each with distinct outcomes on BMP adoption behaviour. Further refining and testing consistent variables will ensure that results are robust across the BMP adoption literature. There is an opportunity for behavioural studies to refine the understanding of these variables by isolating variables and experimentally identifying cause and effect relationships.

The BMP adoption literature has already seen some studies apply economic experiments to understand adoption behaviour. The majority of these studies have focused on understanding producer risk preferences, information and awareness, and the effectiveness of financial incentives for increasing BMP adoption. The experimental literature has applied laboratory experiments, artefactual experiments, randomized control trials and framed field experiments to study BMP adoption behaviour. In addition to testing the validity of correlated effects on BMP adoption, experimental research could be used to address the inconsistencies of existing research to understand behavioural factors influencing producer decision-making. Economic experiments can offer greater control over variables to isolate causal relationships and develop a better understanding of BMP adoption outcomes related to producer age, producer experience, land tenure, producer risk aversion, farm diversification, and farm size. Furthermore, future research could apply behavioural experiment to better understand the underlying behavioural mechanism that can be used to develop policy interventions that are cost-effective and motivate behavioural change. This would be especially useful to understand behavioural factors that impact the adoption of aquaculture BMPs since there is limited research regarding the adoption of BMPs in the aquaculture sector.

Across all the studies reviewed in this summary, few of them focus on BMP adoption in a Canadian context. Future research opportunities would benefit from exploring variables and policy implications in Canada to determine if results are consistent with the rest of the literature. Additionally, a majority of the economic experiments reviewed in this summary are either carried out in developing countries or Europe, with a few conducted in the United States and China. The application of experimental and behavioural economics to study BMP adoption in Canada would add considerable value to the BMP adoption literature. For example, applying behavioural interventions such as nudges or framing to programs under the CAP could identify both successful program features and barriers to participation. This information can enhance programs for Canadian producers and encourage the adoption of BMPs using behavioural economic approaches that motivate change. Overall, understanding BMP adoption in a Canadian context will expand the current literature and improve policies and programs to support the adoption of BMPs in Canada.

Conclusion

This summary reviewed the BMP adoption literature including the theoretical framework, major themes, BMP characteristics, industry trends, policy implications, and research opportunities. The behavioural theories relevant to study BMP adoption include utility, prospect theory, the theory of planned behaviour and the diffusion of innovation theory. The application of these theories to model producer adoption behaviour relies on collecting and understanding real-world data using an empirical evidence-based approach. The BMP adoption literature applies both qualitative and quantitative methods of observation combined with regression modeling and non-parametric approaches for empirical analysis. Examination of the BMP adoption literature for major themes revealed four categories of frequently studied variables including socioeconomic variables, risk and uncertainty, information and awareness, and financial variables. Review of BMP characteristics revealed that profitability is one of the main determinants of BMP adoption. Additionally, the observability, complexity, and trialability of a BMP influences adoption, however, these are less frequently studied as determinants for BMP adoption. Furthermore, environmental, and social factors revealed the importance of social networks and environmental awareness influencing adoption behaviour. The review of industry trends considered differences in BMP adoption behaviour in livestock, crop, and aquaculture productions. This revealed different contributions to global environmental problems and specific BMPs designed to reduce negative externalities associated with each industry. Distinct agricultural industries and BMP characteristics promote diverse policy implications. Review of policy implications revealed strategies that remove barriers, provide quality educational services, targets vulnerable land, and incentivises producers facilitating the voluntary adoption of BMPs. Finally, research opportunities provided an overview of the BMP adoption literature identifying knowledge gaps not fully understood and suggests areas for future research.

BMP adoption behaviour is dynamic and complex with a variety of opportunities for future research. Collective action between producers, governments, the scientific community, and policymakers will encourage widespread BMP adoption. BMPs aim to maintain the economic and social viability of agricultural production for future generations by improving the environmental sustainability of

agriculture. The adoption of BMPs strengthens agricultural productivity and conserves natural resources for long-term food security.

Tables and Figures

Table 1: Summary of factors that influence the adoption of BMPs. A significant positive effect is identified by a + sign, a significant negative effect is identified by a – sign, an insignificant effect is identified by a ⊘ symbol and, no research available is identified by an N. The numbers in square brackets correspond to the references that reported the effect. Specific explanations for the effects summarized in this table can be found in section 2 for general findings and section 3 for findings in specific agricultural sectors.

Category	Factor	Effect (+/-/⊘/N)	General findings across all agricultural sectors	Findings in specific agricultural sectors		
				Livestock production	Crop production	Aquaculture
Socioeconomic variables	Age	-	[12, 34, 67, 78, 88, 100]	[38, 40, 46, 61, 89, 111]	[18, 28]	[31]
		+	N	[60, 86, 98]	N	N
		⊘	[62, 71]	[49, 51]	[104]	[80]
	Farming experience	-	N	[86]	N	N
		+	N	[40, 43, 85, 98]	N	N
		⊘	[12, 19, 34, 62, 67, 71, 88]	N	[28, 32, 69, 72, 104, 105]	[31]
	Formal education	+	[19, 24, 34, 62, 67, 71, 78, 88, 97, 100]	[38, 40, 51, 54, 60, 61, 85, 98, 111]	[28, 32, 69, 104, 105]	[80]
		⊘	[12]	[43, 49, 86, 89]	N	N
	Extension education and participation in government programs	+	[12]	[38, 43, 46, 49, 51, 60, 85, 86, 89, 98, 111]	[15, 28, 69, 72, 104, 105]	[31]
	Attitude or concern towards the environment	+	[7, 12, 19, 62, 67, 88]	[38, 49, 51, 60, 85, 89, 111]	[28, 32, 72]	[80]
		⊘	[32, 78]	N	N	N
	Environmental awareness	+	[12, 32, 59, 62, 67, 71, 88]	N	[28, 69, 72, 104, 105]	N

Risk and uncertainty variables	Tenure	-	N	[89, 48]	N	[80]
		+	[100]	[38, 43, 60]	N	N
		⊘	[12, 19, 62, 71, 78, 88]	[61, 86]	[28, 32, 104, 105]	N
	Risk aversion	-	[14, 70, 71]	[38, 49, 60, 61]	[10, 28]	N
		+	N	[89, 98]	N	N
		⊘	[12, 67, 88]	N	N	N
	Farm diversity	-	N	[61]	N	N
		+	[71, 78, 88]	[38, 60, 89]	N	[80]
	Heritage	+	[32, 71, 88]	[61]	N	N
		⊘	N	[43, 49, 60, 86]	N	N
Financial variables	Income	+	[12, 19, 24, 62, 71, 97]	[38, 49, 54, 85, 111]	[18, 104]	N
		⊘	[88]	[61, 86, 40]	[72]	[80]
	Debt	-	[62, 97]	[43, 60, 61, 85, 111]	N	N
	Farm size	-	N	[43, 61, 98]	[32]	N
		+	[9, 12, 71, 88, 100]	[46, 51, 54, 86 89, 111]	[18]	[80]
		⊘	[24, 32, 62, 78]	[38, 60, 49]	[28, 69, 72, 104, 105]	[31]

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