Application of the TEEBAgriFood Evaluation Framework to Corn Systems in Minnesota, U.S.A

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Harpinder Sandhu, PhD *et al.*
harpinder.sandhu@flinders.edu.au

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Authors affiliations
Harpinder Sandhu (EcoStratEx, University of South Australia, and Flinders University, Australia), Nadia Scialabba (FAO, Rome), Chris Warner (Simetrica, London, UK), Fatemeh Behzadnejad (Simetrica, London, UK), Kieran Keohane (Simetrica, London, UK, Richard Houston (Simetrica, London, UK), Daniel Fujiwara (Simetrica, London, UK), Ryan Noe (Institute on the Environment, University of Minnesota, USA), Peter Hawthorne (Institute on the Environment, University of Minnesota, USA), Bonnie Keeler (Institute on the Environment, University of Minnesota, USA), Jennifer Schmitt (NorthStar Initiative, University of Minnesota, USA)

Project Advisory Committee
Mauricio Bellon (CONABIO), David Bakter (Earth Economics), George Boody (Land Stewardship Project), David Gould (IFOAM), Mike Hamm (Michigan State University), Patrick Holden (Sustainable Food Trust), Kathleen Merrigan (George Washington University), Alexander Müller (TEEBAgriFood), Carl Obst (Institute for the Development of Environmental-Economic Accounting), Stephanie White (Michigan State University), Jane Maland Cady (McKnight Foundation), Bruce Hirsch (Clarence E. Heller Foundation), Ruth Richardson (Global Alliance), Lauren Baker (Global Alliance), Zanele Sibanda (Global Alliance)

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Acronyms

BMP Best Management Practice
Bt *Bacillus thuringiensis*
Bu Bushel
CDL Cropland Data Layer
CH_4 Methane
CI Chemical Input
CIMMYT International Maize and Wheat Improvement Center
CO_2e Carbon di Oxide Equivalents
CONABIO National Commission for the Knowledge and Use of Biodiversity, Mexico
CRP Conservation Reserve Program
CSP Conservation Stewardship Programs
DDG
EMA Environmental Management Accounting
EPA Environmental Protection Agency
EQIP Environmental Quality Incentive Program
ERS Economic Research Service
FDA Food and Drug Administration
GAFF Global Alliance for the Future of Food
FAO Food and Agriculture Organisation
UNE United Nations Environment
GCFI Gross Cash Farm Income
GDP Gross Domestic Product
GI Glycaemic Index
GM Genetically Modified
GMO Genetically Modified Organisms
HFCS High Fructose Corn Syrup
Ht Herbicide Tolerant
ICTs Information and Communication Technologies
IPES The International Panel of Experts on Sustainable Food Systems
K Potassium
LU Land Use
MARCH Methodology for valuing the Agriculture and the wider food system Related Costs of Health
MN Minnesota
N Nitrogen
N_2O Nitrous di Oxide
NASS National Agricultural Statistics Service
NCGA National Corn Growers Association
NIFA National Institute of Food and Agriculture
NOx Nitrogen dioxide and nitric oxide
OECD Organisation for Economic Co-operation and Development
OI Organic Input
P Phosphorus
PM2.5 Particulate Matter smaller than 2.5 micrometres (0.0025 mm) in diameter
QALY Quality Adjusted Life Year

SCI Social capital index
SDG Sustainable Development Goals
SEEA System of Environmental-Economic Accounting
SNA System of National Accounts
SWV Subjective Wellbeing Valuation
TCA True Cost Accounting
TEEB The Economics of Ecosystems and Biodiversity
TEEBAgriFood The Economics of Ecosystems and Biodiversity for Agriculture and Food
TEF TEEBAgriFood Evaluation Framework
UNSD United Nations Division for Sustainable Development
UNU-IHDP United Nations University - International Human Dimensions Programme
USA United States of America
USD United States Dollar
USDA United States Department of Agriculture
WHO World Health Organisation
WVS World Values Survey

Conversion factors

1 Bushel of Corn = 56 pounds = 25.40 kg
1 Acre = 0.4 hectare = 4046 square metre

EXECUTIVE SUMMARY

The report highlights key positive and negative externalities associated with genetically modified (GM) and organic corn production systems using TEEBAgriFood Evaluation Framework (TEF). TEF is developed and supported by the Global Alliance for the Future of Food in partnership with United Nations Environment. Its main goal is to make agriculture and food systems more accountable and transparent using true cost accounting (TCA) method. This report applies TEF to examine various impacts and dependencies within the value chain of corn in Minnesota, as a part of understanding practice in the Mississippi river basin production systems. It also describes various opportunities for shifting practices, and policies to improve outcomes for farmers, industry and policy makers in the region.

Corn, with a global production of 42 billion bushels from 467 million acres, is second to sugarcane in terms of production. In global trade, it is the second largest agricultural commodity after wheat. Corn plays an important role in the global economy, with USA producing over one-third of the global corn from 82.7 million acres. In USA, about 88% of the corn is GM, followed by hybrid varieties, whereas, certified organic corn represents only 0.02% of the total area. In order to examine diverse corn-based farming systems, two contrasting management systems– GM corn and organic corn were selected in this study. GM corn is grown in rotation with soybean as a monoculture, whereas, certified organic corn is grown in mixed farming systems.

The TEF is applied to these two corn production systems along with their value chains in Minnesota to reveal impacts and dependencies on produced, social, human (including health) and natural capital to evaluate hidden costs and benefits of corn production. There are four key elements of the TEF - stocks, flows, outcomes and impacts. A systems approach is applied to quantify stocks and flows of four capitals and to identify change in social, environmental and economic well-being of farming and wider community. The study reviewed existing scientific literature to assess all capitals. We used Minnesota State average corn production data in this study. However, the health impacts of corn are based on primary research conducted during this work. Here the key outcomes of the study are provided as stocks and flows of each capital related to two systems, policy and systems drivers, impact and dependencies highlighted by the TEF, and usefulness for decision makers along with key messages and recommendations for research, practice, and policy.

Produced capital

- **Corn is a crop of economic significance.** Total area planted under corn in 2017 was 90.1 million acres (harvested 82.7 million acres), with an average yield of 176.6 bushel per acre in US. Total value of corn was $48.46 billion (average price of $3.30 per bushel) in US. Minnesota was fourth with 8.05 million acres under corn (harvested 7.6 million acres) with an average yield of 194 (range of 131 – 218) bushels per acre. Total value of corn in Minnesota was $4.51 billion (average price of $3.05 /bushel). About 92% of this was genetically modified (GM) and rest was hybrid corn. Minnesota with over 500 certified organic farms and 130,688 acres is ranked ninth in the US for the total number of organic farms. Organic corn in Minnesota is 14 percent of the total US production but about 1% of Minnesota corn. Corn for grains was produced on about 160 farms with 28,524 acres, yielding average of 150 bushels an acre in Minnesota. Organic corn prices are higher than the conventional corn prices, at $7.46 per bushel, where five-year average is above $10 per bushel.

- **GM corn as an energy crop.** In US, GM corn is widely grown for ethanol production with dried distiller grains (DDGs) as a by-product for animal use. Conventional corn comprises of hybrids which are also used for ethanol production or other feed, food or industrial uses.
- **Organic corn as food crop.** Organic corn is grown for niche markets, such as organic animal feed, tortilla chips etc.
- **Cost of production.** Variable inputs cost in GM corn are higher than those in the organic corn based on the average yield data in US. Fixed capital costs in organic farms are higher than GM corn due to their small size. Corn yield based on average data obtained from USDA suggests higher yield in GM corn than the organic corn. Net returns are found to be higher in organic corn in Minnesota as well as in US.
- **Contribution to fuel vs food.** One bushel (56 pounds) of corn yields about 2.8 gallons of ethanol and about 17 pounds of dried distiller grains (DDGs). These DDGs used as animal feed can produce 8.5 pounds of beef. Whereas, one bushel of corn used directly as animal feed can yield 28 pounds of beef. It is noteworthy that organic corn is directly used for animal feed.

Social capital

- **Dominant crop of social importance.** Corn is a dominant crop in Minnesota and is vital for the agricultural economy. About 24,000 corn farmers generated more than $4.5 billion for the economy of Minnesota.
- **Corn-based social networks.** Various types of social networks in Minnesota provide required resources, information and knowledge to corn growers. There are both public and private sector networks and community groups that provide support to corn farmers in Minnesota. There are clear benefits to farming community, environment and society from the social networks associated with both types of corn systems. Social networks enable rural community to cope with the increasing challenges of market volatility, climate change and degradation of natural resources. However, the study did not examine strengths and weaknesses of each network and how they are impacting corn growers' behaviors.

Human capital

- **Urban and rural divide.** There is growing divide between rural and urban population in Minnesota due to urban migration trends since 1900. Partly this is due to increasing size of GM corn farms in order to achieve economies of scale.
- **Ageing farmers.** The average age of farmers is more than 55. Majority of rural population has high school qualification as opposed to urban and towns, where there are higher qualifications.
- **Health costs of GM corn.** There are high health costs associated with GM corn production. Total annual health costs associated with corn production in Minnesota is $1.3 billion, or $233 per capita, or $171 per acre (for 7.6 million acres of harvested corn in Minnesota in 2017). Increasing intensity of corn cultivation by 1% costs each of the residents within a 10 km radius $24.7 per year. These non-financial health costs associated with corn production is equivalent to 28.8% of the total value of corn in Minnesota ($4.51 billion). To estimate the health costs, we applied the Well-being

Valuation (WV) method, which offers an alternative to the Quality-Adjusted Life Years (QALYs) approach of valuing the non-financial costs of health. Health costs estimated here are based on the production side of the corn value chain, linked to the corn intensity effect on environmental quality. These non-financial health costs do not include capital costs incurred in the public health system, individual medical expenditures, loss of economic productivity, and loss of taxes and Gross Domestic Product (GDP). The main health risk pathways of corn consumption come from GM corn-fed livestock and poultry products that may carry contaminants and sweet beverages with HFCS, with the later associated with high incidence of obesity and type 2 diabetes. GM and hybrid corn production systems notably use large amounts of ammonium and nitrate fertilizers and herbicides. Improvements introduced in GM corn management are limited to minimum tillage and cover cropping to save resources while enhancing soil fertility, without addressing the excess chemical load produced by corn systems throughout watersheds. Fertilizers, herbicides and dust from corn systems have been associated with different types of cancer (affecting digestive and reproductive organs and blood) and respiratory diseases. With the increasing adoption of no till systems, NOx and subsequently PM2.5 emissions, are expected to decrease in GM systems.

- **Health impacts of organic corn.** Regarding organic corn production, there is some evidence of the reduced adverse health impact of corn intensity associated with the presence of local organic production. However, a more rigorous analysis of the impact of organic production is required. Organic corn farming does not target High Fructose Corn Syrup production, nor uses genetically-modified seeds and synthetic fertilizers, pesticides and herbicides, so it is assumed that the absence of contaminants in organic corn consumption has a neutral impact on health. In addition, corn consumption *per se* has positive impacts on health, thanks to the absence of gluten, lower glycemic index and higher content of vitamin E and minerals, such as Zn and Se.

Natural capital

- **Benefits.** The benefits and negative externalities associated with corn production in terms of impacts on climate change, water quality, air quality, and soil quality, are estimated, using existing studies.
- **Costs.** Total environmental cost associated with GM corn production is $71.60 per acre or $557.65 million annually in Minnesota, however uncertainty and spatial heterogeneity cause this estimate to vary greatly. Environmental costs estimated here are based on the production side of the corn value chain, linked to the inputs in corn production and do not include environmental costs associated with the transport, processing, and consumption. In addition, costs on agricultural and wild biodiversity are not estimated, nor impacts outside Minnesota, through the Mississippi River watershed.
- **True cost of corn.** Given the data and information presented in this report, we estimate the true cost of corn production as shown in below table.

	GM corn	**Organic corn**
Market price ($/bushel)	3.05	7.46
Environmental costs associated with fertilizer use ($/bushel)	0.37	Not quantified due to lack of data on organic farms.

Environmental costs associated with energy use ($/bushel)	0.02	0.03
Health cost ($/bushel)	0.88	0. Although there is some suggestive evidence for reduced adverse association of organic corn production with general health, quantifying the health costs requires data on exact location and planted area of organic corn farms.

Policy and other system drivers

- **National policy.** Market forces linked with U.S. Federal policy have driven corn production in Minnesota and throughout the Midwest. While corn has been major commodity in the region for decades, recent policy changes to the Farm Bill and the enactment of the Renewable Fuel Standard have protected and incentivized corn production by subsidizing insurance for corn production and mandating production volumes of corn-based ethanol.
- **Demand.** Increased demand for corn for ethanol and reductions in funding for the U.S. Conservation Reserve Program have resulted in conversion of hundreds of thousands of acres of retired land to corn production. These policies contributed to record corn production expansion in the U.S., both through crop switching and expansion on to marginal land.
- **Market price.** US farm policy of the past 50 years has been driving down corn prices, while government support to fruit and vegetable prices has steadily decreased; high fructose corn syrup is nowadays the cheapest substance to produce and the hardest to avoid. Low corn prices have also contributed to the expansion of grain-fed animals which products are higher in saturated fat and cholesterol and lower in beneficiary fatty acids, with antibiotic-resistant bacteria that compound public health risks.

Mapping to TEEBAgriFood framework

- **Dependencies**. Mapping of information to the TEF analysed in this study reveals the impacts and dependencies of corn production on four capitals. Corn production system is dependent on all four capitals. Mapping of data from the analysis suggests there is increase in produced and social capital in both systems. However, there is much scope to increase all four capitals in organic production systems, as the area under organic agriculture is less than 1% in Minnesota.
- **Impacts.** Natural capital and health impacts of GM corn in Minnesota are significant at, $0.56 billion and $1.3 billion, respectively. Current natural capital assessment is based on nutrient use only. However, much of the social costs associated with pesticides use, land use -change, biodiversity etc. remain unaddressed. For **GM corn production systems**, there are positive economic impacts, however, the divide between small- and large-scale farmers is increasing, leading to negative health and environmental impacts. GM corn is used for producing ethanol as it is supported by the current energy policy. It is contributing positively to the economic livelihood of farmers. For **organic production systems**, there are positive economic, and health impacts, while limited environmental impacts due to use of tillage and fossil fuel use in operations.

Decision making

- **Decision makers at farm and policy level** can use the information about social and environmental costs and benefits to modify practices and relevant policies for better outcomes for agriculture and society. Given the negative impacts associated with some of the practices in GM corn systems, farming community can adopt best and sustainable practices or alternative management systems (such as organic system), which are less damaging to the soil, water and biodiversity of the farm and help in conservation of resources and increase productivity. Macro level policies can incentivise different types of farming systems for generating positive social and environmental outcomes in terms of employment, food and ecological security.

Key Messages

- **Corn is a crop of economic importance** in US and Mississippi River Basin, as it adds $48.5 billion and $4.5 billion annually to the US and Minnesota economy, respectively. GM and conventionally (hybrid) grown corn dominate the landscape with organic corn grown in fraction of area in Minnesota. GM corn is grown primarily for ethanol production. A byproduct from ethanol process is used for animal feed. Whereas, organic corn is used directly as animal feed. Renewable Fuel Standard, reduced funding for the U.S. Conservation Reserve Program (USCRP) and market prices are the main drivers of corn expansion.
- **Corn produced for livestock feed is much less efficient at producing human food calories** per unit area than crops produced for direct human consumption. Efficient use of land resources and alternative production systems are required to meet the food and nutrition needs of the population.
- **Net returns are higher in organic corn systems.** GM corn yield is higher than the organic corn. However, net returns are lower due to high variable costs of agrochemicals and lower market price, as compared to the organic corn.
- **Large amount of fertilizers and herbicides are used in GM production systems**. It increases the cost of production and lowers net returns. In addition, there is continuous export of nitrate, phosphorus, and sediments from farmland to watersheds, ravines in the Mississippi river basin leading to hypoxic zone in the Gulf of Mexico. However, these farming systems are being modified to include sustainable practices or Best Management Practices (BMPs), such as inclusion of cover crops, minimum or strip tillage to minimize soil degradation and prevent loss of nutrients from the system. Some of the practices are part of the Environmental Quality Incentive Program (EQIP) and Conservation Stewardship Programs (CSP).
- **TEEBAgriFood framework is a relevant framework** to identify and analyse positive and negative externalities in agriculture and food systems. This is being used to understand various impacts and dependencies and capital base of corn-based farming systems in Minnesota. Corn production depends on produced capital and is supported by extensive social networks in Minnesota. Regarding human capital, there is growing divide between urban and rural population. Moreover, there are significant health costs associated with GM corn production. Natural capital in terms of impacts on climate change, water quality, air quality, and soil quality are impacted negatively by GM corn production in Minnesota.
- **High hidden cost of GM corn.** TCA is used to estimate the hidden cost of corn in Minnesota. Each bushel of GM corn generates negative environmental externalities of $0.39 and $0.88 for health cost, when the market price is $3.05 per bushel. Corn-based ethanol as a fuel source increases demand for corn and thus increases the associated environmental impacts without a clear reduction in the carbon intensity of fuel.
- **GM corn and associated health risks.** The result of study demonstrates that general health of individuals decreases by 0.67% with corn production in the respective zip code, totaling annual non-financial health costs of corn in Minnesota to $1.3 billion. GM and hybrid corn production systems notably use large amounts of ammonium and nitrate fertilizers and herbicides. Fertilizers, herbicides and dust from corn systems have been associated with different types of cancer (affecting digestive and reproductive organs and blood) and respiratory diseases. With the increasing adoption of no till systems, NOx

and subsequently PM2.5 emissions, are expected to decrease in GM systems. Considering that organic corn production refrains from chemical usage, it is assumed that these systems' agri-environment have a neutral impact on health.

Recommendations

- Practitioners can use the outcome from this application of TEF in corn systems to make a decision about production systems and practices that can improve all four capitals. Whereas, policy makers can use this information to incentivize such systems that can enhance social, environmental and economic well-being of farmers and society at large. However, this require a major shift in US agricultural and energy policies that favor the current GM corn systems.
- For social and human capitals, further research is required to link different production systems with impact on these capitals. There is need to understand bonds and linkages of various social networks of corn growers so that these can be improved for better outcomes for both.
- Research on health impacts of corn systems provides tentative evidence for a potentially positive effect of organic corn systems, as compared to GM corn operations. However, more research is required, with finer resolution data than district level data, including detailed locations of survey respondents and planted areas of organic production in order to estimate the health costs of organic corn. Granular data would also facilitate the development of an improved causal framework, affording future research increased confidence in its findings, and offering deeper insights. Expanding the analysis to include other corn-producing states would provide evidence as to whether the negative health effects of corn production hold on a broader scale, and in doing so increase sample size available to researchers.
- The study reviewed impacts of two corn production systems on natural capital especially soil, water, and air. There are significant social costs associated with regards to the nutrients (synthetic fertilizers in GM corn and manures in organic corn) applied in both systems. Best management practices (BMPs) such as minimum tillage and using cover crops are effective at reducing nutrient and soil export in both conventional and organic systems and thus are effective at reducing the social cost associated with nutrient use. Policies that support the use of effective targeting by using integrated assessment models and multi-factor evaluations are required to maximize social benefits. In addition, there are social costs and benefits associated with indirect land use change, and biodiversity impacts of pesticide use, habitat loss, and water use that need to be further investigated.
- Corn-based ethanol production has increased the demand for corn and hence associated environmental impacts without a clear reduction in the carbon intensity of fuel. Moreover, corn produced for animal feed is much less efficient at producing human food calories per unit area than crops produced for direct human consumption. Therefore, efficient use of land resources is required as an alternative strategy to minimize the social costs of food (corn) production.
- TEF used here is most appropriate to guide the analyses. However, further improvement is required to allow single unit for various social, economic and environmental indicators. Guide for the use by practitioners and policy makers will also be useful addition to the existing framework.
- This multi-dimensional assessment has helped to understand key impacts and dependencies and true costs and benefits of two corn production systems, however,

there is need to understand how farmers adopt this new information. There is need to develop pathways for change in consultation with farming community so that the outputs from this research can be conveyed to farming and rural community. There is also need to understand, receptiveness of true cost accounting by farming community, it's utility as a decision-making tool at farm scale and the processes of its adoption by farmers.

Chapter I INTRODUCTION

Meeting food demand of increasing human population requires increased production and also a major policy shift in the way food is produced, processed, distributed and consumed. Another key challenge of global agriculture is to minimise impacts on environment and human health (FAO, 2017). Agriculture worldwide occupies 38% of the total land, its contribution to Gross Domestic Product (GDP) is less than 1% in developed countries and up to 50% in some developing countries (World Bank, 2018), and it produces sufficient calories to meet the current food demand of human population (FAO, 2009). However, 815 million are undernourished worldwide (FAO, 2017). At the same time, 2.1 billion people are overweight and adult obesity is on the rise, which is a major risk factor for non-communicable diseases, such as cardiovascular disease, diabetes and some cancers (FAO, 2017). These non-communicable diseases have high economic costs to individuals, societies and the governments. One-third of the agricultural produce is not consumed and is wasted during harvesting, processing and consumption (TEEB, 2015). Agriculture accounts for one-fifth of the global greenhouse gas emissions. Annually, 145 million tonnes of synthetic fertilisers are applied in agriculture along with pesticides. These agrochemicals along with some high impact agricultural practices, high energy use, have resulted in pollution of water ways, eutrophication, depletion of fresh water resources, increased greenhouse gas emissions, land degradation and loss of biodiversity (Matson et al., 1997; Tilman et al., 2001). In economic terms, these impacts are often known as negative externalities. On the other side, agriculture also produces many benefits to human society in the form of food and fibre resources, maintenance of genetic material, carbon sequestration, landscape aesthetics, recreational opportunities, etc., which are widely known as ecosystem services and increasingly being studied in agricultural systems (Swinton et al., 2007; Zhang et al., 2007; Sandhu et al., 2008, 2016). These are considered as positive externalities in agriculture. However, the current economic system does not capture any negative impacts such as damages to environment and human health, or benefits in the form of ecosystem services, which are linked to agriculture and food sector (TEEB, 2015). Therefore, the society and economy are unable to see any hidden costs or benefits of agriculture and food systems. This often leads to pervasive outcomes such as high cost to society and the environment. To address this gap, ***this report aims to understand key positive and negative externalities associated with agriculture production systems by examining various impacts and dependencies within the value chain of corn in Minnesota as a part of Mississippi river basin production systems.*** It analyses all externalities associated with genetically modified (GM) and organic corn production systems using true cost accounting (TCA) method and report on the opportunities for shifting practices, and policies to improve outcomes for farmers, industry and policy makers.

Global agriculture is unable to adequately account for its externalities, due to lack of tools and mechanisms. Therefore, the Global Alliance for the Future of Food has supported a United Nations Environment led project - The Economics of Ecosystems and Biodiversity for Agriculture and Food (TEEBAgriFood; TEEB 2018). This project has developed a common universal framework to evaluate all externalities of food production systems across the value chain. It aims to understand and value links between natural, social and human capital in agriculture and food systems more holistically and reflect them in an economic system by evaluating true costs and benefits (TEEB, 2018). This can help develop policy response to the growing demand for diverse and nutritious food with less damages to environment and human health.

Evaluation of true costs and benefits of agriculture and food systems can enable decision makers at farm, business and policy level to, i) identify the various positive and negative impacts associated with different production systems and farming practices. This can inform farming community to adopt best and sustainable practices, which are less damaging to the soil, water and biodiversity of the farm and help in conservation of resources and increase productivity; ii) to improve transparency of agriculture and food businesses about various externalities in their businesses. They can account for and internalise the value of environmental externalities and natural capital in their businesses and in consumer awareness; and iii) macro level policies can highlight the values generated by alternative farming systems (with special emphasis on smallholders and family farms) for employment, food and ecological security. It can also facilitate the role of agricultural sector in economic and environmental policies. This can help contribution of agriculture towards the achievement of United Nations Sustainable Development Goals (UN, 2012).

1.1. Aims and objectives

This study aims to capture all externalities in the production systems in the corn dominated landscape in order to understand various inter-dependencies in order to improve policy and practice in the Mississippi river basin in the US.

The study has following objectives,

1) Application of the TEEBAgriFood evaluation framework (TEF) to corn production systems; one of the five families of applications of the framework.
2) To compare two diverse corn production systems using analytical approach described in the TEF.
3) To evaluate true costs and benefits associated with dominant GM and organic corn systems by examining all impacts and dependencies within the value chain of corn in Minnesota.

1.2. Structure of the report

To show all impacts and dependencies and externalities of the corn production system analysed in this study, following prescribed steps by TEF are being undertaken in subsequent chapters.

1. **Purpose of evaluation:** The purpose of the assessment is to compare and contrast two diverse corn producing systems in the Mississippi river basin in US by focusing on the state of Minnesota, and to highlight all positive and negative externalities of the value chain stages. (Chapter 2)
2. **Entry point and spatial scale:** In this study, the entry point is production systems, which are being assessed. Spatial scale is field to landscape levels. The information and data analysed relates to farm level and also aggregated for the entire State of Minnesota. (Chapter 2)
3. **Scope of the value chain:** Two types of value chains for each of the two corn production systems are evaluated in this study. The scope includes corn production through to human consumption of corn-based meat and other food products. GM corn is being indirectly consumed as a part of a by-product from the ethanol

distillation process. The dry distiller grains (DDGs) are consumed as animal feed and not for direct human consumption. Whereas, the organic corn is also processed as animal feed. (Chapter 2)

4. **Focus on specific stocks, flows, outcomes and impacts:** Corn production depends on natural capital at farm and landscape scale. Various stocks, flows, impacts and outcomes for natural capital are being assessed in this study for both systems. Social and human capital are also evaluated at farm scale and landscape scale. For health impacts, the analysis shows heath externalities related to the corn intensity in the State of Minnesota. (Chapter 2). Background and importance of corn is summarized in chapter 3.
5. **Evaluation technique:** Life cycle assessment, value chain analysis, True Cost Accounting and Subjective Wellbeing Valuation techniques are used in the evaluation. (Chapter 4)
6. **Collect data and undertake evaluation:** Data is collected by reviewing literature and official data for each of the four capitals related to corn systems. Evaluation includes impacts of corn production on natural capital, social and human capitals including health related costs associated with corn production. (Chapter 5)
7. **Report and communicate findings:** As corn production involves multiple stakeholders, the reports is directed for practitioners and policy makers. (Chapter 6). Chapter 7 concludes with summarizing key findings.

Chapter II PURPOSE AND SCOPE OF EVALUATION

This chapter provides purpose and scope of the evaluation. It describes the entry point and also focus of the evaluation.

The purpose of this evaluation is to compare and contrast two diverse corn producing systems- genetically modified (GM) and organic corn production system in Minnesota, US and to highlight all positive and negative externalities in the value chain stages using TEF. The boundary for the analysis includes farm/landscape/health impacts in Minnesota. We use state wide farm level data for the Minnesota in order to evaluate two corn production systems. However, the purpose is to understand various externalities and inter-decencies of corn systems in Mississippi river basin in order to improve practice and policy environment. Therefore, the data and analysis provided in the report is focused on Minnesota. We also provide some key statistics for US wide corn data. Policy, systems drivers, and recommendations are focused at Minnesota state and national scale.

2.1. Farming systems

Minnesota was fourth largest corn producer with 8.05 million acres under corn (harvested 7.6 million acres) and yielding average of 194 (range of 131 – 218) bushels per acre. 925 of this corn is GM and rest hybrid (USDA ERS, 2018). Organic corn was grown on about 160 farms with 28,524 acres (less than 1%), yielding average of 150 bushels an acre. GM corn farming system is described as a monoculture in rotation with GM soybean with high inputs of synthetic fertilizers and herbicides. In USA, 19 states accounted for 92 percent of the total corn in 2016 (NASS, 2016). This production includes application of nitrogen at an average rate of 165 kg per hectare, for a total of 5.5 million tonnes, phosphate application at an average rate of 69 kg per hectare, for a total of 1.9 million tonnes and sulphur at an average rate of 18 kg per hectare for a total of 0.2 million tonnes. Amongst the herbicides used to control weeds, Atrazine at an average rate of 1.2 kg per hectare for a total of 25,000 tonnes, was most widely used active ingredient. Glyphosate was used at an average rate of 2.6 kg per hectare for a total of 30,000 tonnes and Acetochlor at an average rate of 1.5 kg per hectare for a total of 16,000 tonnes (NASS, 2016).

Application of unnecessary large inputs of ammonium and nitrate fertilizers and herbicides in corn production has become a major source of various kinds of pollution such as water pollution by fertilizer run off into rivers and streams, which leads to hypoxic, oxygen-deprived area where, aquatic life cannot survive (EPA, 2007). This has been a major challenge in the Mississippi River basin as it flows into the Gulf of Mexico (Smil, 2001; EPA, 2010, 2011). It is established that 40% of the nitrogen pollution that contributes to this comes from fertilizer application in corn as it is high nitrogen demanding crop (Good and Beatty, 2011; Scavia, 2015). Similarly, rising nitrate levels in drinking water is also linked to high fertiliser and pesticide application in the corn growing regions in US (Minnesota Department of Health, 2017). For example, harmful algal blooms in Lake Erie; unsafe levels of nitrate in the rivers Des Moines, Iowa; high nitrate levels in two municipal wells in Randall, Minnesota. Industrial scale corn production also requires large amount of fossil fuel inputs for cultivation, harvesting, drying and transport, which contributes to greenhouse gas emissions (Dunn et al., 2013; Flugge et al., 2017). Excessive use of nitrogen fertilizers in corn also contributes to the rising atmospheric levels of nitrous oxide (N_2O; Hoben et al., 2010). Corn monocultures have also promoted loss of crop and genetic biodiversity of arthropods and other fauna (Altieri, 1998; Tilman, 1999).

The impacts of corn are not only limited to the natural environment but also significantly affect human health (Bray et al., 2004; Bocarsly et al., 2010; Goran et al., 2012). It is the most consumed crop in US and is used in the sodas, potato chips, hamburgers and French fries, sauces and salad dressings, baked goods, breakfast cereals, poultry, milk, etc. Some studies indicate that elevated sugar consumption, intake from High Fructose Corn Syrup (HFCS) in particular, is associated with obesity and type 2 diabetes.

Whereas, organic farming system is a mixed production system where multiple organic crops are grown in rotation with livestock. The focus of this study is these two corn production systems in Minnesota as a part of investigating externalities related with corn systems in the Mississippi river basin. The dominant corn production systems in Minnesota are summarised in Table 1.

Table 1 Farming systems in Minnesota.

	Corn system	**Rotation**	**Practices**	**Tillage**
Very large farms	Genetically Modified corn	Soybean	Conventional	Minimum tillage
Very large farms	Hybrid corn	Soybean	Conventional	Conventional
Large farms	GM/Hybrid corn	Soybean	Sustainable practices	Strip-tillage
Large farms	GM/Hybrid corn	Soybean/ Alfalfa	Sustainable practices	Cover cropping
Farming occupation/low sales	Mixed cropping organic corn	Mixed crops – soybean, oats, barley, pastures, vegetables, fruits	Organic management	Minimum tillage/conventional tillage/rotational grazing

Very large farms: Farms with gross cash farm income (GCFI) of $5,000,000 or more
Large farms: Farms with GCFI between $1,000,000 and $4,999,999
Farming-occupation farms. Small farms whose principal operators report farming as their primary occupation.
Low-sales farms: GCFI less than $150,000.
Moderate-sales farms: GCFI between $150,000 and $349,999
Midsize family farms: GCFI between $350,000 and $999,999
(Source: USDA ERS, 2018)

Large family farm with GM corn/soybean farming system
A typical family owned farm in Minnesota with 1400 acres of farm area grows GM corn and soybean in rotation. For tillage, strip till is used with over 20% area under cover cropping. Half of the total farm area is used for growing corn in rotation with soybean. Standard corn production practices include addition of synthetic fertilizers such as Nitrogen as pre-emergence and then as side dressing. Phosphorus and Potassium fertilizers are applied with strip till in fall season. Herbicides are also applied as pre-emergence and post emergence stages. Diesel, gasoline, liquid propane and electricity are used for running machinery and

drying corn. All plastic and cardboard waste is recycled. There is usually mechanical loss of 1% of grains. The output from the farm is about 212 bushels of corn per acre with the market price of $3.65 per bushel. The corn is primarily used for ethanol production and is directly transported to the processing plant.

Large organic farm
A typical organic farm in Minnesota comprising of 550 acres of total farm land grows corn for feed, food, in rotation with a number of crops such as barley, oats, field beans, soybean(feed) etc. Crop rotations are used to build soil fertility and also for the management of pests a, diseases and weeds. Rotations include organic Corn-Soybean-Oats/Alfalfa, organic Corn-Soybean/Oats/Alfalfa-Alfalfa or soybean-winter rye where fall-planted rye is
incorporated in the spring prior to planting soybeans. Untreated hybrid seed is used for corn production. Unlike conventional or GM corn, organic practices prohibit the use of synthetic fertilizers, therefore, equivalent rates of nitrogen are applied with swine hoop-house compost or similar compost. Weeds are managed in the organic corn and soybean fields through cultivation using rotary hoe, harrow, row cultivator, and propane flame cultivator. Rye is planted prior to corn and soybean and is ploughed in for its natural allelopathic chemicals that mitigate weed seed establishment. The output from the farm is about 154 bushels of corn per acre with the market price of $8.65 per bushel. The corn is primarily used for animal feed and corn flour milling and is directly transported to the processing plant.

2.2. Value chains of corn
A value chain is a concept first defined as, “a set of activities that a firm operating in a specific industry performs in order to deliver a valuable product or service for the market” (Porter, 1985). This concept is increasingly being used by agribusinesses in the new millennium to manage their global activities from farm production to consumption of food products. Table 2 summarises dominant value chains of corn in US.

In US, GM corn is widely grown for ethanol production with Dried Distillers Grains (DDGs) as a by-product for animal use mostly in concentrated animal feeding operations (CAFO). Conventional corn comprises of hybrids which are also used for ethanol production or other feed, food or industrial uses. Organic corn is also grown for niche markets such as organic animal feed, chips etc.

Table 2 Summary of various value chains of corn in US.

Production	**Processing**				**Consumption**
Conventional/ GM corn	Ethanol plant/DDGs	Animal feed	Animal production: cattle/pigs/ poultry	Processing/ market/retail	Consumption/ household/ restaurants
Conventional/ GM corn	Ethanol plant	Ethanol blended gasoline	Transport use		
Conventional corn	Food and beverage/high fructose corn syrup	Carbonated beverages	Processing/ market/retail	Consumers	

Above + sustainable practices - Strip-tillage/cover cropping	Ethanol plant/DDG	Animal feed	Animal production: cattle/pigs/ poultry	Processing/ market/retail	Consumption/ household/ restaurants
Above + sustainable practices - Strip-tillage/cover cropping	Ethanol plant	Gasoline	Transport use		
Organic corn	Animal feed	Animal production/ cattle/pigs/ poultry	Processing/ market/retail	Consumption/ household/ restaurants	
Organic corn	Chips/tortillas	Retail	Consumption		
Mixed cropping organic corn	Local meat production/pigs	Processing/ market/retail	Consumption/ household/ restaurants		

2.3. Value chains explored in the study

There are two dominant value chains in the corn growing regions in US, which are explored in this study. These are based on GM/hybrid corn (Figure 1) and organic corn (Figure 2). Key components of value chains explored in the study include,

- Inputs: GM or hybrid seed, fertilisers, herbicides, diesel, gasoline, petrol, electricity use etc.
- Production: Crop type, tillage systems, rotation practices, livestock grazing, pest/disease management, harvesting, drying, transport,
- Processing: Ethanol, DDGs used in animal feed
- Transport: Transport fuel use
- Human consumption: Meat for human consumption (livestock and poultry).

2.3.1. GM and Hybrid corn

GM and hybrid corn are grown primarily for ethanol production, where, DDGs are a byproduct used as animal feed for livestock or poultry, and these meat products are consumed by humans. GM/hybrid corn is either grown in rotation with soybean or two subsequent corn crops are grown year after year. These practices dominate the landscape. In addition, there are some practices such as addition of cover crops followed by green manuring or livestock grazing, which are being promoted to improve sustainability of corn production systems. Conventional tillage is mostly used for the soil preparation, however, there is increase in strip-tillage use due to its economic and environmental benefits in terms of saving resources and time and improvement in soil health.

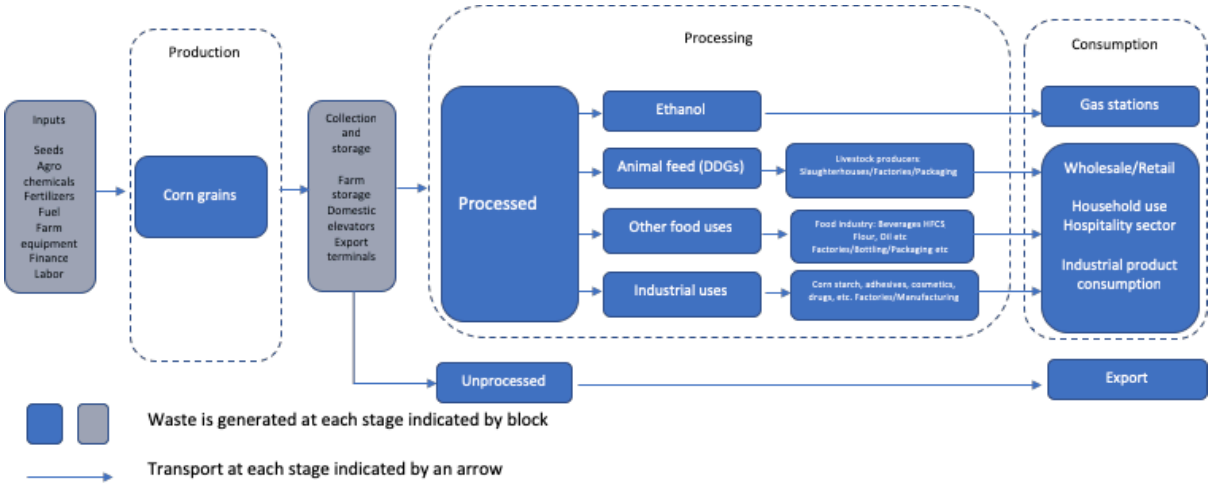


Figure 1 Value chain of GM corn.

2.3.2. Organic corn

Organic corn is primarily used as animal feed for livestock and poultry which are consumed by humans as meat products. Organic grains are also used for direct consumption and in various food products such as chips. Organic production depends on rotation to maintain soil health and livestock is increasingly becoming part of this rotation.

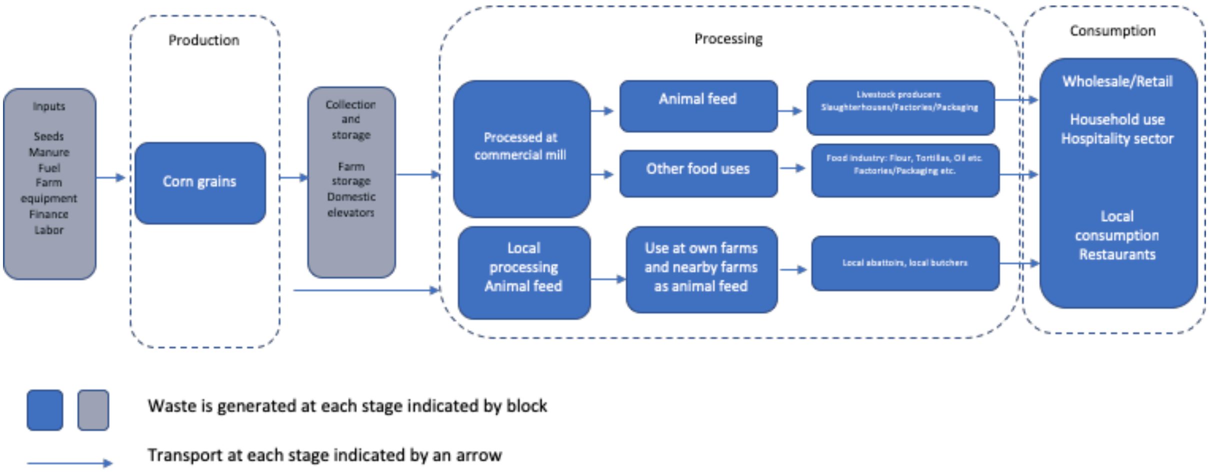


Figure 2 Value chain of organic corn.

2.4. Entry point, scope and focus

For evaluation, the entry point is corn production system in the Minnesota state. Two types of value chains for two corn production systems are evaluated in this study. The scope of evaluation includes corn production through to human consumption of corn-based meat and other food products. Corn production depends on natural capital at farm and landscape scale. Social and human capital are also evaluated at farm scale and landscape scale. For health impacts, the analysis includes impact in Minnesota State.

Chapter III OVERVIEW OF CORN

This chapter briefly provides background and uses of corn.

3.1. Background

Corn (*Zea mays* L.) has been part of various ancient cultures and civilisations in the American continent (Hernández, 2009; CONABIO, 2017). With domestication and continuous improvements in the last 10,000 years, it has become a crop of global significance (Bird, 1980; CIMMYT, 1999). Corn is a coarse cereal grain and has become the leading agricultural commodity worldwide in 20th century due to its economic contribution. Currently, with global production of 1.06 billion tonnes from 187 million hectares, it is second to sugarcane and in global trade, it is the second largest agricultural commodity after wheat (FAOSTAT, 2018). Corn plays an important role in the global economy, with USA as the leading producer at 384 million tonnes from 35 million hectares (2016), which accounts for over one-third of the global corn production (Figure 3, FAOSTAT, 2018). Corn is grown across all continents of the world (Figure 1). In industrialised countries, it is mostly used as animal feedstock followed by ethanol and other industrial uses. Whereas, in other countries, most of the corn is used directly for human consumption.

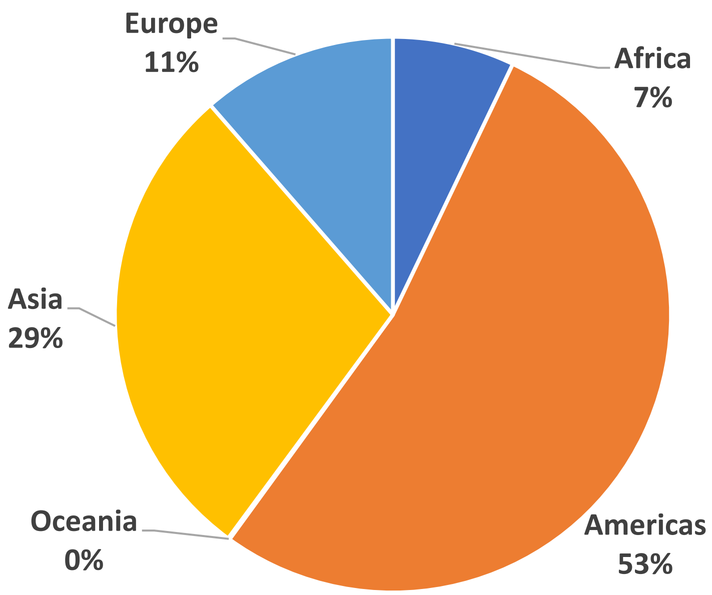


Figure 3 Production share of corn by region, average between 1994-2016 (FAOSTAT, 2018).

There are several varieties of corn such as dent corn, flint corn and soft corn that are economically important and are grown widely (Table 3). Field corn or dent corn is widely used for cornmeal flour, corn chips, tortillas, taco shells, high-fructose corn syrup, livestock feed, and for the production of ethanol. Dent corn comprises of 62% starch, 3.8% oil, 15% moisture and 19.2% fiber and protein (NCGA, 2018). Most of the field corn varieties are genetically engineered or hybrid varieties. In USA, much of the corn (88%) grown is genetically engineered, followed by hybrid varieties, whereas, organic corn is grown on about 85,000 hectares that represents only 0.02% of the total area in US (NASS, 2018).

Table 3 Key corn varieties.

Common name	Botanical name
Dent corn	*Zea mays* var. indentata
Flint corn	*Zea mays* var. indurata

Soft corn	*Zea mays* var. amylacea
Pop corn	Z. mays convar. everta
Sweet corn	Z. mays convar. saccharata
Pod corn	Z. mays convar. tunicata
Waxy corn	Z. mays convar. ceratina

3.2. Uses of corn

Corn is processed in variety of ways and is used in over 200 products used in food, feed and industrial uses (Appendix A). In US, corn is used mostly as animal feed (37.6%), followed by ethanol production (30%) and other food and industrial uses (Figure 4, USDA, 2018). The main processing methods of corn include – traditional processing, wet-milling and dry-milling. Traditional processing includes consuming whole grains, flour or meal. This may include roasting and/or fermenting for traditional food and drinks.

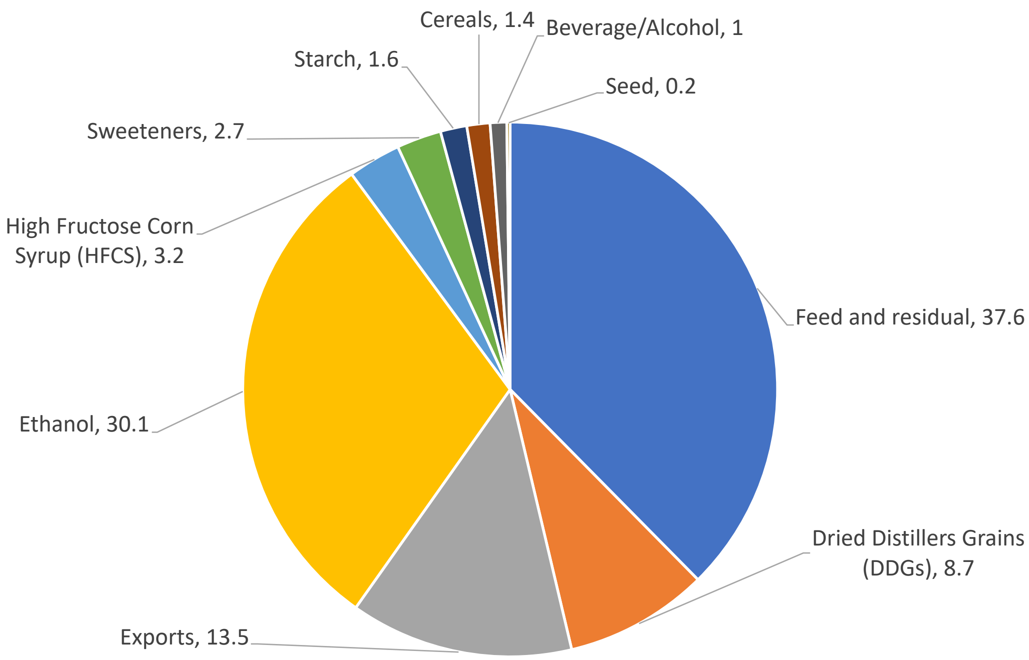


Figure 4 Corn usage (%) by segments in US (USDA, 2018).

The wet-milling process includes extraction of the germ which is further processed to remove the corn oil. The germ meal remaining after the oil is extracted is used as animal feed. The fiber in this process is used to produce corn gluten feed, a 60% protein feed. The starch products are used in the food, paper, and textile industries. Starch is also processed into products such as sweeteners or ethanol. An average bushel of corn yields 31.5 lbs. of Starch, or 13.5 lbs. of Gluten Feed, 2.5 lbs. of Gluten Meal and 1.6 lbs. of Corn Oil or 22.4 lbs of polylactic acid polymers that can be made into plastics and fibers or 33 lbs of sweeteners (NCGA, 2018).

The dry milling process focuses primarily on the production of grain ethanol and Distiller's Dried Distillers Grains (DDGs), a low-value animal feed product.

Chapter IV METHODOLOGY

This chapter describes methodology to identify and analyse natural, social and human capital associated with corn production systems and value chains of two production systems by focusing on the Midwestern corn systems (Minnesota state) in the USA using TEF.

4.1. Conceptual model for analysis of externalities in the corn systems

There are five key applications of the TEEBAgriFood evaluation framework - agricultural management systems; business analysis; dietary comparison; policy evaluation; and national accounts for the agriculture and food sector. This study is focused on corn based agricultural management systems in US. It extends its analysis to all externalities through the value chain but the primary objective is to contrast two corn production systems in the Mississippi river basin. We used statistical data available at the USDA National Agricultural Statistics Service Information to extract corn related inputs and outputs data. This is supplemented by relevant data from scientific literature and various health and environmental reports. We focus on Minnesota to examine two diverse corn production systems, therefore, we rely on Minnesota State average corn production data.

There are four key elements of the TEEBAgriFood evaluation framework - stocks, flows, outcomes and impacts (Figure 5). These are the basis of conceptual model used in this study to analyse various externalities in the corn value chains. It describes stocks through the description of four types of capitals – produced, social, human and natural by following TEEBAgriFood framework. Stocks of these capitals are accumulated over time. Whereas, flows are the processes over a period of time. Flows can be described in the form of ecosystem services, agricultural inputs and output, and any residual flows such as pollution and greenhouse gas emissions. Outcomes are defined to reflect changes in stocks that impacts wellbeing.

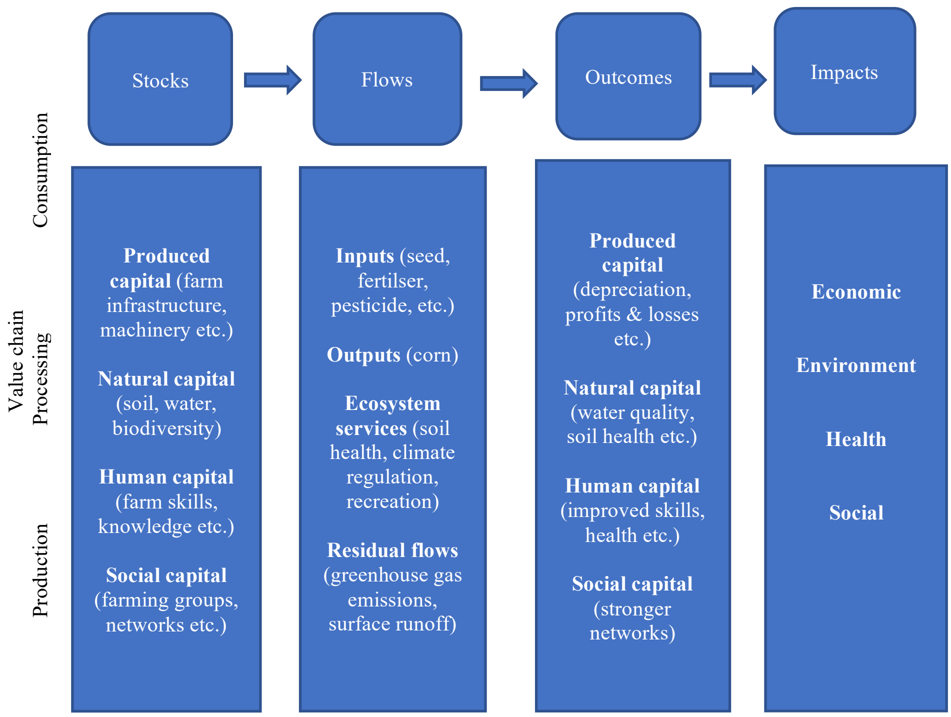


Figure 5 Conceptual model for the application of TEEBAgriFood evaluation framework (adapted from TEEBAgriFood Report, 2018).

4.2. Four capitals framework applied to corn value chain

4.2.1. Stocks

To understand impacts and dependencies, it is important to understand capital base in agriculture. Therefore, four capitals are described below as it provides basis for the analysis in this study.

Produced capital

Produced capital used here is based on the concept measured in the Inclusive Wealth Report (UNU-IHDP and UNEP, 2014) and defined by the TEEBAgriFood Report (2018). In corn production systems and value chain, produced capital includes all manufactured/built capital such as farm buildings, machines and equipment, physical infrastructure (roads, irrigation systems), processing plant, storage, warehouses, retail stores etc; knowledge and intellectual capital embedded in, for example, seed development, fertilisers, agrochemicals, GM/hybrid seed, etc.; and financial capital such as farm loans, investment, insurance, etc. The stocks and flows associated with produced capital are measured by concepts and definitions of accounting standards at farm level, landscape level and corporate level (processing), by using definitions from the System of National Accounts.

Social capital

Social capital is defined as the features of social life, networks, norms and trust, that enable participants to act together more effectively to pursue shared objectives (Putnam 1993, 1995). It's four key features are relations of trust; reciprocity and exchanges; common rules, norms, and sanctions; and connectedness in networks and groups (Pretty, 2003). The social bonds and norms are important for people and communities as they co-operate and it can lower the transaction cost (Coleman, 1988). Social capital is essential to produce other forms of capital. It can be measured by assessing structural (patterns of connections), relational (relationship and interactions) and cognitive (shared goals and values) dimensions using various methods such as World Values Survey (WVS), Social capital index (SCI), and social survey (Acquaah et al., 2014). In agriculture value chains, farming group networks, partnerships with research and development, individual links, market linkages etc. form the social capital.

Human capital

Human capital comprises of individual's health, knowledge, skills and motivation that are essential for productive work. It is based on the premise that individuals and society derive economic benefits from investments in people (Sweetland, 1996). Human capital increases with improvements in the health, skills, experience and education of human population. It is affected by the loss of skills and experience and by changes in human health (OECD, 2001; TEEBAgriFood Report, 2018). In agriculture, it consists of farmers knowledge, proficiency in farm practices, use of software, health etc.

Health externalities: From a health perspective, the heavy use of fertilizers and herbicides in corn systems are reasons of concern when leached in the water system. Phosphate fertilizers from radioactive ores are sources of contamination with natural radionuclides (https://www.epa.gov/radiation/tenorm-fertilizer-and-fertilizer-production-wastes). Uranium content of fertilizers can vary according to their phosphate content. Using phosphate fertilizers containing uranium are ways in which corn field workers may be exposed to doses of radiations (Harb, 2015; Mohammed et al., 2016). Uranium and radium are known carcinogens (especially to liver and kidneys) and the food web (mainly meat products and dairy) and drinking water fluoridation are major risk pathways to the community. GM corn fields receive high amounts of herbicides, mostly glyphosates that are classified as probable carcinogens by WHO (WHO, 2015), and more recently, considered drivers of antibiotic resistance (Kurenbach et al., 2017). Neonicotinoid insecticides are used as preventive seed treatments in 80% of corn grown in USA (Krupke et al., 2017). Nitrates in drinking water and groundwater pollution is reported as a major health concern (e.g., blue baby syndrome, http://www.health.state.mn.us/divs/eh/water/contaminants/nitrate.html#HealthEffects), as well as air quality that is reported to have high levels of nitrogen oxide and Particulate Matter (e.g., asthma and other respiratory problems).

Food calorie delivery: For corn-fed animals, the efficiency of converting grain to meat and dairy calories ranges from roughly 3 percent to 40 percent, depending on the animal production system in question. Little of the corn crop actually ends up feeding USA people: the average Iowa cornfield has the potential to deliver more than 15 million calories per acre each year (enough to sustain 14 people per acre, with a 3000 calorie-per-day diet, if ate all of the corn was locally consumed), but with the current allocation of corn to ethanol and animal production, it is estimated that 3 million calories of food per acre are produced per year, mainly as dairy and meat products, enough to sustain just three people per acre. That is lower than the average delivery of food calories from farms in Bangladesh, Egypt and Vietnam. USA corn crop yield is highly productive, but the corn system is aligned to feed cars and animals instead of feeding people (Foley, 2013).

Nutrition: Corn have complex carbohydrates and poly-unsaturated fatty acids, as well as essential amino acids and vitamin E, a potent anti-oxidant. Color (white, yellow, red) correspond to different levels of carotenoids and flavonoids; Minnesota's corn is yellow for feed and feedstock production and the GM crop has occasional black seeds in the yellow ear that were reported to perform better in ethanol production. Generally, corn protein content is minor as compared to wheat (9% vs. 14-18%), which is better for kidney' functions; in addition, it does not contain and have important content of Fe, K, Mg, Zn and chiefly Se (15 micro mg %, https://www.einkorn.com/wp-content/uploads/2009/12/Grain-Nutrition-Comparison-Matrix.pdf). There is no evidence of increased digestibility or nutritional value of white or yellow corn, but consumers may have different preferences (e.g., Mexicans prefer white corn).

Cooking: If cooked at temperature above 80^{o}c and with calcium, niacin (vitamin PP) becomes available to correct oxidative metabolism and certain nervous system degenerative pathologies (as known by ancient Central American people; Grandi Maurizio, 2008).

Main benefits: For those suffering from Celiac disease or wheat intolerance (no gluten), type 2 Diabetes (lower glycemic index, GI), skin pathologies such as psoriasis, dermatitis and eczema (due to saturated lipids and Vitamin E), facilitated kidney and liver functions (less proteins), digestive system cancers (due to Vitamin E, Zn and Se; Aufiero and Pentassuglia, 2015).

Main limitation: High Phosphorus content (256 mg% vs. 99 mg% for wheat) may be a limitation for those with kidney pathologies (Aufiero and Pentassuglia, 2015).

Main health risk pathways of corn:

a. Agri-environmental pollution of air, water and soil, mainly by synthetic fertilizers and herbicides;
b. Indirect GM-corn consumption through meat and dairy products containing foreign genes (bacteria, viruses) which have never been in the human food supply create proteins that trigger diseases;
c. Drinking of sweet beverages facilitated by cheap high-fructose corn syrup.

Considering that nutrition and health linkages involve a myriad of factors (beyond any single crop causality), this research was beyond the scope of this study. Thus, health impacts considered here are restricted to agri-environmental conditions.

Agricultural inputs and incidence of diseases:

a. Cancers: all types, with focus on digestive and reproductive organs (P-fertilizers affecting pancreas, kidneys and liver, while nitrates affect ovaries, bowel and colon) and blood (pesticides causing leukemia and non-Hodgkin lymphoma) cancers;
b. Respiratory diseases and asthma from fertilizers usage;
c. Pesticide toxicity to workers: endocrine-disrupting chemicals and impacts on neuro-degenerative and developmental disorders;
d. Anti-microbial resistance, since GMOs and glyphosates entered the food system;
e. Obesity and type 2 diabetes caused by high fructose corn sweeteners in beverages.

The study explores the health costs associated with corn production in Minnesota using the wellbeing valuation approach (Appendix B). This approach values in monetary terms the changes to subjective wellbeing associated with certain outcomes. For the purpose of this study, the changes in health status related to corn production are valued in monetary terms by valuing their knock-on impact on wellbeing.

Natural capital

Natural capital includes natural resources such as air, water, soil, biodiversity and ecosystems that provide various benefits to human beings in the form of ecosystem goods and services (Costanza et al., 1997). Natural capital can be measured by using the System of Environmental-Economic Accounting (SEEA, UN 2014). In agriculture, it includes soil, air, water, agrobiodiversity and rural landscape.

Soil: The quality and productive potential of soil is affected by loss in soil due to wind or water erosion, as well as degradation in soil quality due to changes in organic matter, nutrient content, and/or water storage capacity, among other factors. Soil serves as a valuable natural capital stock supporting agricultural production and associated ecosystem services. We review and synthesize existing literature on observed trends in the soil loss and quality of the soil stock under different agricultural management options considered in this study (Organic vs. conventional), with a focus on studies from the Midwestern U.S.

4.2.2. Flows

Flows are the benefits and impacts during the use of various capitals. These are described by using the principles of wealth accounting.

Inputs and outputs in agriculture

All inputs and outputs in corn production system through the value chain can be captured using farm accounts, business accounts as recorded in System of National Accounts (SNA).

Ecosystem services

These are defined as the benefits that are provided by agricultural landscapes to support farming and rural society (Daily, 1997; MEA, 2005). In agriculture, ecosystem services include nutrient cycling, pollination, carbon sequestration, soil health maintenance, water regulation, conservation of habitat and biodiversity, recreation, cultural services etc. and amenity values. Trade-offs between different ecosystem services will be assessed using TEF.

Provisioning: The value of agricultural production is a function of crop price and crop yield of a given hectare of farmland. We assemble data on corn prices in Minnesota over the past two decades and reported corn yields per county. For each management scenario, we estimate the net present value of agricultural production based on estimated yields from reported data and farmer input.

Residual flows

These include waste, food losses, greenhouse gas emissions on farm, processing and consumption of the food. These are measured by using SEEA Central Framework (UN, 2014).

Water quality: Agriculture is the dominant driver of water pollution in Minnesota, with the majority of nutrient export coming from corn production. Agricultural pollutants include nutrients such as nitrogen and phosphorus, as well as sediment, and agricultural chemicals such as pesticides and herbicides.

Nitrogen: Nitrates pose a threat to drinking water quality locally, degrade stream and river habitats, and are the major driver of eutrophication in the Gulf of Mexico. Because of spatial heterogeneity in risk of nitrates reaching drinking water sources and exposure to those sources, the costs of these externalities are spatially variable. We apply the cost metrics developed in Keeler et al. (2016) to account for the costs of nitrogen from corn production on a county-by-county basis. We estimate changes in nutrient export under different management scenarios and then apply costs functions outlined in Keeler et al. (2016) based on the expected number of additional wells contaminated by nitrates.

Phosphorus: The externalities of phosphorus pollution are primarily from negative impacts to lake and river water quality. In large enough quantities, it causes lakes to shift from clear to eutrophic, a state dominated by algae. Willingness to pay surveys (Mathews, 2002) have found high values associated with people's desire for clear lakes as recreation sites. To assess the value of phosphorus pollution, we apply a willingness to pay approach based on methods described in Johnson et al. (2015) and compare these with estimated loss in recreational value based on travel cost models presented in Keeler et al. (2015).

Air quality: Increases in particulate matter and associated health impacts are a global consequence of fertilizer application (Bauer, et al. GRL, 2016). As described in Keeler, et al (2016), we use an atmospheric transport model (InMAP, Tessum, 2017) to estimate concentrations of NOx and PM2.5 and resulting health impacts from fertilizer application in Minnesota. As with water quality, these impacts vary spatially dependent on concentrations and number of people affected. We use either a premature or QALY-based valuation (Gourevich, 2018) to assess damages associated with each production system.

Climate: We value climate-related impacts of corn production by estimating CO_2e emissions along several pathways and multiplying by a social cost of carbon. The pathways we evaluate are:

- GHGs from energy inputs to fertilizer production and any associated direct emissions. We will review existing literature to estimate kg CO_2e per applied kg of fertilizer.
- Gains or losses in soil carbon between different management types. We identify best available estimates for these as part of the soil quality impacts review.
- N_2O emissions associated with fertilizer use. These are quantified following the method in Keeler, et al. (2016).

Field vs supply chains: Not all impacts from corn production occur on the farm field. Impacts are spread across the entire life cycle of corn production, from cradle to grave. This can include the production of farm inputs all the way through to consumption of the final product. We also consider these value chains and impacts for both GM and organic corn.

Health externalities boundary

In this study we apply the methodology introduced in MARCH (2017) to measure the association between corn production near individuals residences' and their general health in Minnesota. To do this, we link satellite data on agricultural land use to measures of general health from the Gallup Daily tracking survey. We then use the Well-being Valuation (WV) method to monetize the general health impact of corn production. This method works by calculating the equivalent amount of money that would induce the same impact on life satisfaction in order to find the implied non-financial health costs of corn production.

4.2.3. Outcomes/change in wellbeing

Outcomes can be assessed by change in capital base. These can be either positive or negative. In this study, we will report outcomes in wellbeing through change in four types of capital – produced, natural, social and human, in two diverse corn production systems.

4.3. True Cost Accounting (TCA) in corn production systems

To understand the impacts of economic activities on environment and human health, and to account for these impacts in economy, Environmental Management Accounting (EMA) has been developed since 1990, led by the United Nations Division for Sustainable Development (UNSD). UNSD led the development of “System of Economic and Environmental Accounting (UN, 1993) to take stock of all positive and negative externalities that are not recorded in public or private accounts. These are recently revised and is known as the “System of Environmental-Economic Accounting Central Framework” (UN, 2014). EMA intends to account for losses from environmental damage and gains from ecosystem services provided by nature.

True cost accounting (TCA), is an EMA tool, which is similar to other cost accounting systems such as full cost accounting, life-cycle costing, environmental balanced scorecard and material flow cost accounting (Jasinski et al., 2015). TCA includes all environmental and social costs and benefits of agriculture and food systems. It distinguishes from other EMA tools that do not include social costs in accounting. TCA uses damage function approach (damage costs) and the cost of control approach (avoidance, restoration, abatement and maintenance costs) to estimate the true cost of food production through the value chain (Jasinski et al., 2015).

4.4. Mapping to TEEBAgriFood framework

Mapping of all (known and unknown) dependencies, impacts and externalities (positive and negative) related to the chosen systems including: environmental, social, cultural and health externalities.

The information is summarised in a tabular format as described in Table 4 by following TEF standards.

Table 4 Assessing the coverage of an evaluation of corn production system.

		Production Farm/Landscape	Processing	Consumption
Stocks	Natural capital			
	Produced capital			
	Social capital			
	Human capital			
Flows	Ecosystem services			
	Inputs			
	Residual flows			
	Production			
Outcomes	Social			
	Environmental			
	Economic			
	Health			

Legend				
	Descriptive information available			
	Quantitative information available			
	Monetised information available			
	Not included in study			

Chapter V RESULTS

This chapter provides an assessment of all positive and negative externalities associated with corn production systems in Minnesota by following the TEF. The price of corn and reported social and environmental costs provide an estimate of the magnitude of these costs to society and the environment.

5.1. Produced capital

Produced capital used here is based on the concept measured in the Inclusive Wealth Report (UNU-IHDP and UNEP, 2014) and defined by the TEEBAgriFood Report (2018). In corn production systems and value chain, produced capital includes all manufactured/built and financial capital, which is not consumed in one crop cycle.

Following is the summary of fixed capital assets on a farm.

- Farm buildings including sheds to store machinery, workshop for repair of farm equipment.
- Grain storage includes infrastructure for drying and storing grains.
- Energy infrastructure for the supply of power to shed and grain drying facility.
- Communications network for connectivity to other services such as utilities, market, financial institutions, research, community at large.
- Farm roads includes gravel or dirt roads, pathways on farm for access of machinery and transport vehicles to the roads.
- Farm machinery and equipment include corn planters, tillage equipment, sprayers, harvester combine, tractors, trucks, bins.

Consumption of built capital is estimated by economic depreciation. Depreciation is the reduction in the useful service life of capital. This could be due to obsolescence and age of the asset. Opportunity cost of capital includes the return on capital if it is invested in the next best alternative. Financial capital includes farm loans, investment, crop and farm insurance, professional fees etc. The costs of running a farm also include property taxes, insurance expenses, licenses, fees, etc. Knowledge and intellectual capital embedded in, for example, seed development, fertilisers, agrochemicals, GM/hybrid/organic seed, etc. is also included in produced capital. In organic agriculture, management skills replace agricultural inputs and such capital is vital in organic farming. However, replacing private goods (e.g., fertilizers) with public goods (e.g., knowledge) has a much longer time frame in terms of accrued benefits. In Minnesota there are a number of organisations that provide these services, including training, to farmers.

In addition to fixed assets, there are variable assets on a typical farm, which included inputs such as seed, fertilizers, herbicide/pesticide, fuel etc. Variable capital on farm includes farm expenditure, which is consumed during the crop cycle. Number of farm operations in Minnesota are 73,200 (2.05 million US wide) with 25,900,000 (910 million acres US wide) acres of cultivated land (USDA ERS, 2018a). Average farm size is 354 acres (444 acres US wide) in Minnesota. US farm number are decreasing since 1900 and the average acreage has tripled from 150 to 450 per farm (Figure 6). In Minnesota, same trend is observed between 1900-2017 (Figure 7). In Minnesota, the average farm expenditure (% share) is summarised in Figure 8. Figure 9 summarises total and average per farm expenditure from 2008-2017 in US. Table 5 provides farm expenditure on per acre and total for Minnesota agriculture. The total farm expenditure in Minnesota is higher than the US average. Farm production expenditure by farm, average in Minnesota in 2017 is summarised in Figure 10. For corn farms, highest expenditure is on farm services, followed by seed, supplies and fertilizers.

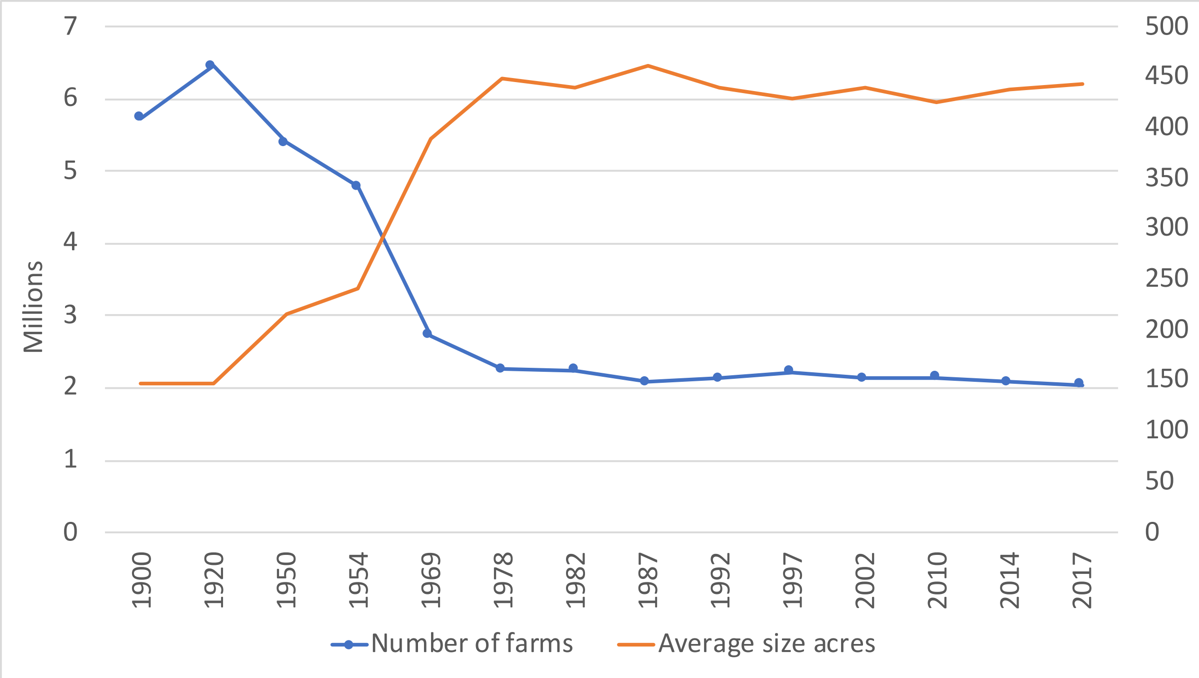


Figure 6 US farm number and size in acres 1900-2017. (Source: USDA NASS, 2018a).

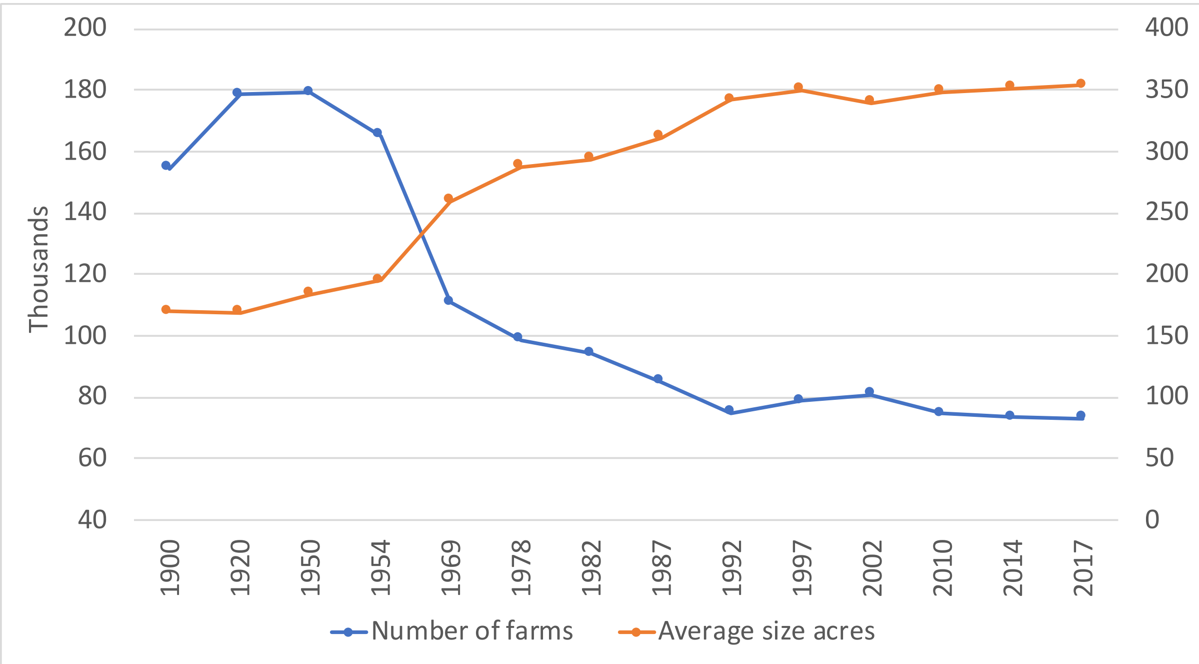


Figure 7 Farm number and size in acres in Minnesota from1900-2017. (Source: USDA NASS, 2018a)

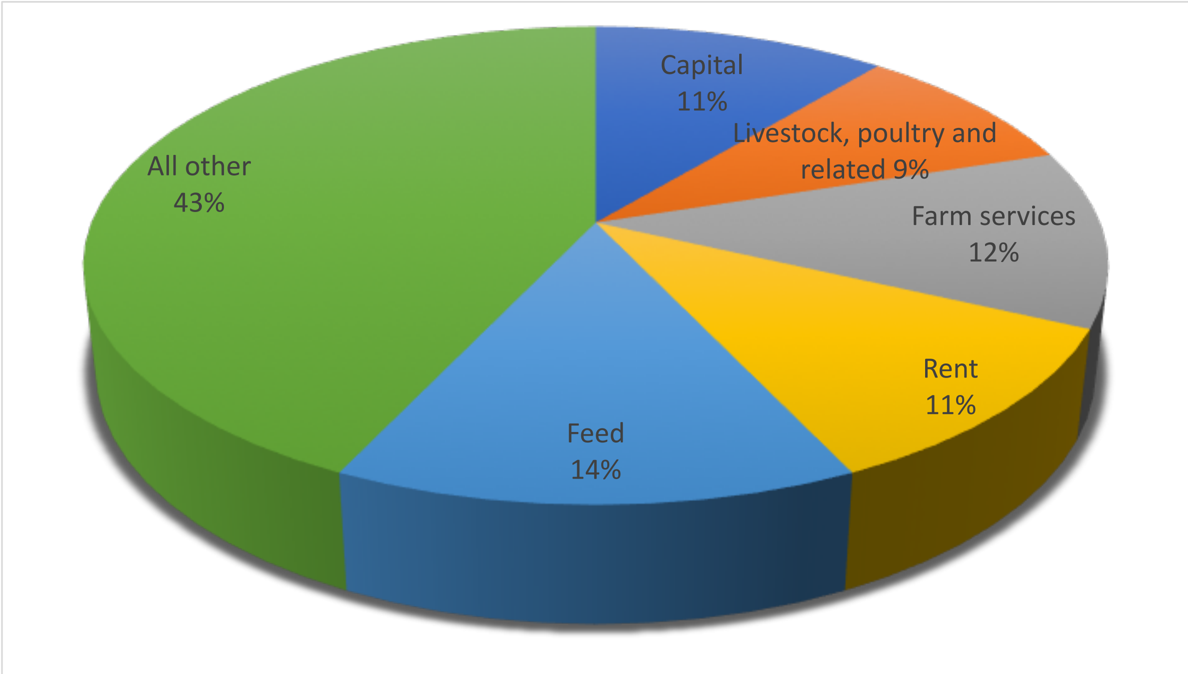


Figure 8 Farm expenditure by % share in Minnesota, 2017. (Source: USDA NASS, 2018b).

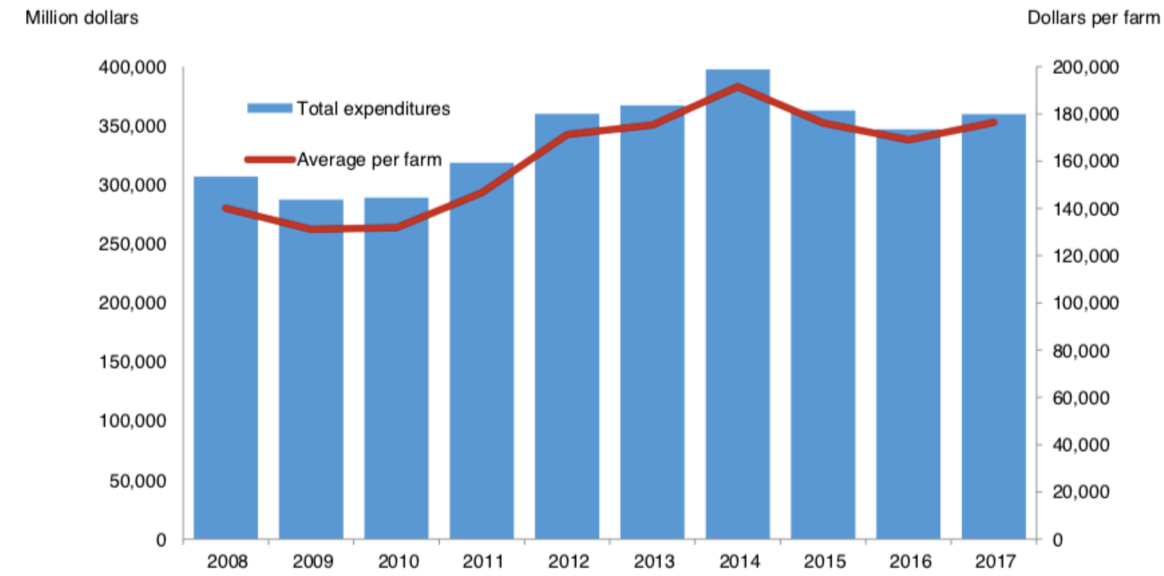


Figure 9 Farm production expenditure by farm, average and total in US from 2008 – 2017. (Source: USDA NASS, 2018b).

Table 5 Farm production expenditure by farm, average and total in Minnesota. (Source: USDA NASS, 2018b).

	Average per farm ($)		**Total expenditure ($ Million)**	
	2016	**2017**	**2016**	**2017**
Total Farm Production Expenditures	234,720	228,005	17,205	16,690
Livestock, Poultry and Related Expenses	20,737	20,219	1,520	1,480
Feed	36,835	32,787	2,700	2,400
Farm Services	26,194	27,459	1,920	2,010
Rent	28,922	25,273	2,120	1,850
Agricultural Chemicals	9686	10,792	710	790
Fertilizer, Lime and Soil Conditioners	19645	18,306	1,440	1,340
Interest	7913	8,470	580	620
Taxes (Real Estate and Property)	9141	8,743	670	640
Labor	10232	9,973	750	730
Fuel	7231	8,470	530	620
Farm Supplies and Repairs	12,551	12,432	920	910
Farm Improvements and Construction	10,095	9,563	740	700
Tractors and Self-Propelled Farm Machinery	6,958	7,514	510	550
Other Farm Machinery	4,229	5,191	310	380
Seeds and Plants	21,828	20,492	1,600	1,500
Trucks and Autos	2,183	2,049	160	150
Miscellaneous Capital Expenses	341	273	25	20

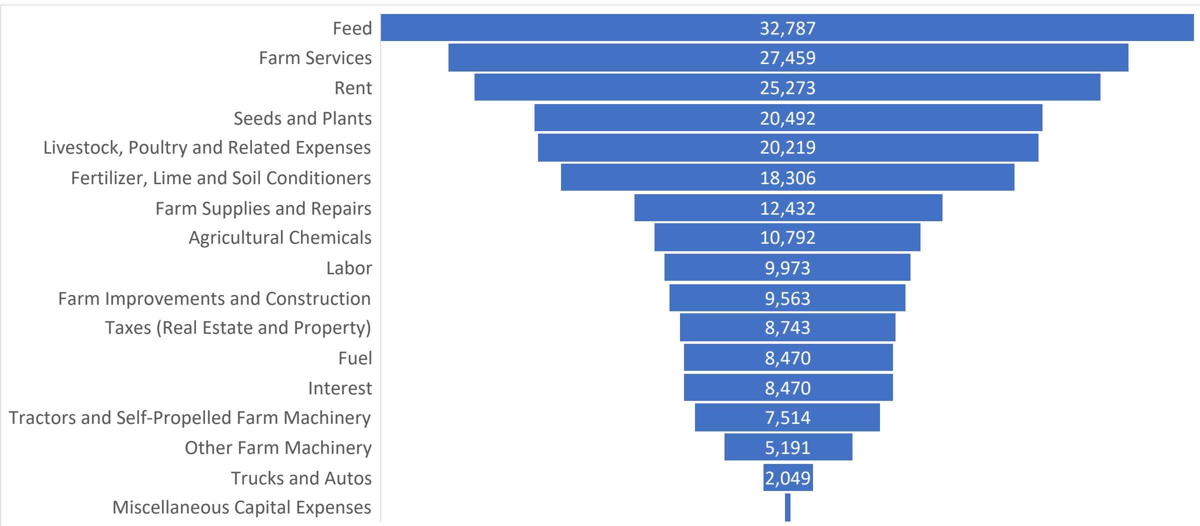


Figure 10 Farm production expenditure by farm, average in Minnesota in 2017. (Source: USDA NASS, 2018b).

5.1.1. Corn production in Minnesota, US

Produced capital includes all production (inputs and outputs) from corn farm. Here we summarise all inputs and outputs in two production systems – GM corn and organic corn. US is divided into nine resource regions by USDA (USDA ERS, 2010; Figure 11). Total area planted under corn in 2017 was 90.1 million acres (harvested 82.7 million acres), with yield of 176.6 bu/acre. Total value of corn was $ 48.46 billion (average price of $3.30 /bu) in US (USDA ERS, 2018). With 13.3 million acres, Iowa was the leading corn producing State. Minnesota falls under two regions - heartland and northern crescent. Minnesota was fourth with 8.05 million acres under corn (harvested 7.6 million acres) and yielding average of 194 (range of 131 – 218) bushels per acre. Total value of corn in Minnesota was $ 4.51 billion (average price of $3.05 /bu) in US (USDA ERS, 2018). About 92% of this was genetically modified (GM) and rest was hybrid corn.

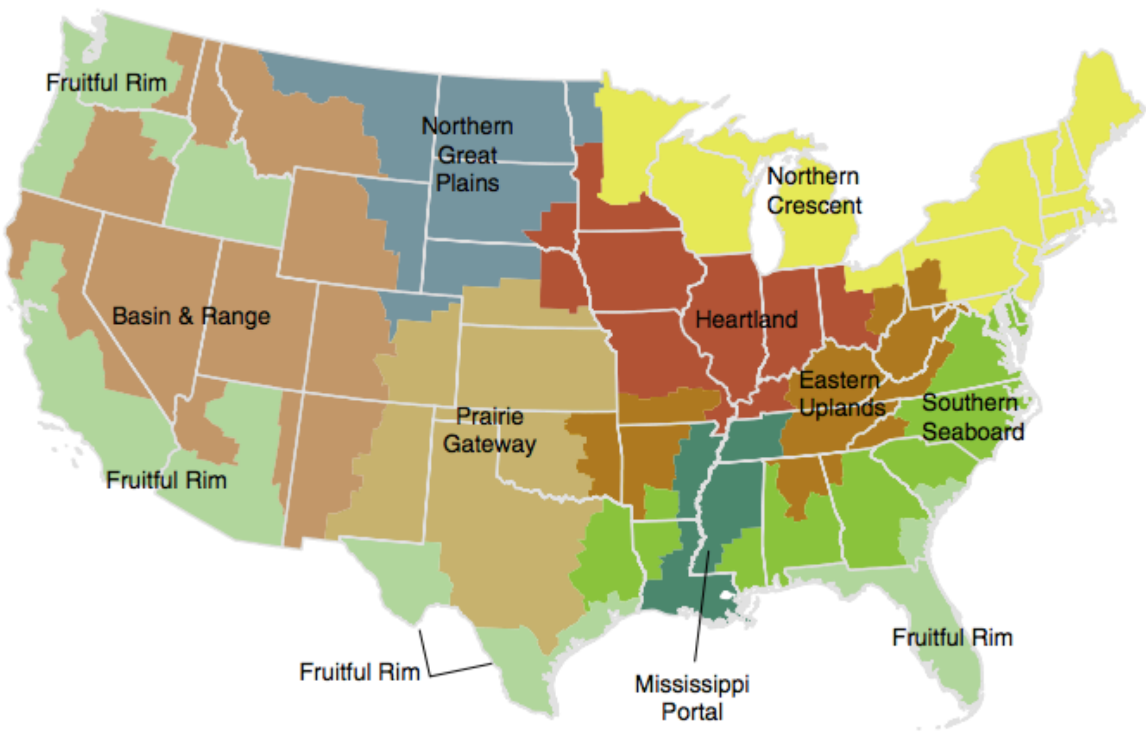


Figure 11 U.S. Farm Resource Regions. (Source: USDA ERS, 2010).

There are about 24,000 corn farmers that generate corn crop value more than $4.5 billion for Minnesota. Farm size varies from less than 250 acres to over 1000 acres. Corn growing season is from April to October in Minnesota. Various stages of corn growth are planting, emergence, silking, denting, maturing and harvesting.

Historical prices for GM corn are summarized in Figure 12. Currently the corn is trading at $3.36 per bushel. One bushel of corn grains is 56 pounds (25.4 kg). The low prices of corn are due to high production in US in the last few seasons.

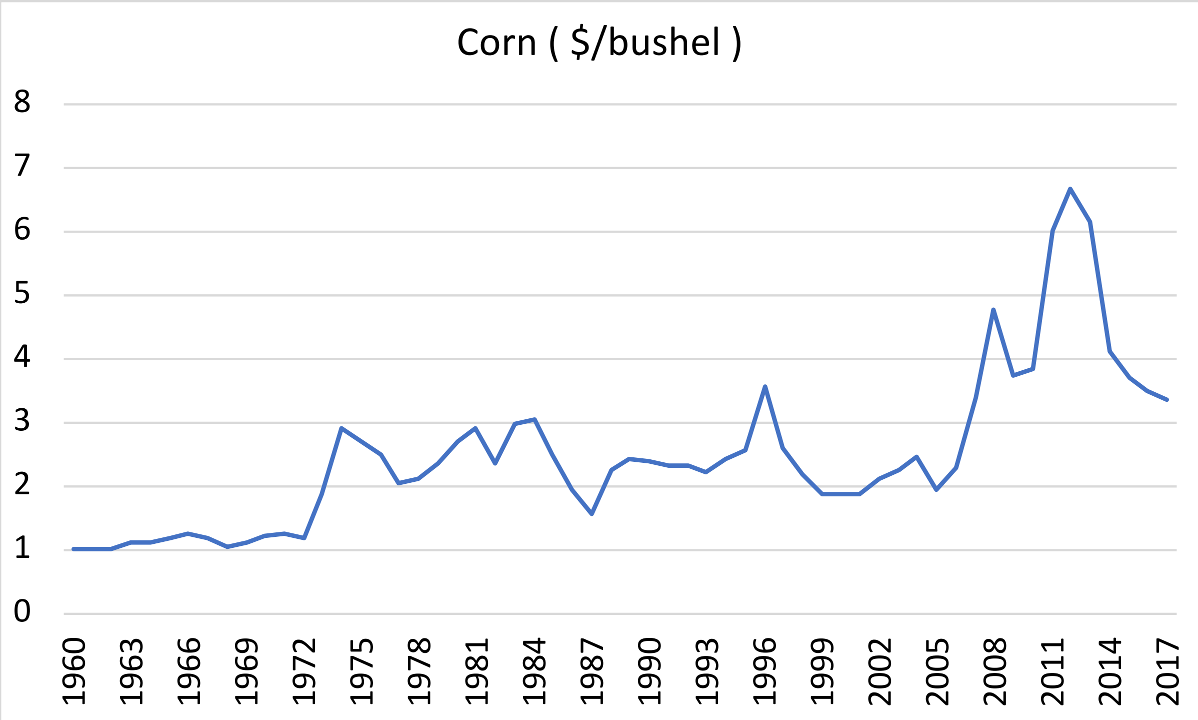


Figure 12 Historical prices of corn in US. (Source: USDA NASS, 2018c).

5.1.2. GM corn production

Corn is mostly grown in rotation with soybeans - with 28% corn and 61% soybean and 6% to idle or conservation programs. Corn is mostly rainfed crop. However, small number of farms are irrigated, about 4% in the Heartland region. Corn farmers are implementing cover crops, reduced tillage, strip-tillage, conservation tillage, variable-rate nitrogen management as best management practices that lead to a healthier and more productive agricultural system.

Below is the summary of inputs required for field corn production in Minnesota as reported in the USDA ERS (2014).

Seed: GM corn forms 90% of the corn planted with 32000 - 34000 seed per acre. There are three dominant types of GM/transgenic corn varieties used in US – Herbicide-tolerant (HT) corn, Bacillus thuringiensis (Bt) corn and Stacked (HT & Bt) corn. HT corn is tolerant to herbicides such as glyphosate, glufosinate, and dicamba. They provide farmers with a broad variety of options for weed control. Bt corn is insect-resistant and provide protection against the corn rootworm, the corn earworm and the European corn borer. Figure 13 illustrate increases in adoption rates for 'stacked' varieties, which have both (in some cases, multiple) HT and Bt traits (USDA ERS, 2018).

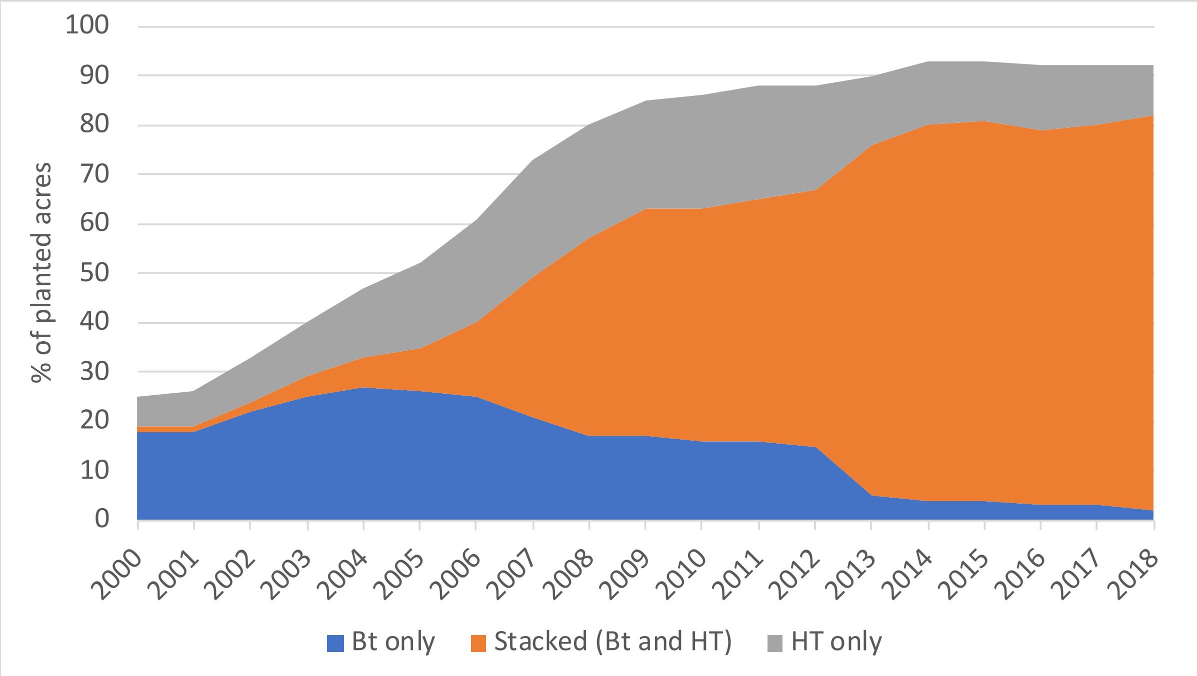


Figure 13 Adoption of GM corn varieties in US from 2000-2018. (Source: USDA ERS, 2018b).

Fertilizers: Corn requires high Nitrogen and on an average each corn acre applied about 147 lbs, phosphorus at the rate of 61 lbs, Potash at 80 lbs per acre and Sulphur 33 lbs per acre. Fertilizer application depends upon various factors such as soil organic matter, price of the fertilizer, and yield goals. For soils with higher organic matter content the requirement for fertilizers decreases significantly.

Herbicides: Four major types of common herbicide used in corn are Atrazine (1.08 lbs/acre), Glyphosate potassium salt (1.33 lbs/acre), Glyphosate isopropylamine salt (1.01 lbs/acre) and Acetochlor (1.37 lbs /acre).

Fuel and energy use: Diesel, gasoline, propane and electricity are used in corn production for transport, farm vehicles, planting and harvest operations, and drying of grains. Diesel at 3.5 gallons, gasoline at 1.8 gallons and propane at 1.4 gallons per acre are used to run farm machinery and for transport. Electricity is also used at the rate for 14.6 kWh per acre to remove 10 percentage points of moisture.

Tillage systems: Corn fields are prepared in variety of ways using no-tillage, strip-tillage, shallow tillage, conventional tillage systems in Minnesota. There is increased interest in farmers to use cover crops that can improve soil health.

Field corn is grown for ethanol production and is transported from farms to the nearby plants. There are about 20 ethanol plants in Minnesota with production capacity of more than one billion gallons.

Corn use: About 42% of corn grains grown in Minnesota are exported, 37% are processed for ethanol (30% of which is dried distiller grains, DDGs and are used in animal feed), 14% is directly used for animal feed and 7% are used in other ways.

Corn is primarily grown in Minnesota for ethanol (ethyl alcohol) productions. There are 19 ethanol plants and one biobutanol plant in the State. These plants have a combined production capacity of more than one billion gallons per year.

Ethanol plants can produce about 2.8 gallons of ethanol per bushel of corn by dry-mill process. In addition, about 17 pounds of dried distiller grains (DDGs) are produced per bushel of corn. Dry millers process corn into flakes for cereal, corn flour, corn grits, corn meal, and brewer grits for beer production.

Wet milling can yield 15.1 kg of high-fructose corn syrup (HFCS) from one bushel of corn, which yield an average of 31.5 pounds (14.3 kg) of starch. This process also produces glucose and dextrose, starch, corn oil, beverage alcohol, industrial alcohol, and fuel ethanol.

Direct consumption of corn for food is very limited. Much of the corn is used as animal feed and then meat and other products such as beverages containing HFCS, cereals, cooking oil etc. are used for human consumption.

Waste: Waste generated on corn farms is of two types – organic and non-organic. Organic waste constitutes crop residue (stovers) and any loss of grains at harvest. Harvest loss is generally about 1% of grain during harvest and transport. Stover yield is about 75% of the grain yield. If grain yield is 160 pounds per acre, then the stover yield is 120 pounds per acre. Typically, 20% of this is left on the ground for conservation purpose and 80% is removed. This stover is rich in carbon, nitrogen and many nutrients (Table 6).

Table 6 Corn stover nutrient concentration at the time of grain harvest. (Source: Sawyer and Mallarino, 2014).

Nutrient	Average (lb/ton DM)
P	3
K	19
Ca	8
Mg	4
S	1
Zn	0.033
Mn	0.096
Cu	0.013
B	0.01
Fe	0.148

Non-organic waste includes plastic waste, used pesticide and herbicide containers, packaging cardboards, used oil, worn out machinery parts etc. Bulk containers are returned to retailer

Plastic containers are rinsed and collected for disposal/recycling. Machinery components and batteries are recycled.

5.1.3. Organic corn production

Minnesota with over 500 certified organic farms and 130,688 acres is ranked ninth in the US for the total number of organic farms in 2016. Organic corn in Minnesota is 14 percent of the total US production. Corn for grains was produced on about 160 farms with 28,524 acres, yielding average of 150 bushels an acre. Organic corn prices are higher than the conventional corn prices, at $7.46 per bushel in 2017 (Figure 14), where five-year average is above $10 per bushel.

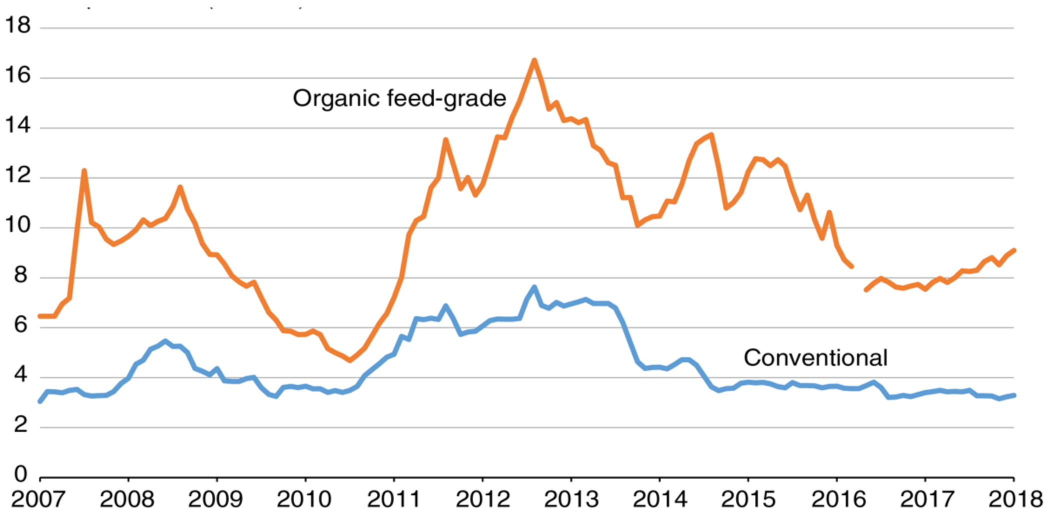


Figure 14 Farm gate organic corn feed grain prices ($/bushel) between 2007-2018. (USDA ERS, 2018).

Corn is grown in rotation with soybean and other crops depending upon the type of farm. Majority of organic farms are mixed enterprises – include crops and livestock and are diversified operations. These farms use crop and livestock rotations to improve soil health, manage soil borne diseases, prevent pest outbreaks and also to maintain economic viability of the farm.

Organic corn production uses light tillage as opposed to strip -tillage used in conventional GM corn farms. Weed management utilises rotary hoes, harrows or row cultivators for weed management. Reduced tillage is also used with cover crops to manage weeds. Goal of tillage is to enhance soil structure, tilth, organic matter, soil fauna, nutrient cycling, and microbial activity. This requires appropriate crop rotations with perennials and legumes in the cropping system. Organic farmers grow hybrid seed at the rate of 28000-34000 seed per acre.

Fertilisers: Manure or compost is used in corn production with the application rates of 50lbs per acre of Nitrogen, 20 Phosphorus, 30 Potassium, and 0.1 tons per acre of Lime application. About 80% of the organic corn growers use these applications. Animal manures are good source of all essential nutrients required by crops on organic farms (Table 7). Manures can supplement the availability of soil nutrients by improving its structure and organic matter. Nutrient content of manures varies and depend on types of livestock, their bedding, manure handling and storage systems and any dilutions.

Fuel and energy use: Diesel, gasoline, propane and electricity are used in corn production for transport, farm vehicles, planting and harvest operations, and drying of grains. Diesel at 7.5 gallons, gasoline at 1.8 gallons and propane at 1.8 gallons per acre are used to run farm machinery and for transport. Electricity is also used at the rate for 21.6 kWh per acre to remove 10 percentage points of moisture.

Table 7 Range of nutrients in manure from five species of livestock. (Source: Minnesota Environmental Quality Board, 1999).

Elements	**Cattle (steer)**	**Swine**	**Cage layer**	**Broiler**	**Dairy**
N	3.2	3.8	4.8	4.75	2.4
P	1.6	2.13	2.22	2	0.76
K	0.5	1.34	1.63	1.38	0.75
S	-	0.3	-	-	0.24
CP	20.3	23.5	30	29.7	150
Ash	11.5	15.3	30.4	17.5	-
Ca	0.87	2.72	8.13	3.4	1.9
Na	0.88	2.75	0.46	0.47	0.24
Cl	1.32	-	1.01	-	0.6
Mg	0.4	0.93	0.65	0.53	0.32
Fe	1340	190	1773	1690	560
Cu	31	114	70	32	20
Co	-	6	2	-	-
Mn	147	342	374	432	800
Zn	242	530	477	326	80
Se	-	-	0.6	-	-
Mo	-	0.3	-	-	-

5.1.4. Comparison of GM and organic corn production systems

There are significant differences in the practices, inputs and outputs in GM and organic corn farms, which are summarised in Table 8 and 9.

Table 8 Mean characteristics and practices of US conventional and organic corn farms, 2010 (Source: McBride et al., 2015).

		Organic (N=243)	**Conventional (N=1,087)**
Farm characteristics	Farm acres operated (per farm)	451	794
	Off-farm occupation (percent)	11	18
	Age (years)	51	56
Education	Less than high school (percent)	24	8
	Completed high school (percent)	29	45
	Attended college (percent)	47	47
Production practices	Harvested corn acres (per farm)	103	209
	Genetically modified seed (percent)	0	92
	Continuous row crop	17	77
	Idle year	35	10
	Moldboard plow	65	9
	No-till planter	5	35
	Row cultivator	68	5
	Applied commercial fertilizer	51	97
	Applied manure or compost	75	22

Table 9 Costs and returns of conventional and organic corn by region in US. (Source: USDA ERS, 2014).

	Conventional							**Organic**		
Item	**Heartland**	**Northern Crescent**	**Northern Great Plains**	**Prairie Gateway**	**Eastern Uplands**	**Southern Seaboard**	**United States**	**Heartland**	**Northern Crescent**	**United States[4]**
Gross value of production ($/acre)										
Corn grain	723.11	689.52	574.56	614.86	633.15	557.76	**688.47**	855.60	809.08	**902.66**
Corn silage	0.24	5.06	1.18	1.01	4.69	0.00	**0.92**	0.20	2.05	**0.87**
Total, gross value of production	723.35	694.58	575.74	615.87	637.84	557.76	**689.39**	855.80	811.13	**903.53**
Operating costs										
Seed	87.76	75.43	80.05	63.23	56.00	67.14	**81.63**	66.70	56.85	**60.75**
Fertilizer[1]	118.25	122.41	94.92	84.80	131.42	137.83	**112.13**	39.42	90.15	**73.29**
Chemicals	26.96	25.94	18.35	26.47	24.58	35.32	**26.32**	0.43	0.00	**0.21**
Custom operations[2]	15.29	20.32	16.16	18.96	6.27	17.77	**16.38**	7.73	14.33	**16.61**
Fuel, lube, and electricity	22.18	23.63	26.75	42.38	18.99	31.67	**25.78**	28.73	37.63	**41.39**
Repairs	21.77	23.48	26.85	32.34	22.68	26.02	**23.95**	28.45	34.32	**33.03**
Purchased irrigation water	0.00	0.00	0.76	0.38	0.00	0.00	**0.11**	0.00	0.00	**0.00**
Interest on operating capital	0.29	0.29	0.26	0.27	0.26	0.31	**0.28**	0.17	0.23	**0.22**
Total, operating costs	292.50	291.50	264.10	268.83	260.20	316.06	**286.58**	171.63	233.51	**225.50**
Allocated overhead										
Hired labor	2.62	3.57	3.17	3.34	2.33	4.13	**2.96**	2.27	5.93	**3.90**
Opportunity cost of unpaid labor	20.17	29.79	26.58	24.35	33.76	32.48	**22.49**	50.50	50.41	**48.54**
Capital recovery of machinery and equipment	81.18	73.69	95.86	100.94	71.86	81.79	**84.35**	102.44	96.83	**105.72**

Opportunity cost of land	150.65	82.66	75.46	86.35	72.64	66.88	**127.42**	123.46	83.79	**109.95**
Taxes and insurance	7.76	9.03	8.85	10.45	10.96	11.91	**8.45**	13.30	14.39	**13.26**
General farm overhead	17.37	23.74	18.08	16.85	23.38	25.68	**18.09**	30.86	35.78	**30.39**
Total, allocated overhead	279.75	222.48	228.00	242.28	214.93	222.87	**263.76**	322.83	287.13	**311.76**
Total, costs listed	572.25	513.98	492.10	511.11	475.13	538.93	**550.34**	494.46	520.64	**537.26**
Value of production less total costs listed	151.10	180.60	83.64	104.76	162.71	18.83	**139.05**	361.34	290.49	**366.27**
Value of production less operating costs	430.85	403.08	311.64	347.04	377.64	241.70	**402.81**	684.17	577.62	**678.03**
Supporting information										
Yield (bushels per planted acre)	167	156	144	142	135	112	**159**	120	113	**121**
Price (dollars per bu at harvest)	4.33	4.42	3.99	4.33	4.69	4.98	**4.33**	7.13	7.16	**7.46**
Enterprise size (planted acres)[3]	314	148	390	371	63	132	**282**	89	59	**80**
Production practices										
Irrigated (percent)	5	0	19	43	0	15	**11**	1	11	**15**
Dryland (percent)	95	100	81	57	100	85	**89**	99	89	**85**

[1] Cost of commercial fertilizers, soil conditioners, and manure.
[2] Cost of custom operations, technical services, and commercial drying.
[3] Include planted conventional and organic corn acres.
[4] Includes data for all operations in the two major regions plus those outside these regions.

Economic performance of corn in Minnesota

A case study showing comparison of profitability in chemical and organic input corn in Minnesota is illustrated here (Delbridge et al., 2011).

High consumer demand for organic food products since 1990s has led to the expansion of organic agriculture in US. However, total organic area in US remains small as compared to the conventional agriculture in US due to high transition costs and uncertainty regarding future returns (Kuminoff and Wossink, 2010). In Minnesota, about 30000 acres out of total 8.5 million acres are under organic. One major barrier is the productivity and profitability of organic farm as compared to the chemical input ones. A case study focused on 4-year and 2-year rotation of chemical input (CI) and 4-year rotation of organic input (OI) corn analyzed profitability and risks in both systems. Profitability is defined as the net returns from corn production operation and risks include varying yields, input costs, and corn prices. The study (Delbridge et al., 2011) used 18 yr of data from 1993 to 2010 for yield and farm management data from the University of Minnesota's Variable Input Crop Management Systems (VICMS) trial located in southwestern Minnesota.

Production cost in the CI 2-yr rotation were higher than both the CI 4-yr and OI 4-yr rotations (\$488 ha^{-1}, \$405 ha^{-1}, and \$409 ha^{-1}, respectively). Machinery cost was higher in the OI rotation. These input cost differences were due to lower nutrient application rates in the CI 4-yr rotation and lower seed and pesticide expenses in the OI 4-yr rotation. No significant difference was found in the average corn yield between the three rotations. Without any price premium for OI, the average net return for the CI 2-yr rotation was the highest of the three rotations analyzed. However, net returns of OI rotation was higher than that of the CI 4-yr and 2-yr rotations (\$1329 ha^{-1}, \$675 ha^{-1}, and \$846 ha^{-1}, respectively), when organic price premiums were applied. It was also found out that the OI rotation is much better in risk aversion due to yields, inputs costs and fluctuation in market prices of corn.

5.1.5. Key findings

Comparison of GM and organic corn

Variable inputs cost in GM corn are higher than those in the organic corn based on the average yield data in US (Figure 15a). Capital costs in organic farms are higher than GM corn due to their small size (Figure 15b). Corn yield based on average data obtained from USDA suggests higher yield in GM corn than the organic corn (Figure 15c). Net returns are found to be higher in organic corn (Figure 15d).

Given higher net return from organic corn, a greater number of conventional or GM corn farmers should convert to organic. However, organic practices are not being widely adopted. One main reason is the safety net in place for conventional farmers due to Farm Bill programs. There is nothing comparable to cover risks, especially during the transition process for organic farmers. There are a number of barriers such as technology required for weed control, organic seed availability, market, insurance etc., which prevent mass scale conversion to organic farming.

Fuel vs Food
One bushel (56 pounds) of GM corn yields about 2.8 gallons of ethanol and about 17 pounds of dried distiller grains (DDGs). These DDGs used as animal feed can produce 8.5 pounds of beef. Whereas, one bushel of corn used directly as animal feed can yield 28 pounds of beef. It is noteworthy that organic corn is directly used for animal feed. However, this does not address the land use and market effects that define the fuel vs food dilemma.

Figure 15 Comparison of GM and organic corn, a) input cost, b) capital cost, c) production per acre, and d) net returns per acre.

5.2. Social capital

Social capital is defined as the features of social life, networks, norms and trust, that enable participants to act together more effectively to pursue shared objectives (Putnam 1993, 1995). In agriculture, social capital helps to improve outputs through the network of farmers, agri-businesses, community groups, research and development, and government institutions. This form of capital supports the production and marketing activities. These networks facilitate new information and technology, which is essential for farming and can enhance the economic and environmental sustainability of agricultural systems, leading to improved well-being of rural community. Four key features of social capital are relations of trust; reciprocity and exchanges; common rules, norms, and sanctions; and connectedness in networks and groups (Pretty, 2003). The social bonds and norms are important for people and communities as they co-operate and it can lower the transaction cost (Coleman, 1988). Social capital is essential for the production of other forms of capital.

There are three main dimensions of social capital – structural, relational and cognitive (Figure 16). The structural dimension is the pattern of connections and networks among actors and includes bonding, bridging and linking of social interactions (Table 10, Narayan, 1999; Putnam, 2000; Chazdon et al., 2013). Bonding is interaction between members of a relatively homogenous group (family or close friends), while bridging refers to the interconnections between heterogeneous groups (agri-businesses, farming groups etc.). Ties between individuals, or the groups they belong to, etc are known as linking social capital.

Relations between people and groups due to trust among actors are included in the relational dimension of social capital (Granovetter, 1995). It includes trust and trustworthiness (Fukuyama, 1996), norms and social sanctions (Coleman, 1990; Putnam, 1995) and reciprocity (Coleman, 1990; Granovetter, 1995; Nyhan Jones and Woolcock, 2007).

The third dimension of social capital is referred as the cognitive dimension, which is defined by the shared goals and values among actors. It facilitates a common understanding of collective goals in the absence of specific links and relations between individual members of the group (Ostrom, 2000). It captures the essence of 'the public good aspect of social capital' (Portes, 1998).

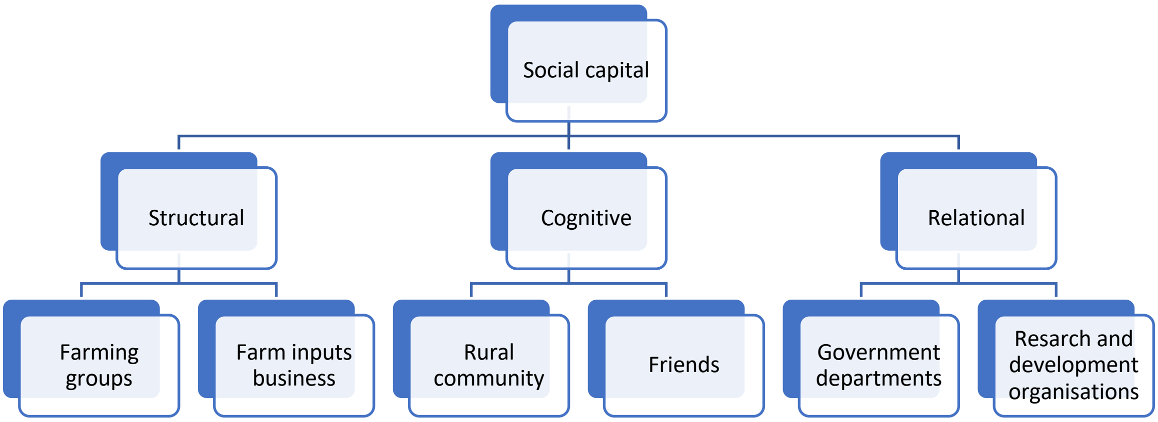


Figure 16 Dimensions and sub-dimensions of social capital in agriculture (Adapted from Chazdon et al., 2013).

Table 10 Social capital items in farming community (Adapted from Chazdon et al., 2013).

Bonding trust	Trust neighbours
	Trust other farmers
Bonding engagement	Can count on someone in the community if you need some extra help
	You and people in your community do favors for each other
	You would ask your neighbors for help if you were sick
Bridging trust	Trust people from other farming group
	Trust people new to the group
	Trust people in the same group
Bridging engagement	Level of contact with people who practice different farming techniques/crop rotation
	Level of contact with small/large farmers
	Level of contact with people who have less education than me
	Level of contact with people who have different political views
Linking trust	Trust local government/extension/market
	Trust educational organizations in your community
	Trust people in extension/environment protection
Linking engagement	Number of times you attended any farm group meeting
	Number of times you attended any club or organization meeting
	Number of times you tried to get your local government to pay attention to sustainable farming
	Number of times you organized a community effort

In Minnesota, corn growers have extensive network that extends from individuals to community and from farm level to national level (Table 11). This network extends in both private and public sectors of the corn-based economy in US.

Table 11 Social networks available to growers in Minnesota. X means available.

	Network	**Dimension**	**In GM corn**	**In Organic**	**Informal/Formal/Transactional**
Government	US Department of Agriculture	Relational	X	X	Informal
	Minnesota Department of Agriculture	Relational	X	X	Informal
	US Department of Agriculture-Rural Development	Relational	X	X	Informal
	Farm service in counties	Relational	X	X	Informal
	American Farm Bureau	Relational	X	X	Informal
	Minnesota Farm Bureau	Relational	X	X	Informal
	National Farmers' Union	Relational	X	X	Informal
	Minnesota Extension Service	Relational	X	X	Informal
	Agricultural Utilization Research Institute	Relational	X	X	Informal
	Center for Farm Financial Management	Relational	X	X	Informal
	Minnesota Agriculture Education Leadership Council	Relational	X	X	Informal
	USDA Farm Service Agency (FSA)	Relational	X	X	Formal
	USDA Natural Resources Conservation Service	Relational	X	X	Formal
	Minnesota	Relational	X	X	Formal
	USDA Animal and Plant Health	Relational	X	X	Formal

	Inspection Service				
	USDA Risk Management Agency	Relational	X	X	Formal
	Farm Service Agency/Board of Water and Soil Resources	Relational	X	X	Formal
	Minnesota Conservation Reserve Enhancement Program (MN CREP)	Relational	X	X	Formal
	Reinvest In Minnesota Reserve Program (RIM)	Relational	X	X	Formal
	Conservation Cost-Share Program	Relational	X	X	Formal
	Agriculture BMP Loan Program (AgBMP)	Relational	X	X	Formal
	Minnesota Agricultural Water Quality Certification Program (MAWQCP)	Relational	X	X	Formal
	Environmental Quality Incentives Program (EQIP)	Relational	X	X	Formal
	Conservation Stewardship Program (CSP)	Relational	X	X	Formal
	Agricultural Conservation Easement Program (ACEP)	Relational	X	X	Formal
	Faribault County Soil/Water Clean Water Partners Cover Crop Assistance Program	Relational	X	X	Formal
Research	The Minnesota	Relational	X	X	Informal

	Institute for Sustainable Agriculture				
	University of Minnesota Extension	Relational	X	X	Informal
	University of Minnesota: Department of Applied Economics	Relational	X	X	Informal
	University of Minnesota: Department of Family Social Science: Rural MN Life	Relational	X	X	Informal
	University of Minnesota: College of Food, Agriculture and Natural Resource Sciences	Relational	X	X	Informal
	Economic Research Service, USDA	Relational	X	X	Informal
	Center for Transportation Studies	Relational	X	X	Informal
	Kellogg Collection of Rural Community Development Resources	Relational	X	X	Informal
	National Sustainable Agriculture Information Service	Relational		X	Informal
	Sustainable Agriculture Research and Education	Relational		X	Informal
	Rural Policy Research Institute			X	Informal
Farming/environment groups	Minnesota Farmers Union	Structural/cognitive/relational	X		Formal
	Cover crop group	Structural/cognitive/relational	X		Informal
	Strip tillage group	Structural/cognitive/relational	X		Informal

	Soil health partnership	Structural/cognitive/relational	X	X	Informal
	The National Corn Growers Association	Structural/cognitive/relational	X		Informal
	Minnesota Corn Growers Association	Structural/cognitive/relational	X		Informal
	The Land Stewardship Project	Relational	X	X	Informal
	The Sustainable Farming Association of Minnesota	Structural/cognitive/relational		X	Informal
	MOSES-Midwest Organic and Sustainable Education Services	Structural/cognitive/relational		X	Informal
	ALBA-Agricultural and Land Based Association	Structural/cognitive/relational		X	Informal
	Attra- National Sustainable Agricultural Information Services	Structural/cognitive/relational		X	Informal
	Farmers' Legal Action Group	Structural/cognitive/relational	X	X	Informal
	Local Dirt	Structural/cognitive/relational	X	X	Informal
	Renewing the Countryside	Structural/cognitive/relational	X	X	Informal
	American Farmland Trust	Structural/cognitive/relational	X	X	Informal
	Smart Communities Network	Structural/cognitive/relational	X	X	Informal
	Minnesota Environmental Initiative	Structural/cognitive/relational	X	X	Informal
	Minnesota Land Trust	Structural/cognitive/relational	X	X	Informal
	Mississippi Headwaters Board	Structural/cognitive/relational	X	X	Informal
	1000 Friends of Minnesota	Structural/cognitive/relational	X	X	Informal
	Northern Prairie Wildlife	Structural/cognitive/relational	X	X	Informal

	Research Center				
	SmartGrowth	Structural/cognitive/relational	X	X	Informal
	Sprawl Watch Clearinghouse	Structural/cognitive/relational			Informal
Businesses	Agri-chemical dealers	Structural/relational	X		Transactional
	Seed dealers	Structural/relational	X	X	Transactional
	Ethanol plant cooperatives	Structural/relational	X		Transactional
	Corn buyers	Structural/relational	X	X	Transactional
	Insurance companies/agents	Structural/relational	X	X	Transactional
	Banks	Structural/relational	X	X	Transactional
	Cooepratives	Structural/relational	X		Transactional
	Farm machinery companies	Structural/relational	X	X	Transactional
	Organic certification	Structural/relational		X	
Individuals	Neighbours/friends	Cognitive/relational	X	X	Personal
	Rural town/community	Cognitive/relational	X	X	Personal
Foundations and Non-profits	Blandin Foundation	Cognitive/relational	X	X	Informal
	McKnight Foundation	Cognitive/relational	X	X	Informal
	Minnesota Council on Foundations	Cognitive/relational	X	X	Informal
	Minnesota Council of Non-profits	Cognitive/relational	X	X	Informal
	Bush Foundation	Cognitive/relational	X	X	Informal
	Center for Rural Strategies	Cognitive/relational	X	X	Informal
	Farm Foundation	Cognitive/relational	X	X	Informal

5.2.1. Benefits of social capital

There are two main benefits of social capital – to individuals and group benefits (Chazdon et al., 2013). Social resources and networks are more important for individuals than personal resources, such as education or wealth (Lin 2001). Individuals can enhance their competitive advantage based on their position within the social network (Burt, 1992). At the same time, social capital is a collective asset produced and shared by members of a group (Putnam 1993; Bourdieu 1986).

Social capital includes both formal and informal networks. Informal networks can be used to acquire training from others who have already adopted new practices. Whereas, formal networks can help obtain assistance to implement various practices through extension activities, participation in conservation programs etc. Agriculture sector provides employment to vast majority of rural community. Therefore, social networks can help facilitate employment and market opportunities (Fafchamps and Minten, 1998; Granovetter, 1995; Montgomery, 1991; Rauch and Casella, 2001). Farmers also play vital role in enhancing other forms of non-agriculture activities such as cultural and natural heritage, social cohesion, the promotion of entrepreneurial initiatives and for the creation of a social identity (cultural, civic, religious, developmental, women's and youth associations, environmental groups, etc.) (Jordan et al. 2010). Another benefit of social capital is the promotion of sustainable practices and environmental sustainability in the region, which are led by farmers. Practitioner farmers can have positive influence on the group members in promoting sustainable farming technology and practices (Mathijs 2003; Munasib and Jordan 2011). Below table describes various items of social capital

Social capital creates better farming communities as summarised in Table 12 (Flora 1995). Figure 17 provides a framework on how social networks lead to benefits to individual and community.

Table 12 Benefits of strong social capital in agriculture. (Source: Flora 1995).

Benefit	**Signs of strong social capital**
Stronger farming community	• Farmers spend more time in farm community organizations. • There are more volunteers. • Farmers spend more time socializing with family, friends and neighbors.
Economic Prosperity	• Social connections help people market their produce and improve incomes/returns. • Cooperation and communication help farmers to take on community leadership roles. • Collective action leads to innovations such as use of cover crops, strip-tillage, conservation agriculture and adapt to changing market conditions.
Public Health and Individual Well-being	• Farming community which is socially connected is happier and healthier. • They are also more likely to monitor their use of environmental resources. • Meeting in groups reduces stress, and less stress leads to improved well-being.

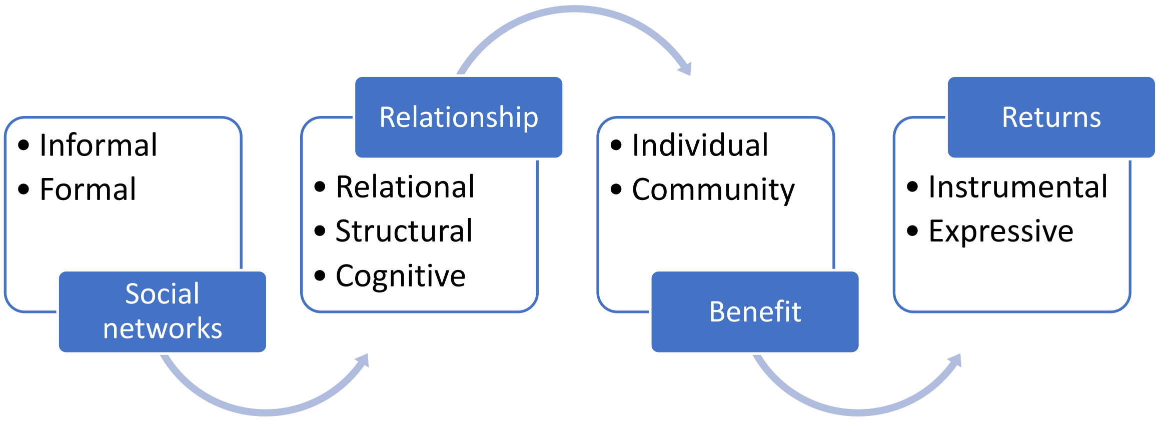


Figure 17 Framework of social capital leading to returns to individuals and community (Adapted from Rostilla 2010).

Cover cropping group and social capital

A cover crop is a plant that is used to provide ground cover in-between row crops in order to improve soil health. Some of the common cover crops used in agriculture are grasses, legumes, brassicas etc. There are multiple benefits of cover crops such as reduction of soil erosion, enhancement of water availability, restriction in weed emergence, control of pests and diseases, increased biodiversity. These translate to improvement in soil health and also leads to increase in grain productivity. For example, corn grown with cover crops yields 3.4 bu/acre more than the one without cover crops. There are a number of resources available to corn growers in Minnesota to learn about the practices, costs and benefits of cover crops. For example, Midwest Cover Crop Council's Minnesota Cover Crop Decision Tool, Midwest Cover Crops Field Guide, USDA-ARS (From the U.S. Department of Agriculture Agricultural Research Service, Northern Great Plains Research Laboratory), Cover Crops Learning Center (From North Central Region-Sustainable Agriculture Research & Education, NCR-SARE).

Farming groups working in partnership with these networks are helping to spread the knowledge about costs and benefits of cover crops in corn growing region. There is continuous increase in number of farmers adopting cover crops and acreage. This demonstrates improvement in social network and trust amongst farmers and resource providers. Social capital improvement through spread and adoption of cover crops extends beyond the farm.

Some of the multi-functional aspect of cover crops for example improvement in soil health, organic matter leads to increase in carbon sequestration by soil thereby contributing to the removal of carbon from the atmosphere and hence mitigating the impacts of climate change. This benefits the society at-large. Reduction in surface run-offs of agro chemical due to ground cover also improves water quality. It is also estimated that better pests and disease suppression can result in decrease in the quantity of agrochemical use, which leads to improvement of air quality.

5.2.2. Key findings

Corn is a dominant crop in Minnesota and is vital for the agricultural economy. About 24,000 corn farmers generate more than $4.5 billion for the economy of Minnesota.

Various types of social networks in Minnesota provide required resources, information and knowledge to corn growers.

There are both public and private sector networks and community groups that provide support to corn farmers in Minnesota.

There are clear benefits to farming community, environment and society from the social networks associated with corn production.

Social networks can enable rural community to cope with the increasing challenges of market volatility, climate change and degradation of natural resources.

5.3. Human capital

Human capital is defined as “the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being” (OECD, 2001, p18). Measurement of human capital includes cognitive skills and explicit knowledge of a person. In addition, various non-cognitive skills and other attributes contribute to well-being and also form the part of human capital.

Human capital comprises of individual’s health, knowledge, skills and motivation that are essential for productive work. It is based on the premise that individuals and society derive economic benefits from investments in people (Schultz 1962; Sweetland, 1996). In agriculture, human capital includes farmers knowledge, proficiency in farm practices, farm workers health etc. Human capital increases with improvements in the health, skills, experience and education of human population. It is affected by the loss of skills and experience and by changes in human health (OECD, 2001; TEEBAgriFood Report, 2018). Some key skills and personal attributes relevant to human capital are summarised in Table 13.

Table 13 Key skills and personal attributes in human capital. (Source: OECD, 2001).

Skills	**Attributes**
Communication	– Listening – Speaking – Reading – Writing – Numeracy
Intra-personal skills	– Motivation/perseverance – “Learning to learn” and self-discipline (including self-directed learning strategies) – Capacity to make judgements based on a relevant set of ethical values and goals in life
Inter-personal skills	– Teamwork – Leadership
Other skills and attributes	– Facility in using information and communications technology – Tacit knowledge – Problem-solving (also embedded in other types of skills) – Physical attributes and dexterity

5.3.1. Rural population in Minnesota

To understand the type and form of human capital associated with corn production systems in Minnesota, we provide a snapshot of demographic information about the human population (Table 14) and then discuss various aspects of rural population.

Out of total population of 5.57 million, 1.22 live in rural Minnesota. There is continuous trend in decline in rural population due to migration to urban areas since 1900 (Figure 18).

Out of 1.22 million rural population, there are about 73400 farmers in Minnesota. The average age of famer is more than 55 (Figure 19). About 8.5% are women operators (Figure 20). Majority of rural population has high school qualification as opposed to urban and towns where majority has Bachelor’s degree or above (Figure 21).

Table 14 Demographics of Minnesota. (US Census data).

Population	Population estimates, July 1, 2017	5,576,606
	Female persons, percent	50.20%
Race	White alone, percent	84.40%
	Black or African American alone, percent	6.50%
	American Indian and Alaska Native alone, percent	1.40%
	Asian alone, percent	5.10%
	Native Hawaiian and Other Pacific Islander alone, percent	0.10%
	Two or More Races, percent	2.50%
	Hispanic or Latino, percent	5.40%
	White alone, not Hispanic or Latino, percent	79.90%
	Veterans, 2012-2016	331,516
	Foreign born persons, percent, 2012-2016	7.80%
	Households, 2012-2016	2,135,310
Housing	Persons per household, 2012-2016	2.49
	Language other than English spoken at home, percent of persons age 5 years+, 2012-2016	11.10%
Education	High school graduate or higher, percent of persons age 25 years+, 2012-2016	92.60%
	Bachelor's degree or higher, percent of persons age 25 years+, 2012-2016	34.20%
Health	With a disability, under age 65 years, percent, 2012-2016	7.20%
	Persons without health insurance, under age 65 years, percent	5.10%
Economy	In civilian labor force, total, percent of population age 16 years+, 2012-2016	69.80%
	In civilian labor force, female, percent of population age 16 years+, 2012-2016	66.10%
	Total accommodation and food services sales, 2012 ($1,000)	11,722,627
	Total health care and social assistance receipts/revenue, 2012 ($1,000)	40,403,572
Income	Median household income (in 2016 dollars), 2012-2016	$63,217
	Per capita income in past 12 months (in 2016 dollars), 2012-2016	$33,225

	Persons in poverty, percent	9.50%
Businesses	Total employer establishments, 2016	150,115
	Total employment, 2016	2,661,627
Geography	Population per square mile, 2010	66.6

The cropping systems calculator and human capital

Decision making in farming depends upon several factors such as, knowledge, technology, costs, benefits etc. Farmers require an analysis of costs and benefits to adopt new technology or farming system. The Land Stewardship Project (https://landstewardshipproject.org/) through its Chippewa 10% project, has developed a cropping systems calculator in order to facilitate decision making at farm level. It allows farmers to analyse various planting and grazing scenarios in terms of costs and benefits of each option. It is an Excel-based tool that allows comparison of various crop rotations for up to six years and provides average yearly returns with a yearly breakdown for Minnesota regions.

Such tools help farmers to analyse various rotations, different farming systems and to weigh in options for transitions. It develops farmers skills and knowledge in the area of benefit-cost analysis. They are able to use it for decision making and planning their operations more effectively. Such effective and user-friendly tools help build human capital in agriculture systems.

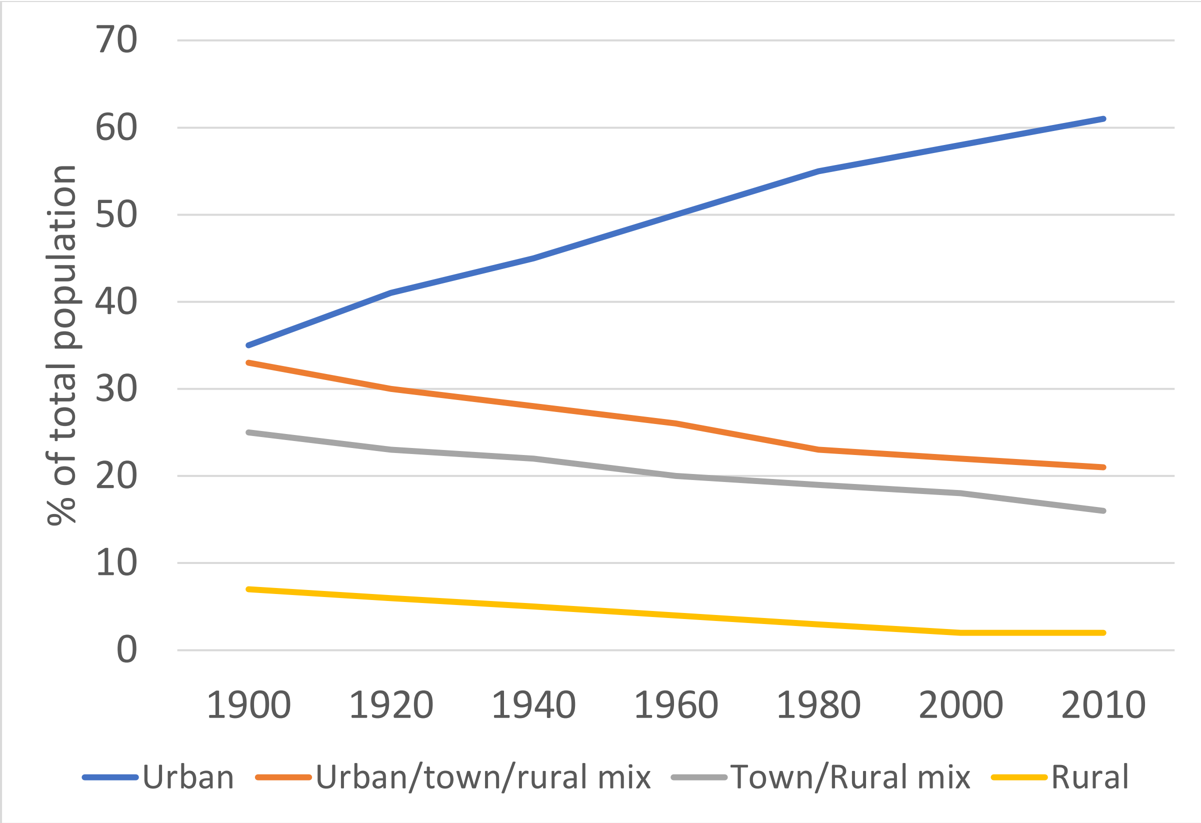


Figure 18 The share of Minnesota's population (Asche, 2018).

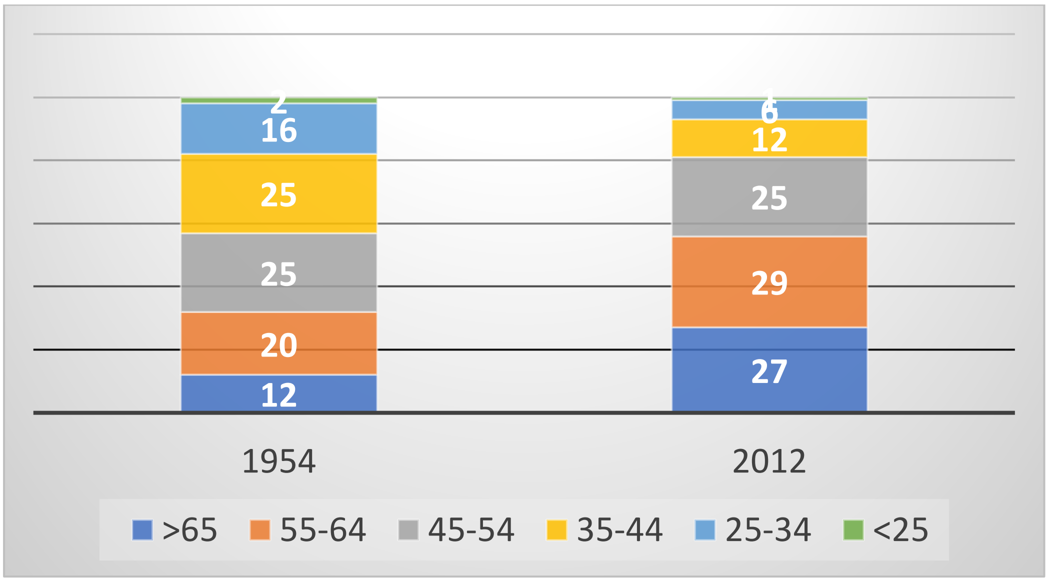


Figure 19 Age distribution among Minnesota farm operators in 1954 and 2012.

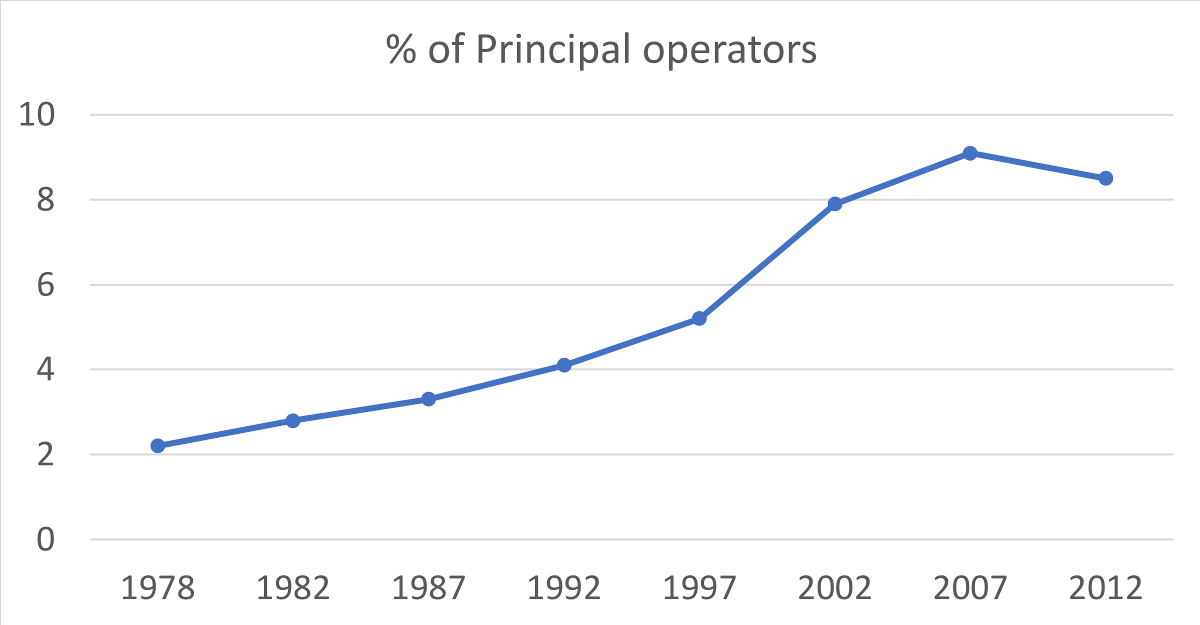


Figure 20 Women as share of farm operators from 1978 to 2012.

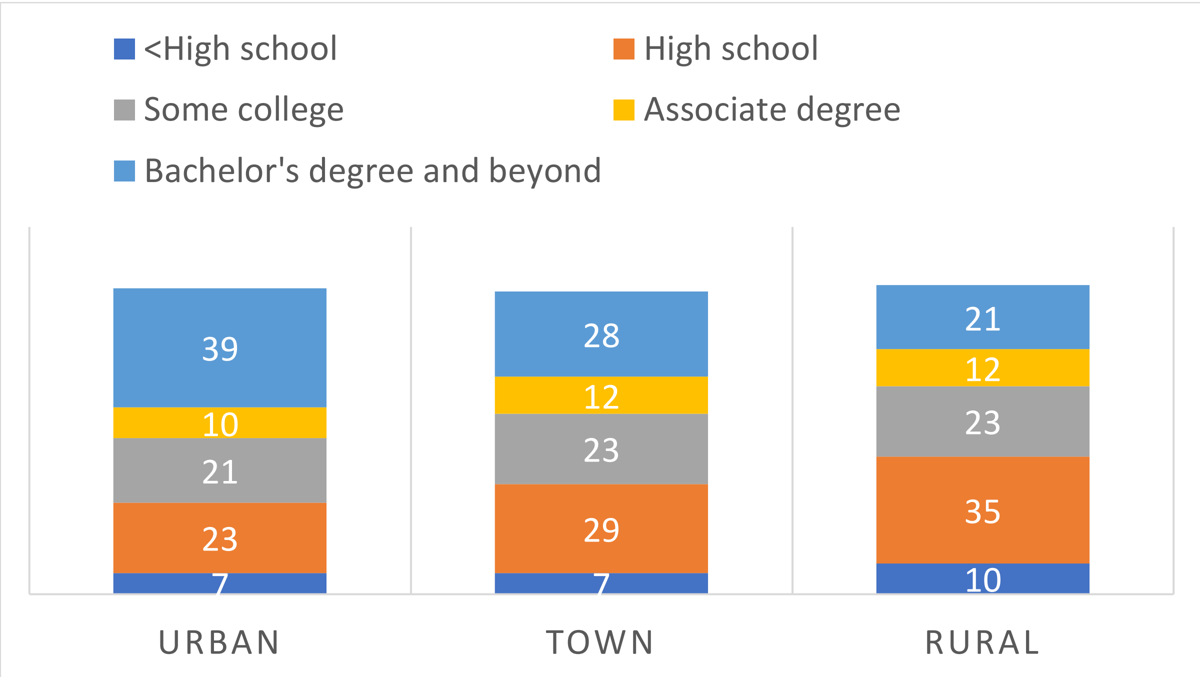


Figure 21 Status of education in urban, town and rural Minnesota.

5.3.2. Health in Rural Minnesota

Obesity is higher in rural than urban areas (Figure 22). There are five leading causes of death in Minnesota - Cancer, Heart Disease (Figure 23), Unintentional Injury, Chronic Lower Respiratory Disease (Figure 23) and Stroke.

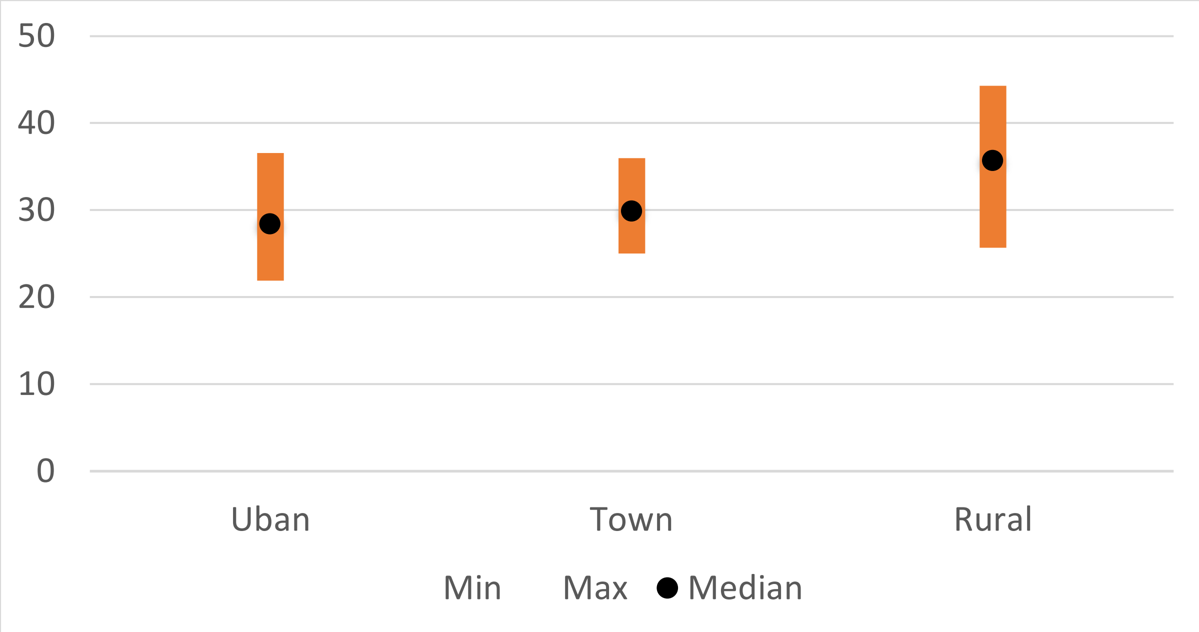


Figure 22 Percent of adults who are obese according to BMI.

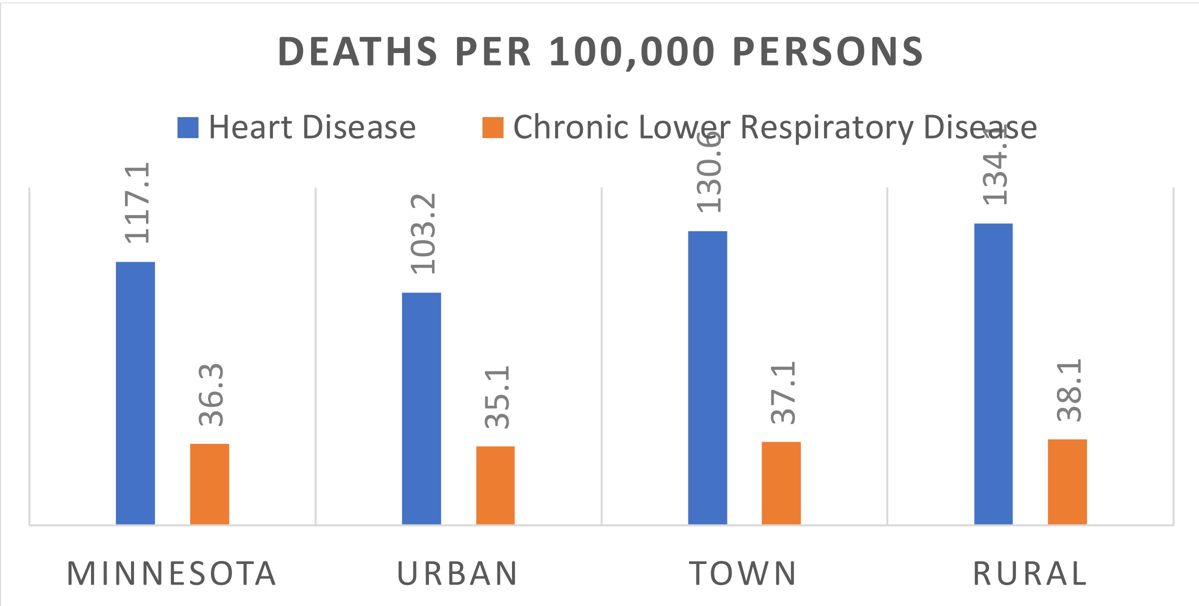


Figure 23 Heart Disease, and Chronic Lower Respiratory Disease: Age-Adjusted Mortality Rates (2011-2015).

5.3.3. Valuation of non-financial health costs associated with corn production

The valuation of non-financial health costs of corn production is based on the well-being valuation method. This method as well as the models and the estimated coefficients discussed in the rest of this section are explained in detail in Appendix B. Model (1) estimates the impact of corn intensity (δ) on general health. From Table 15, estimating the model using 5 km and 10 km buffers results in a value for δ of -0.0021 and -0.0025, respectively (statistically significant at the 5% level). The sign of δ indicates a negative association between experienced corn intensity and an individual's health. Based on these estimations, the negative impact is statistically significantly higher in the 10 km buffer compared with 5 km buffer. As the geographical area of a ZIP code is large[1], particularly in rural areas, the corn intensity measured in a 10 km buffer more precisely represents the intensity experienced by individuals throughout the ZIP code area.

The value of δ implies that an increase in corn intensity in a 10 km buffer by 1% will decrease general health by 0.0025 points (where general health is measured by a 1-5 scale). Increasing the corn intensity by 9.74%, which is the average land used for corn production in 10 km buffer in our sample, implies a decrease of 0.024 points in general health. In other words, going from no corn production to the average level of corn production (holding other factors in the model constant) implies a 0.67% decrease in general health (relative to average levels of general health).

Consequently, we apply the WV method to estimate the non-financial health costs of corn intensity in the respondents' surrounding area. Table 15 shows the results of the WV method for our sample. The non-financial health costs associated with a 1% increase in corn intensity in the vicinity of an individual's residence is 20.7 $ per year in the 5km buffer and 24.7 $ per year in the 10 km buffer. These results are based on Minnesotan average household income 2016 which, according to US Census Bureau, was $83,100.

Table 15 Estimated per-person association of corn intensity and general health and valuation of non-financial health costs.

	Model with a 5 km buffer around ZIP-code centroid	**Model with a 10 km buffer around ZIP-code centroid**
Association of corn intensity with general health	-0.0021**	-0.0025***
Annual value of health costs associated with an additional 1% corn intensity per person	$20.7	$24.7
Annual value of health costs per person associated with corn intensity=9.74% (the average intensity for Minnesota in the sample)	$180.1	$240.3

**=Statistically significant at 5% level
***= Statistically significant at 1% level

[1] The average, minimum, and maximum values for the ZIP code geographic areas in Minnesota are 244 km^2, 0.15 km^2, and 289 km^2.

Next, we estimate model (2) for the analysis of the impact of organic production on general health. As we are interested in comparing the impact of organic and non-organic production in the areas where some production exists, we limit our data set here to individuals with corn intensity higher than 1%. Column (1) in Table 16 shows the results of model (2) for the sub sample of respondents with at least 1% corn intensity. The impact of a 1% increase in corn intensity is −0.0025 points which is the same as the impact obtained for the whole sample in Table 16.

Column (2) of Table 16 shows the estimated coefficients from model (2). The association of corn intensity on health is -0.0042 for individuals in ZIP codes with no organic corn farm and is 0.0019[2] for those who live in ZIP codes with some organic corn production. Thus, the (positive) impact of the interaction variable indicates that the impact of corn intensity is reduced by 0.002 for individuals with some organic production in their ZIP code. However, the interaction impact is only marginally significant at the 10 % level.

[2] This figure is obtained by summing the association of corn intensity with general health (-0.0042) with the association of the interaction of having at least one organic farm in a zip code with corn intensity (0.0023)

Table 16 Estimated association of corn intensity and general health while accounting for the impact of organic production.

	Model (1) with the sub sample having corn intensity >1% in 10 km buffer	Model (2) with the sub sample having corn intensity >1% in 10 km buffer
Association of corn intensity with general health	-0.0025*** (-2.7859)	-0.0042*** (-3.4156)
Association of interaction of organic farm in the ZIP code and corn intensity		0.0023 (1.5894)
Association of having at least one organic farm in the ZIP code		-0.0235 (-0.6884)

***= Statistically significant at 1% level

This analysis is suggestive evidence for the reduced adverse association of corn intensity with general health caused by some organic production in the proximity of individuals. A more rigorous analysis of the impact of organic production would require access to the exact planted area (or total yields) of all organic farms within each ZIP code (this data was not available).

Our analysis in this part reveals that although 26% of the sample have at least one organic farm with some corn production in their ZIP code, organic corn farms are particularly small on average comprising 1.3% of total land used for corn production as estimated in section 2.8. This means that the proportion of sample likely to be impacted on by an organic corn farm is much lower than that of a non-organic farm. The relatively lower size of organic corn farms might be an important issue in identifying the health impacts of organic versus non-organic corn production in case that we have access to a more complete and detailed data set.

Aggregating Health Costs: To calculate annual non-financial health costs associated with corn production in Minnesota, we follow the following steps:

1- Using the **WV method**, we obtain the monetary value of the average **health costs** on individuals of a **1% increase** in the **intensity of corn** production in their respective ZIP code.

2- Using data from the United States Census Bureau, we find the population for each county in Minnesota. The **population of each county** is then **multiplied** by the health **costs** obtained in step 1. This will give us the health costs per 1% corn intensity in each county. Note that our estimates are based on a sample of respondents aged over 18. If we assume that individuals aged under 18 are not affected differently by corn intensity, we multiply the whole population of each county to the health costs per individual. For example, for Dakota county, with a total population of 421,751, the annual health costs associated with a 1% increase in land used for corn in a 10 km buffer will be:

   421,751 × $24.7 = 10.42 million $

3- To calculate the health costs of corn production per county, we **multiply** the number obtained in step 2 by **average corn intensity** for the county. For Dakota county, the average corn intensity in a 10 km buffer is 8.63%, so the annual health costs of corn production are:

   10.42 × 8.63 = 89.90 million $

   Table 17 shows the 40 counties with the highest health costs of corn production based on relative intensity in a 10 km buffer. Subjective health in Minnesota by county, where 1 is poor heath and 5 is excellent health is shown in Figure 24.

4- Finally, we find the total health costs in **Minnesota** by **aggregating all counties health costs**. Based on our model, the annual non-financial health costs of corn production in Minnesota are about 1.3 billion $ (approximately 233 $ per capita). This is broadly aligned with the costs obtained in MARCH (2017). In this study, the annual non-financial health costs of the UK food system for different health problems were between 107 $ per capita and 1372 $ per capita.

Caveats: In the WV method, the values should be estimated based on robust and unbiased estimates of the impact of the non-market good, (here corn intensity) and income on wellbeing. The models are estimated using multivariate regression analysis, which relies on including (controlling for) confounding factors that influence both corn intensity and well-being. In this study, the main determinants of well-being are controlled for, following the established standard in the wellbeing literature, but some of these factors are unobservable in the data. For example, it is hard to measure and control for local environment conditions that vary across each congressional district and are correlated with both corn intensity and wellbeing.

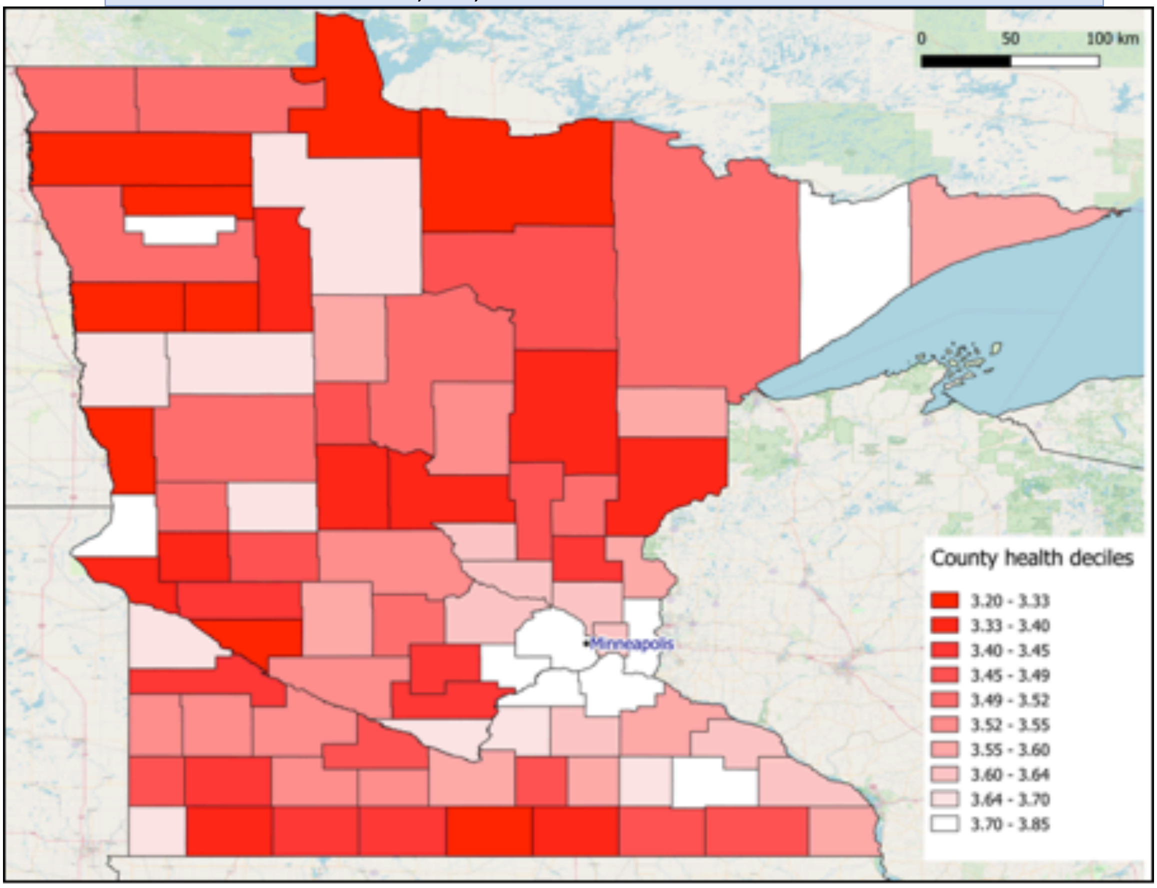
While our results show a statistically significant association between corn intensity in the proximity of individuals and their health, we cannot determine the channels through which this relationship is realised. Water and air pollution from corn production is one possible explanation but quantifying the specific channels through which corn intensity affects health requires further exploratory analysis.

Whilst the statistical approach and models used are in line with best-practice academic research in this area, it should be recognized that there is always a potential for bias in studies of this nature which use observational (i.e. non-randomised) data. Where this is the case, estimates of the costs of corn intensity may also be biased to some extent. This is a caveat that needs to be borne in mind as the results of these types of studies are used and interpreted, though these issues are pertinent to most forms of policy evaluation, as random assignment is normally impractical.

Table 17 Non-financial health costs associated with corn production for each county in Minnesota.

Rank	County	County Population	Average corn intensity in 10 km buffer (%)	Annual health Costs based on 10 km Buffer (Million $)
1	Dakota	421,751	8.63	89.90
2	Olmsted	154,930	17.57	67.20
3	Stearns	157,822	17.17	66.90
4	Wright	134,286	15.37	51.00
5	Blue Earth	66,973	27.08	44.80
6	Washington	256,348	7.01	44.40
7	Rice	65,968	27.03	44.00
8	Scott	145,827	11.52	41.50
9	Carver	102,119	14.53	36.70
10	Mower	39,566	33.87	33.10
11	Steele	36,887	35.56	32.40
12	Hennepin	1,252,024	1.04	32.10
13	McLeod	35,884	34.85	30.90
14	Kandiyohi	42,743	29.05	30.70
15	Nicollet	33,966	35.10	29.40
16	Goodhue	46,304	23.55	26.90
17	Lyon	25,831	41.78	26.70
18	Freeborn	30,535	33.91	25.60
19	Nobles	21,944	41.97	22.80
20	Brown	25,194	36.17	22.50
21	Benton	39,937	22.66	22.40
22	Martin	19,850	44.53	21.80
23	Sherburne	94,570	8.95	20.90
24	Clay	63,569	13.12	20.60
25	Le Sueur	28,111	27.64	19.20
26	Dodge	20,762	37.18	19.10
27	Waseca	18,787	40.54	18.80
28	Otter Tail	58,345	11.91	17.20
29	Anoka	351,373	1.95	16.90
30	Meeker	23,131	29.04	16.60
31	Sibley	14,869	41.79	15.30
32	Renville	14,645	41.74	15.10
33	Redwood	15,272	39.68	15.00
34	Faribault	13,784	43.76	14.90
35	Fillmore	20,980	23.58	12.20

36	Watonwan	10,840	45.48	12.20
37	Chisago	55,308	8.74	11.90
38	Winona	50,873	9.14	11.50
39	Isanti	39,582	11.68	11.40
40	Wabasha	21,608	21.14	11.30
	First 40 counties	4,073,098	11.17	1123.80
	All other counties	1,503,508	4.75	176.53
	Minnesota	5,576,606	9.74	1300.33



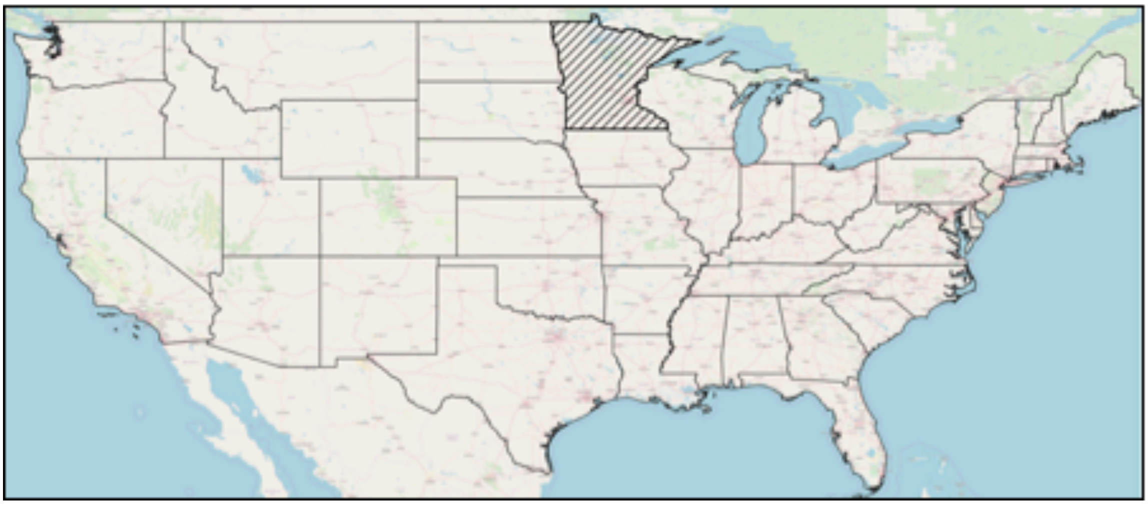


Figure 24 Subjective health in Minnesota by county, where 1 is poor heath and 5 is excellent health.

5.3.4. Key findings

There is growing divide between rural and urban population in Minnesota due to urban migration trends since 1900.

The average age of farmers is more than 55. Majority of rural population has high school qualification as opposed to urban and towns, where there are higher qualifications.

Rural residents have high rate of obesity and hearth diseases as compared to those in urban areas.

There are high health costs associated with GM corn production. Total annual health costs associated with corn production in Minnesota is $ 1.3 billion or $ 233 per capita or $ 171 per acre (for 7.6 million acres of harvested corn in Minnesota in 2017). Increasing intensity of corn cultivation by 1% costs each of the residents within a 10 km radius $ 24.7/year. These non-financial health costs (usually expressed in Quality Adjusted Life Years) associated with corn production is equivalent to 28.8% of the total value of corn in Minnesota (US 4.51 billion).

Regarding organic corn production, there is some evidence of the reduced adverse health impact of corn intensity associated with the presence of local organic production. However, a more rigorous analysis of the impact of organic production would require access to the exact planted area (or total yields) of all organic farms within each ZIP code. This may become available if the prevalence of organic corn farming increases over time.

Health costs estimated here are based on the production side of the corn value chain, linked to the corn intensity effect on environmental quality. These non-financial health costs do not include capital costs incurred in the public health system, individual medical expenditures, loss of economic productivity, and loss of taxes and GDP.

5.4. Natural capital

5.4.1. Valuation pathways for conventional corn production

We provide an estimate the benefits and externalities associated with corn cultivation in terms of impacts on climate change, water quality, air quality, and soil quality, in addition to the benefit of crop production (Table 18). For each metric we rely primarily on published studies that have assessed environmental and economic impacts of corn production in the Upper Midwestern U.S. Below we briefly describe each metric and associated valuation approach and include references to primary literature for more detailed information regarding each study design.

Ecosystem services (Crop Production)

To estimate the economic value of provisioning ecosystem services (corn production), we used the annual U.S. Department of Agriculture (2018) value of corn grain produced in Minnesota measured in dollars. We took the average of the last 20 years (1997-2017) and adjusted each year for inflation using the Bureau of Labor Statistics Consumer Price Index.

Residual flows

Climate Change

Damages from climate change are globally distributed, and emerge from emissions of greenhouse gases from different pathways associated with crop production. Here, we valued climate-related impacts of corn production by estimating CO_2e emissions related to synthetic N fertilizer production and application and multiplying estimated emissions by a social cost of carbon value (Interagency Working Group on Social Cost of Greenhouse Gases, 2016). We use the 20 year average application rate to estimate the total amount of fertilizer applied to MN corn systems (U.S. Department of Agriculture, 2018).

Greenhouse gas emissions associated with synthetic N fertilizer production

We apply a production emissions factor of 0.004 Mg CO_2e per kg of N fertilizer (Kool et al., 2012) to statewide application estimates for corn (U.S. Department of Agriculture, 2018).

N_2O emissions associated with synthetic N fertilizer use

We multiplied the social cost of N_2O emissions from fertilizer application used in Keeler et al. (2016) by the average annual N fertilizer application in Minnesota (U.S. Department of Agriculture, 2018).

Water Quality

Agriculture is the dominant driver of water pollution in Minnesota, with the majority of nutrient export coming from agricultural production (Minnesota Pollution Control Agency, 2014). Agricultural pollutants include nutrients such as nitrogen and phosphorus, as well as sediment from runoff.

Nitrogen

Nitrates pose a threat to drinking water quality and are the major driver of eutrophication in the Gulf of Mexico. Because of spatial heterogeneity in risk of nitrates reaching drinking water sources and heterogeneous exposure of streams and rivers to nitrates, the impacts and associated costs of these externalities vary spatially.

Gourevitch et al. (2018) value the impacts of nitrate contamination of drinking water by estimating the costs of various treatment options and applying a weighted cost function based on the observed adoption of those technologies as a proportion of total treatment. Some observed people opted not to treat elevated nitrates in drinking water, so Gourevitch, et al. include the cost of health impacts from increased nitrate consumption in the cost calculations, weighted by the no-treatment fraction. We applied the median values of the social cost functions developed in Gourevitch et al. (2018) to the average annual statewide N application to corn in Minnesota (U.S. Department of Agriculture, 2018).

Phosphorus

The externalities of phosphorus pollution are primarily from negative impacts to lake and river water quality. In large enough quantities, phosphates cause lakes and other bodies of water become eutrophic, a state dominated by excessive plant growth and algal blooms. Corn production contributes to phosphorus pollution in Minnesota, thus changes in agricultural policies or associated land uses that affect phosphorus export will increase or decrease value attributed to clean water accordingly.

Previous studies examined the social cost of phosphorus pollution using hedonic (Krysel et al., 2003) and recreation travel cost (Keeler et al., 2015) approaches. However, because travel cost and hedonic methods rely on understanding the biophysical responses of individual lakes and local market conditions that cannot be extrapolated statewide, we did not apply them to the water quality impacts of corn production.

We use estimates of P export from cropland modeled by the Minnesota Pollution Control Agency (2014) and weighted those by the proportion of cropland that is used for corn production. We multiply this by a shadow cost of P export estimated by the Wisconsin Department of Natural Resources (2012).

Air Quality

Increases in particulate matter and associated health impacts are a global consequence of fertilizer application. As described in Keeler, et al. (2016), we used an atmospheric transport model (Tessum et al., 2017) to estimate atmospheric concentrations of PM2.5 emissions from corn production, and resulting health impacts. These impacts vary spatially, depending on pollutant concentrations and number of people affected. We used the median value of $0.54 per kg N presented in Gourevitch et al. (2018) and multiplied it by the average amount of N application in Minnesota (U.S. Department of Agriculture, 2018).

Soil loss

Erosion driven by wind or water reduces the quality and productive potential of soil, and eroded sediment in waterways can damage infrastructure and fisheries. We used long- term measurements of water and wind erosion on cultivated land in Minnesota (U.S. Department of Agriculture, 2015a) and multiplied soil quantity lost by costs as compiled in a review by Hansen and Ribaudo (2008).

Table 18 Environmental benefits and costs in Minnesota corn production.

Natural Capital Change	Metric	Unit quantity and type	Marginal social cost (2017 $)	Net benefit (2017 $)	Supporting references
Climate Change	CO_2 emissions from N fertilizer production	1,570,995 Mg CO_2e (392,748,819 kg N x 0.004 Mg CO_2e per kg N fertilizer production)	$42.55 per Mg CO_2 Emissions in 2015 assuming a 3% discount rate	Statewide: -66,850,863 Per hectare of corn: -21.47 Per Mg of corn: -2.26	(Kool et al., 2012) (Interagency Working Group on Social Cost of Greenhouse Gases, 2016)
Climate Change	N_2O emissions from N fertilizer application	392,748,819 kg N fertilizer application to corn	$0.235 per kg N Assuming a 3% discount rate	Statewide: -92,316,643 Per hectare of corn: -29.65 Per Mg of corn: -3.12	(Keeler et al., 2016) (U.S. Department of Agriculture, 2018)
Water Quality	Increased groundwater nitrate concentration s from leaching of N fertilizer	392,748,819 kg N fertilizer application to corn	$0.075 Median cost of exposure of NO_3^- per kg N	Statewide: -29,285,663 Per hectare of corn: -9.41 Per Mg of corn: -0.99	Gourevitch et al. 2018 (U.S. Department of Agriculture, 2018)
Water Quality	Increased phosphorus loading in surface waters	1,991,320 kg P per year from corn production	$55.43 per kg P	Statewide: -44,774,633 Per hectare of corn: -14.38 Per Mg of corn: -1.52	(Wisconsin Department of Natural Resources, 2012) (U.S. Department of Agriculture, 2015b)

					(U.S. Department of Agriculture, 2018)
Air Quality	Premature mortalities caused by particulate matter 2.5 emissions from N fertilizer application	392,748,819 kg N fertilizer application to corn	$0.55 Median cost of exposure of PM2.5 per kg N	Statewide: -216,633,669 Per hectare of corn: -69.59 Per Mg of corn: -7.33	(Tessum et al., 2017) (Gourevitch et al., 2018) (U.S. Department of Agriculture, 2018)
Soil Loss	Damage to infrastructure, recreation, and business from sediment runoff. Soil productivity from loss of topsoil.	14.2 Mg soil loss per ha of corn production per year	$5.93 per Mg Estimates for corn belt region	Statewide: -107,784,217 Per hectare of corn: -34.62 Per Mg of corn: -3.65	(Hansen and Ribaudo, 2008) (U.S. Department of Agriculture, 2015a) (U.S. Department of Agriculture, 2018)
Crop Production	Corn production value	Average 1997-2017	N/A	Statewide: 4,444,450,399 Per hectare of corn: 1,427.62 Per Mg of corn: 150.44	(U.S. Department of Agriculture, 2018)

Other considerations in estimating the full social cost of corn
While the included variables incorporate most of the key factors that influence the social cost of corn production, inclusion of additional factors or refinement of the above evaluations could increase or decrease estimates of the net social cost of conventional corn production. In reviewing the existing approaches, that uncertainty remains high. For example the plausible social costs to drinking water, air quality, and N_2O derived climate change, from 1 kg of N fertilizer applications reported in Gourevitch et al. (2018) ranged from $0.05 to over $10. Using the assumptions presented above, the state-wide social cost could range from $19.6 million to $3.9 billion for just those metrics. Similarly, the standard deviation of the estimates for P export reported by the Wisconsin Department of Natural Resources (2012) was over five times the central estimate, and the range included both positive and negative values.

The values reported here focused only on corn production in Minnesota because the social cost of corn production varies spatially. For example, production upwind of population centers has greater air quality costs caused by more people being exposed to PM2.5 emissions. Groundwater nitrate contamination risk is heavily influenced by the geology of the region, and the change in water clarity in response to the same amount of P loading varies from lake to lake. For these reasons, applying the costs presented here to other regions will not reflect the local social costs of corn production.

The above analysis compares the social costs of corn production in Minnesota to a counterfactual without cultivation for corn production. It does not consider the impacts of production and land use change in a global economic market context, which would require a host of assumptions about market responses and other factors. Other impacts that are outside of the scope of this analysis include, but are not limited to, pesticide impacts on human health and biodiversity, habitat and species loss, long term changes in soil carbon storage, flooding, and groundwater availability. Further research is needed to robustly quantify the economic and social impacts of these changes so they can be included in this framework.

5.4.2. Conventional vs Organic

Organic corn and conventional corn are rarely studied with comparable practices. Cover crops and diverse, multi-year, rotations were commonly used in organic systems, in contrast to a two-year corn-soy rotation in a conventional system. Due to these differences, we found few instances where we could make definitive quantitative statements about the differences between these systems with regards to the metrics in this analysis.

Ecosystem services (corn production)

Organic practices have a slight, but negative impact on corn yield. In Minnesota, a study compared 4-year organic and conventional crop rotations from 1993-2010 and found that the average crop yields were 10.48 Mg ha^{-1} (165 bushels per acre) and 10.88 Mg ha^{-1} (171 bushels per acre) respectively (Delbridge et al., 2011). The Rodale Institute Farming Systems trial in Pennsylvania similarly found that in the initial transition years, the organic system yield averaged 4222 kg per ha (66 bushels per acre) whereas the conventional system yield averaged 5903 kg per ha (93 bushels per acre). After the first 5 years of the experiment, the difference between systems did level off and the average yields were 6431 kg per ha (101 bushels per acre) and 6553 kg per ha (103 bushels per acre), respectively for organic and conventional systems (Pimentel et al., 2005).

The average price of organic corn is higher (ex. \$284 per Mg^{-1} for organic versus \$182 per Mg^{-1} for conventional in 2010). However, these prices reflect a much lower supply of organic corn relative to conventional (approximately 0.35% of corn production in MN is organic).

Residual flows

Climate Change

Organic corn has less CO_2 emissions than conventional corn but similar N_2O and CH_4 emissions (Johnson et al., 2012; Robertson et al., 2000). The reduced CO_2 emissions come from the lack of synthetic N-fertilizer production. However, if more land is required to meet demand under organic production, land use change could negate these benefits (Balmford et al., 2018; Phalan et al., 2016).

Water Quality
The primary difference between the two systems with regards to nitrate leaching is conventional systems typically use synthetic fertilizer, which is more water soluble and can create runoff more easily than manure used in organic systems that is mixed in with the soil (Hansen et al., 2001). However, studies have found both that organic systems leach less (Cambardella et al., 2015) and no differences in leaching between conventional and organic systems (Pimentel et al., 2005). More research is required to understand the magnitude of differences in leaching between the systems.

The use of manure as a fertilizer source may provide more P than is needed to achieve maximum yields on Minnesota soil. However, no studies quantifying the P export of organic systems were reviewed.

Air Quality
Liu (2005) found lower NOx emissions in a no till system compared to tilled system. Increased tillage required for weed control in organic systems may result in greater NOx and subsequently greater PM2.5 emissions, however, research specifically comparing the precursors to PM2.5 emissions between conventional and organic systems was not found.

Soil Loss
While soil loss has been studied in conventional tillage and no-till systems, comparisons for conventional and organic were not found. As with air quality, the reliance on tillage for weed control in organic systems could result in more soil loss, but these differences have yet to be quantified.

5.3.3. Key findings

The benefits and externalities associated with corn production in terms of impacts on climate change, water quality, air quality, and soil quality, in addition to the benefit of crop production are estimated.

Total environmental cost associated with GM corn production is $71.60 per acre or $557.65 million annually in Minnesota. However, the range of estimates in the underlying studies was very large.

Environmental costs estimated here are based on the production side of the corn value chain, linked to the inputs in corn production and do not include environmental costs associated with the transport, processing, and consumption.

Based on the data and information analysed in the study, value chain of GM corn (Figure 25) and organic corn (Figure 26), stocks and flows of produced, social, human and natural capital along with positive and negative impacts are shown.

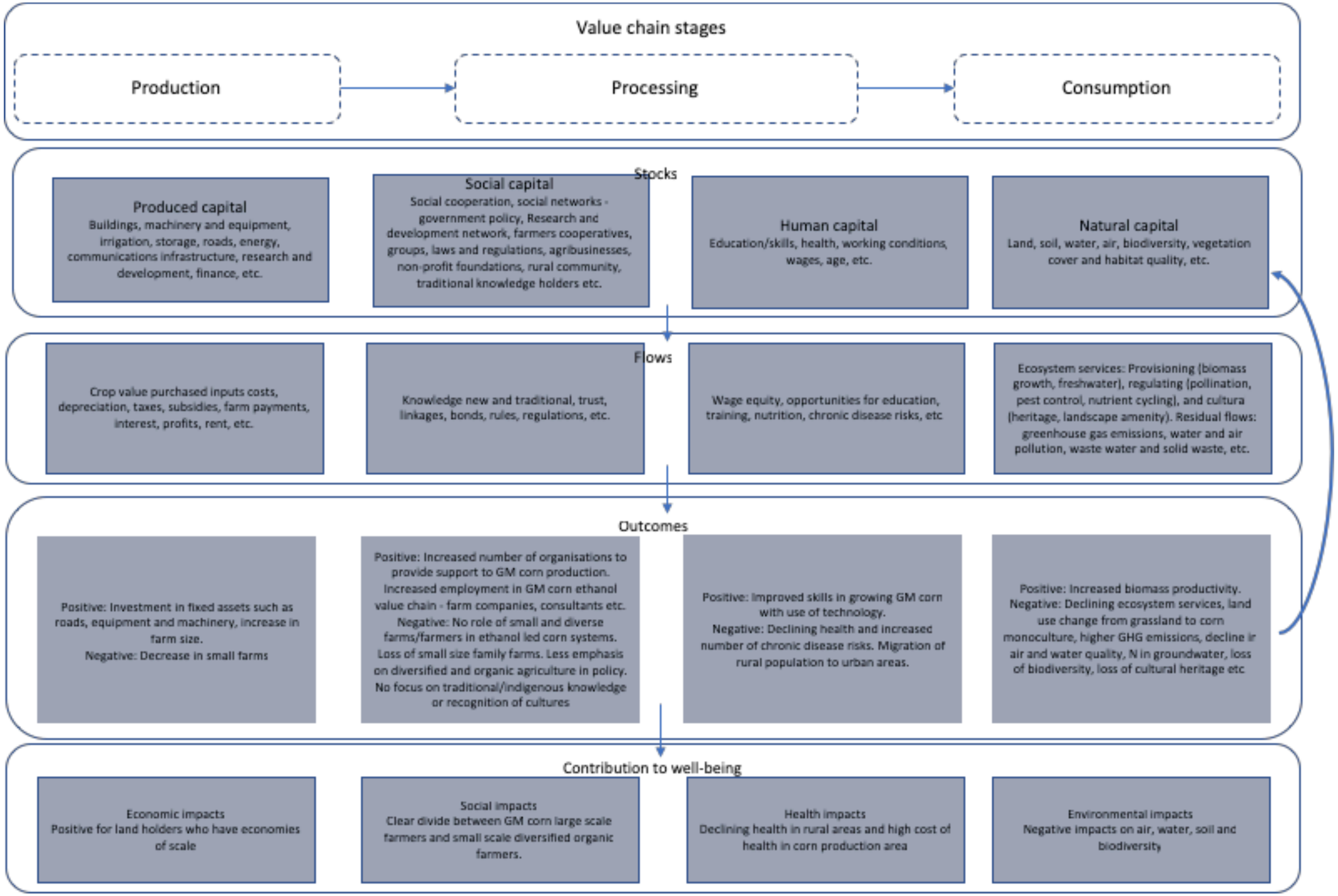


Figure 25 Value chain of GM corn showing stocks and flows of produced, social, human and natural capital. It also shows outcomes for each capital and the impacts on well-being.

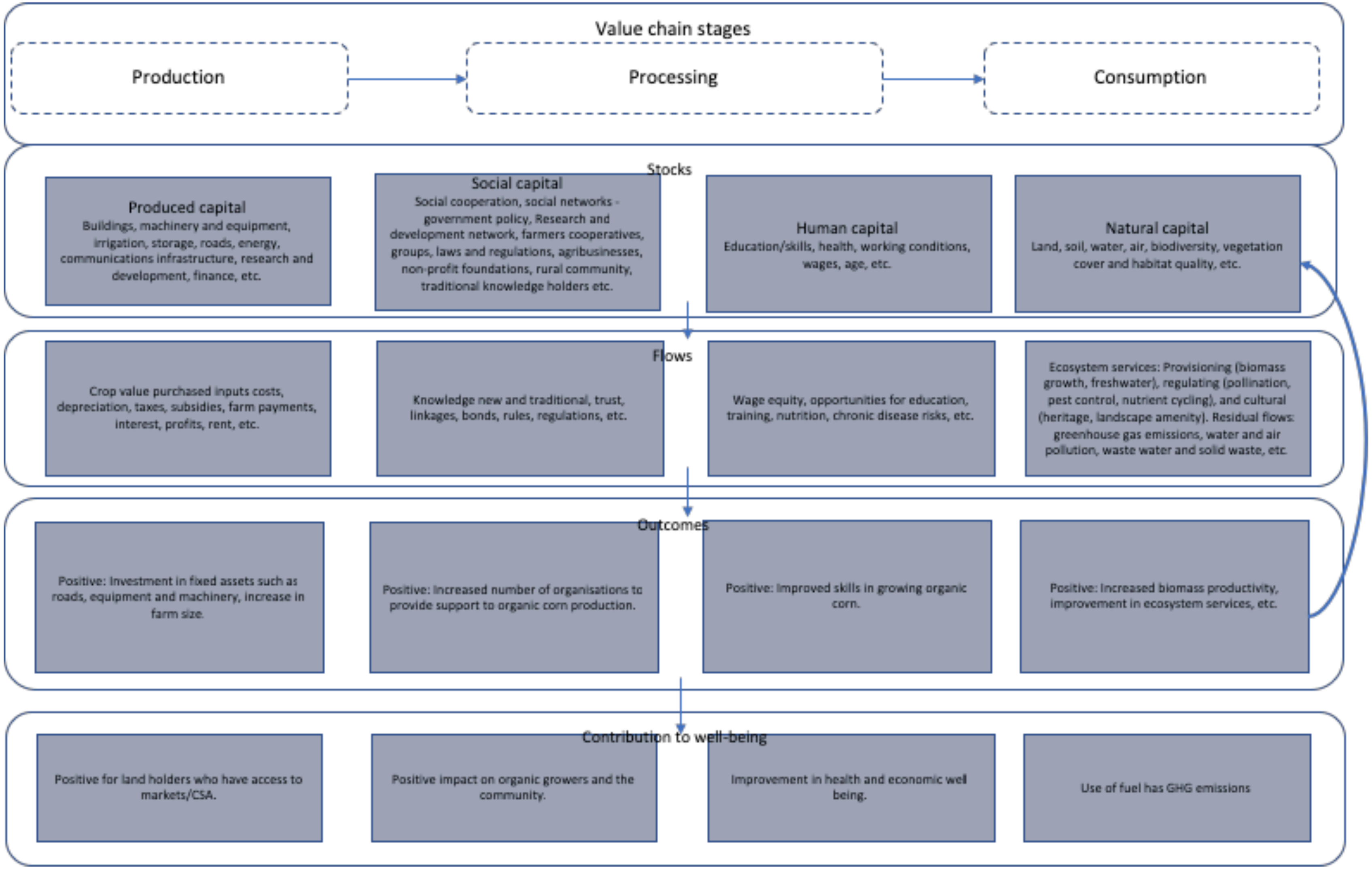


Figure 26 Value chain of organic corn showing stocks and flows of produced, social, human and natural capital. It also shows outcomes for each capital and the impacts on well-being.

5.5. Risk profile of GM and organic corn production systems

Organic corn is grown in only a fraction of total area under corn in Minnesota. However, the farm budget data showed clear advantages in terms of net returns, which are higher in organic corn than the GM corn. There are other differences in reliance on technology, policy, networks, market etc. identified in this study, which are summarised in Table 19.

Table 19 Summary of risks in GM and organic corn production.

	GM corn	**Organic corn**
Reliance on input companies, market, subsidies, government payments, energy, financial sector	High reliance	Low to medium
Technology	High reliance on technology, GM seed, fertilizers, chemicals to control pests and weeds.	Less reliance on technology and agro-chemicals. More emphasis on mechanical or biological weed control and pest control.
Dependence on social networks and impacts on social capital	High reliance on business and financial sector that have operations in many countries. High reliance makes farm operations riskier.	Less reliant on multinational networks - companies and financial sector. More reliance on local networks of producers, buyers and consumers.
Dependence on market	High. Any change in global market, energy policy adds risk to corn growers.	Low risk due to local supply chains.
Returns	Net returns depend on varying commodity prices in global market. Low net returns therefore depend on scale to remain viable. This leads to disappearance of small farms as data shows the average size of farms are increasing.	Net returns are higher as corn prices are high due to low supply and high demand of corn for organic animal feed. Organic farms are small and self-sufficient as they are more profitable even with lower productivity.

Supply chain	There is more extensive network available for GM corn growers as the supply chain extends from local to global scale.	Organic corn supply chain is local to national. There is a price premium. High demand leads to import of organic corn grains for animal feed. Therefore, much scope to expand organic corn production.
Investment	Much investment is available for GM corn.	There is scope for investment in organic corn to increase area.
Policy	High reliance on farm, energy and environmental policy. If energy policy changes then corn for ethanol will be affected significant. Similarly, any change in international trade or barriers will affect farms.	Low to moderate dependence on any policy.

5.6. True cost of corn production systems

Given the data and information presented in the early sections in this report, we estimate the true cost of corn production as shown in Table 20. Figure 26 summarises the proportion of each cost for both systems. In organic system, the entire produce is used as food through animal feed value chain. Whereas, in GM corn the primary use is ethanol production. Each bushel of corn (56 lbs) produces 2.8 gallons of ethanol and 17lbs of dried distiller grains (DDGs), which are then used as animal feed.

Table 20 Summary of health and environmental cost $/bushel of corn under two production systems.

	GM corn	**Organic corn**
Market price ($/bu)	3.05	7.46
Environmental costs associated with fertilizer use ($/bu)	0.37	Not quantified due to lack of data on organic farms.
Environmental costs associated with energy use ($/bu)	0.02	0.03
Health cost ($/bu)	0.88	Not quantified. Although there is some suggestive evidence for reduced adverse association of organic corn production with general health, quantifying the health costs requires data on exact location and planted area of organic corn farms.
Proportion of health and environmental cost of market price of corn (%)	42	0.4

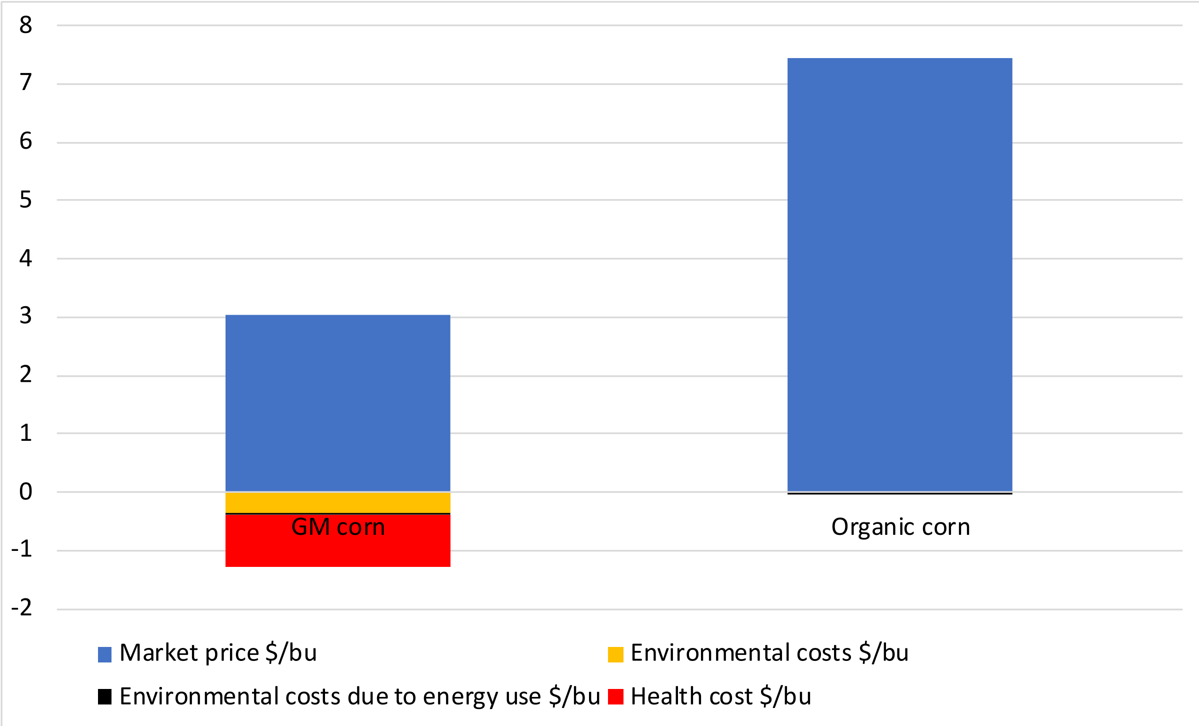


Figure 27 Market price, environmental and health costs of corn in GM and organic corn.

Chapter VI POLICY, SYSTEMS DRIVERS AND RECOMMENDATIONS

This chapter describes policy, systems drivers and recommendations for improving corn production systems as related to the natural and produced capitals, and corn systems related to human capital and health.

The negative externalities such as nutrient run-offs, generation of greenhouse gas emissions, wastage in the entire value chain of food systems, damage to human health etc. estimated in the study have been known to the practitioners and policy makers. However, these are never captured in economic terms and reflected in farm and national accounting systems due to lack of tools. Through the use of TEF and true cost accounting, we have been able to identify the types and magnitudes of such costs and benefits, which can in turn initiate appropriate policy responses. This can improve decision making at all levels – farm, market and government. We also identified policy system drivers and offer some recommendations for policy, research and practice.

6.1. Policy and other system drivers related to corn production

Market forces linked with U.S. Federal policy have driven corn production in Minnesota and throughout the Midwest. While corn has been major commodity in the region for decades, recent policy changes to the Farm Bill and the enactment of the Renewable Fuel Standard have protected and incentivized corn production by subsidizing insurance for corn production and mandating production volumes of corn-based ethanol.

The U.S. Farm Bill originated in 1930s and is regularly updated to address a wide range issues related to food and agriculture. In 2014, crop insurance subsides were expanded for corn and other crops, reducing the risk producers face from planting commodity crops on marginal land (Johnson and Monke, 2018). Demand for corn was bolstered with the Renewable Fuel Standard, a federal law designed to increase demand for agricultural commodities by mandating production of both corn and cellulosic based ethanol (Bracmort, 2018). While corn production has been sufficient to keep pace with the corn ethanol volumes called for in the law, cellulosic production has not met targets (U.S. Government Accountability Office, 2016). In addition to increased demand for corn, reductions in funding for the U.S. Conservation Reserve Program have resulted in conversion of hundreds of thousands of acres of retired land to corn production (Morefield et al., 2016). These policies contributed to record corn production expansion in the U.S., both through crop switching and expansion on to marginal land (Lark et al., 2015).

6.1.1. Recommendations and guidance for end users

In order to more fully align the public and private benefits of corn production, public policy should be adapted to further encourage sustainable practices. Under the umbrella of the Farm Bill, voluntary incentive payments are the primary mechanism to encourage use of conservation management practices in working lands (under the Environmental Quality Incentive Program and Conservation Stewardship Programs) and retirement of vulnerable and marginal land (under the Conservation Reserve Program).

1. While polluter-pays regulations have been used to manage point-source pollution and occasionally suggested for agricultural lands, the current paradigm for agricultural policy is mostly restricted to incentive subsidies (Shortle et al., 2012). According to USDA reviews, these policies have produced substantial benefits relative to a no-incentive baseline, reducing nitrate, phosphorus, and sediment export from US farmland (U.S. Department of Agriculture Natural Resources Conservation Service, 2017a, 2017b, 2017c). At the same time, substantial challenges remain, such as meeting goals to reduce the Gulf of Mexico hypoxic zone or restoring the 40% of water bodies with

impairments (Minnesota Pollution Control Agency, 2018). Doing this will require expansion and innovation in how policies are applied to better match incentives with benefits (Claassen and Ribaudo, 2016; Shortle and Horan, 2017).

2. The benefits of shifting from conventional to conservation/sustainable practices vary spatially. Within fields or watersheds, slopes and ravines are vulnerable to runoff and soil loss. At larger scales, wind and population patterns dramatically affect air quality impacts of farming in particular locations (Gourevitch et al., 2018). Failure to account for spatial variation in potential benefits is a major source of inefficiency in environmental policies, dramatically reducing the benefit per dollar (Armsworth et al., 2012).

3. Targeting land that is upwind of a population center or in a drinking water supply area makes incentives more cost effective than making them available to any producer (Gourevitch et al., 2018; Keeler et al., 2016).

4. Targeting has been explored in a few cases, such as in draft rules by the Minnesota Department of Agriculture. The rule limits fall fertilizer application only in regions where ground water nitrate contamination is likely due to the soil and underlying geology (Minnesota Department of Agriculture, 2018). Research indicates farmers are receptive to targeted incentives (Arbuckle, 2013; Kalcic et al., 2014). Because of the complexity and variety of pathways through which conservation practices benefit people and the environment, effective targeting will need to rely on integrated assessment models and multi-factor evaluations to maximize attained social benefits (Engel et al., 2008; Kling et al., 2017). At the same time, these models can maximize their immediate utility if they link readily observable field characteristics with potential management practices. For example, the Agricultural Conservation Planning Framework is one such model that provide field-scale recommendations within a watershed context, providing detailed spatial targeting maps and quantitative estimates of changes in nutrient pollution resulting from a suite of practice modifications (Tomer et al., 2015).

5. BMPs such as minimizing tillage and using cover crops are effective at reducing nutrient and soil export in both conventional and organic systems and thus are effective at reducing the social cost that were included in this analysis (Liu et al., 2005). However, there are social costs and benefits that are outside the scope of this analysis, such as indirect land use change, and biodiversity impacts of pesticides, habitat loss, and water use. While significant progress has been made understanding the social cost of nutrient and sediment export, further research is required to fully account for the social costs beyond those from nutrient use in conventional, organic, and alternative systems.

6. An agroecological approach to farming requires a systems approach. Adopting continuous living cover, including cover crops, changes a farming system to be more biologically oriented in management, practices and function.

7. While assessing the social cost of conventional corn production, we also reviewed the literature for similar estimates in organic corn production systems. While organic corn production makes up less than one percent of corn production in Minnesota, it is a more realistic comparison than no crop production at all. Unfortunately, we found very little

research in Minnesota that used comparable practices in conventional and organic systems. Conventional corn production relies on a two-year corn-soy rotation, while organic systems often use cover crops and four or more year rotations of diverse crops. When comparable practices were used, comparisons were still difficult because the organic system struggled with weed management in some years (Johnson et al., 2012). Furthermore, some research on organic systems found water quality benefits (Cambardella et al., 2015), however, these benefits are dependent on management practices which are not considered in the organic standard (Hansen et al., 2001).

8. An alternative to attempting to minimize the impacts in conventional and organic systems is to reduce the demand for corn and reduce the area in cultivation. Using corn-based ethanol as a fuel source increases demand for corn and thus increases the associated environmental impacts without a clear reduction in the carbon intensity of fuel (Fargione et al., 2008). Similarly, corn produced for livestock feed is much less efficient at producing human food calories per unit area than crops produced for direct human consumption (Cassidy et al., 2013). Efficient use of land resources to meet the food needs of the population is a crucial strategy in minimizing the social costs associated with agriculture.

6.2. Human Capital & Health

Corn consumption and health outcomes As described in the Methodology Report of this study, corn is used in over 200 products, and although mainly used for animal feed and ethanol, corn-derived dextrose, corn-starch, refined corn oil, corn syrup and high-fructose corn syrup (HFCS) find their ways in most foods and beverages. The main health risk pathways of corn consumption come from GM corn-fed livestock and poultry products that may carry contaminants and sweet beverages with HFCS, with the later associated with high incidence of obesity and type 2 diabetes. The three leading causes of death in the US (cancer, heart disease and stroke) are all associated with poor diet and overweight/obesity. Antimicrobial resistance associated to meat and dairy produced in industrial livestock systems is hypothesized but so far undocumented. Organic corn farming does not target HFCS production, nor use antibiotics, so it is assumed that organic corn consumption has a neutral to positive impact on health thanks to the absence of gluten, lower glycaemic index and higher content of vitamin E and minerals, such as Zn and Se.

Corn production and health outcomes. GM and hybrid corn production systems notably use large amounts of ammonium and nitrate fertilizers and herbicides and the various kinds of pollution in the water system are well documented. Improvements introduced in GM corn management are limited to minimum tillage and cover cropping to save resources while enhancing soil fertility, without addressing the excess chemical load produced by corn systems throughout watersheds. Fertilizers, herbicides and dust from corn systems have been associated with different types of cancer (affecting digestive and reproductive organs and blood) and respiratory diseases. With the increasing adoption of no till systems, NOx and subsequently PM2.5 emissions, are expected to decrease in GM systems. Considering that organic corn production refrains from chemical usage, it is assumed that these systems' agri-environment have a neutral impact on health.

Health cost of corn systems. The attribution of causation to individual diseases is highly challenging and whatever scientific studies are considered, results will remain debatable. Therefore, this study considered official data (Gallup Daily Survey 2008-2017) that includes general health and disability data (7.2% of population). Cancer is the leading cause of death in Minnesota, followed by cardio-vascular diseases, unintentional injury and chronic lower respiratory diseases. The result of modelling demonstrates that general health of individuals decreases by 0.67% with corn production in the respective zip code, totalling annual non-financial health costs of corn in Minnesota to $ 1.3 billion. The methodological approach adopted considered health outcomes associated to corn production (i.e. environmental quality) within Minnesota (e.g. not the entire Mississippi drainage basin), thus excluding eventual corn consumption impacts.

6.2.1. Policy and other system drivers' impact on corn-related health impacts

Government policy (in)coherence

1. **The disconnect between public health and food system policies**. The major policy disconnect concerns efforts to contrast the alarming increase of obesity. In fact, the US farm policy of the past 50 years has been driving down corn prices, while government support to fruit and vegetable prices has steadily decreased; high fructose corn syrup is nowadays the cheapest substance to produce and the hardest to avoid. Since the 70's, The Commodity Title of the Farm Bill sets government policy on crops such as corn to encourage over-production and thereby, to keep prices for these crops artificially low, allowing food processors to purchase commodities at a fraction of the true production costs. Low corn prices have also contributed to the expansion of grain-fed animals which products are higher in saturated fat and cholesterol and lower in beneficiary fatty acids, with antibiotic-resistant bacteria that compound public health risks. In addition, the inherent biases that current farm policy has toward large, industrial agriculture (large farms, which make up only 7% of the total, receive 45% of all federal payments) displaces the more innovative small- and medium-sized farms who grow a diversity of crops for regional markets and have the energy to seek out direct marketing opportunities. Healthy, regional food systems need this diversity of farmers (Schoonover and Muller, 2006). Chiefly, the specific components of the Farm Bill have so far resulted in fragmented successes, such as set-aside programs, dietary guidelines and commodity policies: the different interests of environmental groups, nutritionists and farm groups need to be brought together to develop a common, well-grounded vision that can draw congressional support away from the dominant industrial, globalized model of agriculture (Muller et al., 2009). What is grown, what is eaten, who will profit, and long-term availability of food and health repercussions are all affected by the provisions of the Farm Bill.

High-fructose corn syrup and obesity

Over the past decades, the supply management programs have slowly evolved into subsidy programs, so rather than maintain a certain commodity price level, most agricultural commodity prices are allowed to drop as low as the market allows, and farmers receive government payments to improve their income. This shift in policy has had a tremendous impact on the procurement decisions of the food industry. A well-known shift was the soft drink industry's complete conversion of sweeteners in the early 1980s from cane sugar to high-fructose corn syrup (HFCS). Low-priced corn resulted in the rapid growth in HFCS consumption and a significant increase in *per capita* sweetener consumption in the United States (USDA ERS, 2009). The price differential between calories cost from fresh fruit and vegetables and highly processed food is likely one of the reasons that of the 300 additional calories per day that Americans ingested from 1985 to 2000, 24% were added fats and 23% were added sugars. Many of these extra calories were processed from two crops, corn and soybeans, as demonstrated by the tremendous growth in HFCS consumption from 1975 to 2000 and a similar trajectory in soybean oil consumption. In 2005, $ 21 billion were spent under the Farm Bill to support commodity crop production, while Americans were spending $ 147 billion a year on obesity-related illnesses, not to mention the costs of time, productivity, and quality of life lost (Finkelstein et al., 2009). The unavoidable obstacle to success of the obesity crusade is the American food supply, the 'upstream determinant' that continues to provide an overabundance of cheap fats, oils, and sugars.

2. **Ineffective prevention of agricultural contaminants**. Farm policies encouraging mass production in the US have resulted in highly centralized farm practices that are more likely to result in environmental degradation and consequently, to chemical and microbiological contaminants that affect human health (Jackson et al., 2009). A US Geological Survey conducted in the 1990s detected pesticide compounds in virtually every stream in agricultural, urban and mixed- use areas, as well as in 30-60% of the groundwater; exposure to these chemicals has been linked to kidney, thyroid, gastrointestinal and reproductive effects. The latest Minnesota Department of Agriculture water survey detected pesticides in 64% of private wells, with a few wells presenting pesticide (i.e. parathion-methyl, cyfluthrin) concentrations above the applicable human health value, while surface waters mostly featured pesticide degradate (hydroxyatrazine), pesticide parents (63-74% of samples), neonicotinoid insecticides (imidacloprid) and some 7 other pesticides above USEPA chronic water quality reference (Minnesota Department of Agriculture, 2017). Similarly, the Agriculture Department monitors nitrates in groundwater and unsafe levels are addressed by the Minnesota Nitrogen Fertilizer Management Plan since 1990, based on Best Management Practices (BMP). When voluntary implementation of BMPs is proven ineffective, and the health risk (such as 'blue baby syndrome') limit of nitrate-nitrogen reaches or exceeds 10mg/l (not in public water systems which are treated but over 10% of private wells and 27% surface waters; Minnesota Department of Health, 2018), regulatory authority is exercised, ranging from design criteria to restrictions on use. In 2006, the elevated nitrate level in public wells has increased the cost of water delivery in Minnesota by fourfold or more (Minnesota Department of Agriculture, 2015).

3. **Minnesota environment and sustainability measures.** The sustainability policies of the Minnesota Department of Agriculture essentially focus on five areas: (i) renewable energy, chiefly promoting bioenergy; (ii) water protection efforts to mitigate agricultural risks to water quality, focused on reducing nitrate losses and monitoring pesticides; (iii) Best Management Practices (BMPs) for fertilizer and pesticide use for

(*inter alia*) corn that encourage integrating cultural, chemical and mechanical techniques (e.g. integrated weed management) to prevent further groundwater contamination; (iv) organic agriculture, and (v) a grazing exchange to connect farmers without cattle, who would nevertheless like to see grazing of their cover crops, to farmers/ranchers who raise cattle. The latter is innovative and points in the direction of reintegrated crop and livestock systems with cattle on the land. BMPs seek not to exacerbate existing groundwater pollution concerns (guidelines are provided for pesticides that have already crossed acceptable limits in groundwater), while safeguarding maximum crop returns (the guidelines for calculating N rate on corn farms considers N fertilizer price). The few non-chemical guidance of BMPs include integrated pest management and alternatives to neonicotinoids to protect pollinators. GM farmers are encouraged to adopt no-till practices which go hand-in-hand with herbicide application and provision of specialized equipment (for seeding and chopping). No system approach is contemplated by BMPs, for instance to address biodiversity, and while end of the pipe issues are addressed and substantially financed, subsidies keep encouraging more of the same unhealthy monocropping.

4. **Organic agriculture.** The US organic market has been steadily growing (23% in 2016) and its wider adoption contributes to both the financial viability of farms and environmental protection, as the basic organic standards forbid the usage of chemical substances throughout the value chain. Although Minnesota's organic corn operations involve some 300 units that represent just 1.3% of corn fields, the State ranks second in the US in certified organic corn for grain and soybean production, comprising 14% of the corn national production (USDA, 2016). Still, domestic supply of organic corn falls well behind demand, currently met through imports from Central Europe, and facing frequent recalls due to fraud. In line with federal USDA National Organic Standards policies, the Minnesota Department of Agriculture makes available resources for cost-sharing transition to organic management ($ 750/year up to 3 years, with funds eligible to be spent on soil tests, to begin working with a certification body, and to attend organic farming conferences) and organic certification (up to $ 750/year per certified operation). Although the University of Minnesota has an Organic Program for research and education, it remains challenging for farmers to convert to organic agriculture without dedicated technical assistance, except for pest control; in fact, assistance could be obtained from the University of Minnesota Extension Office regarding the non-pesticide voluntary BMPs which are very close to organic pest management. Generally, farmers are left alone to face the heavy burden of conversion, including the new venture uncertainties, absence of adapted (input-less) corn varieties, and burden of potential market losses when contaminated by neighbours. In fact, there is still no polluter-pay liability mechanism for farmers who are contaminated by neighbouring GM corn lines, forcing many organic corn farmers to plant later to avoid drift and take further lower yield, while bearing additional costs of testing, buffers and potential market losses when contamination is found.

6.2.2. Agrifood monopolies

1. **The end of choice**. Modern farming is equated to industrial farming and more recently, Information and Communication Technologies (ICTs). Those gaining from an input-dependent food system are those four corporations that control 70% of

seeds and agrochemicals and five farm machinery and data companies that control 41% of the world market - while mega-mergers and acquisitions in every part of the industrial food chain continue to consolidate towards a duopoly dominated by the machinery companies (ETC and IPES Food, 2017). Similarly, US hospital chains are merging with medical suppliers and health insurance providers. The dominant companies seek to prescribe how, when and where farmers buy and use farm inputs, who buys their products and who can access the resulting data to their market advantage – all of which diminishes farmer income and autonomy (Mooney, 2018). For example, from 1990-2015, the price of farm inputs in the US rose faster than farmgate commodity prices, systematically squeezing farmers' income, and on-going mergers are likely to exacerbate these trends. One estimate suggests that seed prices of corn could increase as much as 6% as a result of the Dow-DuPont and Bayer-Monsanto mergers (Bryant et al., 2016).

2. **The great innovation illusion.** The new Big Data platform (i.e. robots, computerized farm machinery, synthetic biology and financial technologies such as blockchain introducing new commodity trading mechanisms) is erecting barriers that suffocate innovation and 'objective science' is being replaced by political opportunism that privileges some technologies over others. Industrial agriculture and the data platform are imperilling workers all along the food chain and fundamentally altering the food that reaches our plates. There is among governments and academics growing recognition that the spin-off effects of seed and pesticide concentration have led to a decline in genuine innovation and erosion of genetic diversity (iPES Food, 2017). For example, the genetic breeding stock publicly available has declined by 75% since 1960s. In 2012, when rootworms were shown to have become resistant to one of Montsanto's Bt corn varieties, scientists proposed slowing the evolving resistance of corn pests by planting refuge areas of non-GM corn. However, there was not enough non-GM corn seed available (ETC, 2017). Overall, the agrifood monopoly translates into political power to influence USDA research agenda, marketing, crop subsidy and crop insurance subsidies and rules – as well as other policies that support concentration by privatizing benefits and shifting costs to the public through policies and rules in USDA, EPA, FDA and IRS, and by quashing regulation at state and local levels.

6.2.3. Recommendations and guidance on implementation

From the Farm Bill to local food initiatives, public health and agricultural communities have many opportunities to work together to develop, support and implement policies that could provide tremendous public health rewards, while at the same time benefiting farmers and rural communities.

Government

Pricing and other policies that address nutrition

- From 1985-2000, the real price of fresh fruits and vegetables went up almost 40 percent in USA, while the real price of added fats and sugars declined, resulting in food processors and restaurants finding ways to utilize more fats and sugars and less produce (Schoonover and Muller, 2006). There is a need to develop government pricing and procurement policies that make healthy foods an economically sensible choice. A Farm

Bill possible elements of a common farmer-public health policy platform could include: nutrition titles that address the root cause of the obesity epidemics by ensuring fair prices to all crops, away from artificially low corn prices and uncompetitive fresh produce prices.

- At the federal level, a challenge has been the traditional division between agricultural policy and food and nutrition policy. Considering that diversified cropping systems are an integral part of a diverse, healthy diet, is crucial for a health-promoting food system. For example, expanding incentives for specialty crops (e.g. fruits, vegetables, and nuts) for US markets—and reducing the incentives for commodity crop production—would close the gap between the recommendations of the Dietary Guidelines for Americans and the number of servings of foods grown in the US (Buzby et al., 2006).

Provisions for healthier ecosystems

- Decades of BMPs implementation and substantial clean-up expenses have proven that the public health risks of agricultural contaminants require restrictions in hotspot areas (Minnesota Department of Agriculture and Department of Health websites). A stricter application of the Water Protection Act could designate sensitive drinking water sourcing areas as chemical-free farming, thus encouraging conversion to organic management, compounded by specific attention to optimum organic nutrient management.
- Similar to the Conservation Stewardship Program of the Farm Bill that rewards farmers with a financial incentive to produce environmental benefits, a Health Stewardship Program could reward farmers for raising produce crops, grass-fed dairy and livestock, or organic products.

Support to organic conversion

- Increasing organic corn acreage contributes to environmental, health and domestic corn demand. To this end, a comprehensive roadmap needs to be developed for the next tier of new organic adopters, complete with transition incentives, credit access and a more sophisticated "one-stop" shop approach with full-array of conversion tools, real time problem-solving, market access and dealing with red tape.
- The Farm Bill subsidy structure should equally support naturally grown specialty crops, including efforts to maintain strong organic certification qualifications.

Big Data and competition policy

- The question of who controls Big Data and thus its usage is becoming increasingly relevant. The government should block cross-sector mergers (such as farm machinery with seeds/pesticides or crop insurance) and require full disclosure from companies based on the principle that market transparency and the public good supersede proprietary business information. Particular attention must be paid to ownership and control of digital information, including genomic information, and the continuous digitization of agriculture must be better monitored and accounted for, to impede the creation of new mega corporations. The 'Better Deal' platform adopted by US Democrats in July 2017 urges a new precautionary approach to current and future mergers and pledges for mega-mergers to account for the role of Big Data control and its possible effects on limiting competition and undermining consumer privacy (IPES Food, 2017).

Researchers

Joining the dots for heightened awareness

- Emphasize the connections between health, food and farm policy so that local, state and national policies benefit both public health and family farmers. Initiatives such as Kaiser Permanente's sponsorship of farmers markets on its medical centres' grounds and Physicians Plus Insurance Corporation's subsidization of community supported agriculture shares demonstrate that these connections are starting to be made (Schoonover and Muller, 2006).
- Water quality is heavily monitored and data is used to identify trends regarding detection frequency and concentration of specific agricultural chemicals found in the waters of Minnesota. Such data can also prompt the evaluation of the effectiveness of BMPs for specific health-related compounds.

Health-oriented crop research

- Support research into the health effects of industrial corn production, including herbicides, corn sweeteners, and other potential risk factors, so that government support to commodity crop research be diverted to alternatives, such as vegetable production or organic corn varieties.
- USDA investment in organic research remains barely a decimal point in the flagship National Institute of Food and Agriculture programs: 0.19% of the Agriculture and Food Research Initiative 2011-2015 and 1.85% of Specialty Crop Research Initiative 2010-2014 (USDA-NIFA, https://www.nifa.usda.gov/grants). Even if the new Farm Bill passes the Organic Agriculture Research and Extension Initiative, funding remains far less than organic market demand, while proactive solutions are lacking. Almost half of all global private sector agricultural research concentrates on corn (IPES Food, 2017), persuading government regulators to create space for the innovations in ways that directly and indirectly impact other crops. In particular, competitive improved organic corn varieties are lacking, due to seed industry consolidation and patents that are locking-up much of the existing improved varieties, while the current 5 public corn breeders are all on retirement tracks without any commitment to replace them.

Farmers and citizens

From oligopoly to cooperation policy

- Corn farmers should take a 'wide-tech' approach, a paradigm shift towards diversified and decentralized innovation, emphasizing locally-applicable knowledge and open access technologies, attuned to the sustainability of the immediate environment and that harness the benefit of Big Data at the farm or community scale (IPES Food, 2017). A farmers' web can set the framework within which high-tech can be evaluated, as it places the priority on communities and cooperation. Promising tools allowing greater farmers access and control over data and equipment are emerging, such as ISOBlue (part of Purdue University's Open Ag Toolkit) and FarmLogs data analytic software (Carbonell, 2016).

- Citizen-led food policies, through local, state and national food policy councils, could develop model laws and finance systems guiding competition and technology towards healthy food systems.

Chapter VII MAPPING TO TEEBAGRIFOOD FRAMEWORK

This chapter includes how the information and data analysed for all (known and unknown) dependencies, impacts and externalities (positive and negative) related to the two corn systems are organised in the TEF.

This study compares two diverse corn production systems, GM and organic corn system in Minnesota. The information and data analysed in the study for GM corn (Table 21) and organic corn (Table 22) systems is summarised in a tabular format by following TEEBAgriFood framework.

Tables 21 and 22 shows various categories analysed two corn systems through the value chain stages. The focus of the study is to compare two systems, therefore, the data analysed relates to the production side of the value chain. However, some descriptive information is also covered for the processing and consumption sides. Corn production system is dependent on all four capitals as highlighted in Tables 21 and 222. Monetary information is available for the stocks and flows of produced and natural capital in corn production system and is analysed in this study. For social capital, description is provided. For human capital, quantifiable information is assessed. All positive and negative outcomes for four capitals that form the base of agri-food systems, are also assessed. The positive and negative impacts on social, economic, health and environmental impacts of each of the two corn production systems are also provided.

Table 21 Mapping of information and data analysed in the study for GM corn production system.

		Production	Processing	Consumption
Stocks	Produced capital	Buildings, machinery and equipment, irrigation, storage, roads, energy, communications infrastructure, research and development, finance, etc. Section 3.1	Buildings, machinery and equipment, irrigation, storage, roads, energy, communications infrastructure, research and development, finance, etc. Section 3.1	Buildings, storage, energy, communications infrastructure, finance, etc. Section 3.1
	Social capital	Social cooperation, social networks - government policy, Research and development network, farmers cooperatives, groups, laws and regulations, agribusinesses , non-profit foundations, rural community, traditional knowledge holders etc. Section 3.2	Social cooperation, networks - government regulation, industry bodies, cooperatives, laws, business, energy industry, foundations, R&D sector, etc. Section 3.2	Social cooperation, hospitality networks - government regulation, laws, business, healthy food promoting foundations, etc. Section 3.2
	Human capital	Education/skills, health, working conditions, wages, age, etc. Section 3.3	Skills, health, occupational health and safety, wages, age, etc. Section 3.3	Skills, health, occupational health and safety, wages, age, etc. Section 3.3
	Natural capital	Land, soil, water, air, biodiversity, vegetation cover and habitat quality, etc. Section 3.4	Land, water, air, etc. Section 3.4	Land, water, air, etc. Section 3.4
Flows	Produced capital	Crop value, purchased inputs costs, depreciation, taxes, subsidies, farm payments, interest, profits, rent, etc. Section 3.1	Fuel value, other industrial products value in the market, profits, taxes, interest, subsidies, etc. Section 3.1	Fuel value, food value, profits, taxes, interest, etc. Section 3.1
	Social capital	Knowledge new and traditional, trust, linkages, bonds, rules, regulations, etc. Section 3.2	Technical knowledges, patents, trust, linkages, rules, regulations, etc. Section 3.2	Technical knowledges, trust, linkages, rules, regulations, etc. Section 3.2
	Human capital	Wage equity, opportunities for education, training, nutrition, chronic disease risks, etc. Section 3.3	Equity, training opportunity, health, etc. Section 3.3	Equity, training opportunity, health, etc. Section 3.3

	Natural capital	Ecosystem services: Provisioning (grain yield), and regulating (climate regulation, air regulation, water regulation, soil loss). Residual flows: greenhouse gas emissions, water and air pollution, waste water and solid waste, etc. Section 3.4	GHG emissions, water quality, air quality, etc. Section 3.4	GHG emissions, water quality, air quality, etc. during use of fuel and preparation of food. Section 3.4
Outcomes	Produced capital	Positive: Investment in fixed assets such as roads, equipment and machinery, increase in farm size. Negative: Decrease in small farms. Section 3.1	Positive: Investment in fixed assets such as roads, equipment and machinery, increase in number and processing capacity. Section 3.1	Positive: Investment in fixed assets such as roads, equipment and machinery, increase in number and processing capacity. Section 3.1
	Social capital	Positive: Increased number of organisations to provide support to GM corn production. Increased employment in GM corn ethanol value chain - farm companies, consultants etc. Negative: No role of small and diverse farms/farmers in ethanol led corn systems. Loss of small size family farms. Less emphasis on diversified and organic agriculture in policy. No focus on traditional/indigenous knowledge or recognition of cultures. Section 3.2	Positive: Increased number of organisations to provide support to ethanol industry. Generation of employment. Negative: less opportunities for unskilled labour. Section 3.2	Positive: Increased number of organisations to provide support to ethanol industry. Generation of employment. Negative: less opportunities for unskilled labour. Section 3.2
	Human capital	Positive: Improved skills in growing GM corn with use of technology. Negative: Declining health and increased number of chronic disease risks. Migration of rural population to urban areas. Section 3.3	Positive: Improved technical skills. Negative: Declining health and increased number of chronic disease risks. Section 3.3	Positive: Improved technical skills. Negative: Declining health and increased number of chronic disease risks. Section 3.3

	Natural capital	Positive: Increased biomass productivity. Negative: Declining ecosystem services, land use change from grassland to corn monoculture, higher GHG emissions, decline in air and water quality, N in groundwater, loss of biodiversity, loss of cultural heritage etc. Section 3.4	Positive: Negative: Higher GHG emissions, decline in air and water quality, etc. Section 3.4	Positive: Negative: Higher GHG emissions, decline in air and water quality, etc. Section 3.4
Impacts	Economic impacts	Positive for land holders who have economies of scale. Section 3.1	Positive for ethanol industry and other allied industries that manufacture corn products such as beverages. Section 3.1	Low cost food products availability for consumers. Section 3.1
	Social impacts	Clear divide between GM corn large scale farmers and small scale diversified organic farmers. Section 3.2	Clear divide between skilled and unskilled labour, large amount of land and resources are used for fuel instead of food. Section 3.2	Loss of social value associated with community food preparation and consumption. Section 3.2
	Health impacts	Declining health in rural areas and high cost of health in corn production area. Section 3.3	Declining health in rural areas and high cost of health in corn production area. Section 3.3	Relatively high health impacts. Section 3.3
	Environmental impacts	Negative impacts on air, water, soil and biodiversity. Section 3.4	Negative impacts on air, water, soil and biodiversity. Section 3.4	Increase in household waste. Section 3.4

Legend

(green)	Descriptive information available
(yellow)	Quantitative information available
(blue)	Monetised information available
(grey)	Not included in study

Table 22 Mapping of information and data analysed in the study for organic corn production system.

		Production	Processing	Consumption
Stocks	Produced capital	Buildings, machinery and equipment, irrigation, storage, roads, energy, communications infrastructure, research and development, finance, etc. Section 3.1	Buildings, machinery and equipment, storage, roads, energy, communications infrastructure, research and development, finance, etc. Section 3.1	Buildings, storage, energy, communications infrastructure, finance, etc. Section 3.1
	Social capital	Social cooperation, social networks - government policy, Research and development network, farmers cooperatives, groups, laws and regulations, agribusinesses, non-profit foundations, rural community, traditional knowledge holders etc. Section 3.2	Social cooperation, networks - government regulation, industry bodies, cooperatives, laws, business, energy industry, foundations, R&D sector, etc. Section 3.2	Social cooperation, hospitality networks - government regulation, laws, business, healthy food promoting foundations, etc. Section 3.2
	Human capital	Education/skills, health, working conditions, wages, age, etc. Section 3.4	Skills, health, occupational health and safety, wages, age, etc. Section 3.4	Skills, health, occupational health and safety, wages, age, etc. Section 3.4
	Natural capital	Land, soil, water, air, biodiversity, vegetation cover and habitat quality, etc. Section 3.4	Land, water, air, etc. Section 3.4	Land, water, air, etc. Section 3.4
Flows	Produced capital	Crop value, purchased inputs costs, depreciation, taxes, subsidies, farm payments, interest, profits, rent, etc. Section 3.1	Value of food, profits, taxes, interest, subsidies, etc. Section 3.1	Food value, profits, taxes, interest, etc. Section 3.1
	Social capital	Knowledge new and traditional, trust, linkages, bonds, rules, regulations, etc. Section 3.2	Technical knowledges, trust, linkages, rules, regulations, etc. Section 3.2	Technical knowledges, trust, linkages, rules, regulations, etc. Section 3.2
	Human capital	Wage equity, opportunities for education, training, nutrition, chronic disease risks, etc. Section 3.3	Equity, training opportunity, health, etc. Section 3.4	Equity, training opportunity, health, etc. Section 3.4

	Natural capital	Ecosystem services: Provisioning (grain yield), and regulating (climate regulation, air regulation, water regulation, soil loss). Residual flows: greenhouse gas emissions, water and air pollution, waste water and solid waste, etc. Section 3.4	GHG emissions, water quality, air quality, etc. Section 3.4	GHG emissions, water quality, air quality, etc. during use of fuel and preparation of food. Section 3.4
Outcomes	Produced capital	Positive: Investment in fixed assets such as roads, equipment and machinery, increase in farm size. Section 3.1	Positive: Investment in fixed assets such as roads, equipment and machinery, increase in number and processing capacity. Section 3.1	Positive: Investment in fixed assets such as roads, equipment and machinery, increase in number and processing capacity. Section 3.1
	Social capital	Positive: Increased number of organisations to provide support to organic corn production. Section 3.2	Positive: Increased number of organisations to provide support to organic industry. Generation of employment. Section 3.2	Positive: Increased number of organisations to provide support to ethanol industry. Generation of employment. Negative: less opportunities for unskilled labour. Section 3.2
	Human capital	Positive: Improved skills in growing organic corn. Section 3.3	Positive: Improved technical skills. Negative: Declining health and increased number of chronic disease risks. Section 3.4	Positive: Improved technical skills. Negative: Declining health and increased number of chronic disease risks. Section 3.4
	Natural capital	Positive: Increased biomass productivity, improvement in ecosystem services, etc. Section 3.4	Positive: Negative: Higher GHG emissions, decline in air and water quality, etc. Section 3.4	Positive: Negative: Higher GHG emissions, decline in air and water quality, etc. Section 3.4
Impacts	Economic impacts	Positive for land holders who have access to markets/CSA. Section 3.1	Positive for ethanol industry and other allied industries that manufacture corn products such as beverages. Section 3.1	High retail cost of organic food products. Section 3.1
	Social impacts	Positive impact on organic growers and the community. Section 3.2	Clear divide between skilled and unskilled labour, large amount of land and resources are used for fuel instead of food. Section 3.2	Some social aspects of community spirit in growing and consuming food maintained especially through CSA and organic production systems. Section 3.2

	Health impacts	Improvement in health and economic well-being. Section 3.3	Declining health in rural areas and high cost of health in corn production area. Section 3.3	Less exposure to harmful pesticides in food may have some positive health impacts. Section 3.3
	Environmental impacts	Use of fuel has GHG emissions. Section 3.4	Negative impacts on air, water, soil and biodiversity. Section 3.4	Improvement in various ecosystem services. Section 3.4

Legend

(green)	Descriptive information available
(yellow)	Quantitative information available
(blue)	Monetised information available
(grey)	Not included in study

Chapter VIII CONCLUSIONS

This integrated assessment and multi-factor evaluation to optimize social, environmental and economic benefits justifies targeted agricultural incentives, from support to producers who provide public goods to protection of hotspot areas, in cooperation with citizen-led councils.

The study used the TEF and true cost accounting to assess key positive and negative externalities associated with two corn production systems in Minnesota. It revealed hidden social, environmental and health related costs associated with two corn production systems by using true cost accounting. This new information on the costs and benefits can help to improve decision making at farm and policy level.

The study reviewed impacts of two corn production systems on natural capital especially soil, water, and air. Natural capital impacts of GM corn are significant at $ 577.65 million annually in Minnesota. There are significant social costs associated with regards to the nutrients (synthetic fertilizers in GM corn and manures in organic corn) applied in both systems. BMPs such as minimum tillage and using cover crops are effective at reducing nutrient and soil export in both conventional and organic systems and thus are effective at reducing the social cost associated with nutrient use. Policies that support the use of effective targeting by using integrated assessment models and multi-factor evaluations are required to maximize social benefits. In addition, there are social costs and benefits associated with indirect land use change, and biodiversity impacts of pesticide use, habitat loss, and water use that need to be further investigated.

Corn-based ethanol production has increased the demand for corn and hence associated environmental impacts without a clear reduction in the carbon intensity of fuel. Moreover, corn produced for animal feed is much less efficient at producing human food calories per unit area than crops produced for direct human consumption. Therefore, efficient use of land resources is required as an alternative strategy to minimize the social costs of food (corn) production.

There are high health costs associated with GM corn production. Total annual health costs associated with corn production in Minnesota is $ 1.3 billion, or $ 233 per capita, or $ 171 per acre in Minnesota. Increasing intensity of corn cultivation by 1% costs each of the residents within a 10 km radius $ 24.7 per year. These non-financial health costs associated with corn production is equivalent to 28.8% of the total value of corn in Minnesota ($ 4.51 billion). Research on health impacts of corn systems provides tentative evidence for a potentially positive effect of organic corn systems, as compared to conventional corn operations. However, more research is required, with finer resolution data than district level data, including detailed locations of survey respondents and planted areas of organic production in order to estimate the health costs of organic corn. Granular data would also facilitate the development of an improved causal framework, affording future research increased confidence in its findings, and offering deeper insights. Expanding the analysis to include other corn-producing states would provide evidence as to whether the negative health effects of corn production hold on a broader scale, and in doing so increase sample size available to researchers.

Mapping of data from the analysis suggests there is increase in produced and social capital in both systems. However, there is much scope to increase both capitals in organic production systems as the area under organic agriculture is less than 1% in Minnesota. For social and human capitals, further research is required to link production systems with impact on these capitals. For GM corn production systems, there are positive economic impacts, however, the divide between small- and large-scale farmers is increasing, leading to negative social, health and environmental impacts. Moreover, GM corn is used for producing ethanol as it is supported by the current energy policy. For organic production systems, there are positive economic, social, health impacts, while limited environmental impacts due to use of tillage and fuel use in operations. Practitioners can use this information to make a decision about production system and practices that can improve all four capitals. Whereas, policy makers can use this information to support systems and practices that improve all four capitals. However, this require a major shift in US agricultural and energy policies (including crop insurance schemes and public funded research favouring GM corn production) that support the current GM corn systems. There is also need to factor in impacts of concentrated animal feeding operations (CAFO) on air and water quality and human health as CAFOs are viable only due to the availability of cheap DDGs, a by-product of ethanol production.

This multi-dimensional assessment has helped to understand all impacts and dependencies and true costs and benefits of two production systems, however, there is need to understand how farmers adopt this new information. There is need to develop pathways for change in consultation with farming community so that the outputs from this research can be conveyed to farming and rural community and also to identify future research needs. There is need to understand, receptiveness of true cost accounting by farming community, it's utility as a decision-making tool at farm scale and the processes of its adoption by farmers. Farming community need support from scientific research, policy, and market to adopt sustainable production systems so that they can contribute effectively towards the improvement of the environment and for the well-being of society.

REFERENCES

Acquaah M, Amoako-Gyampah K, Gray B, Nyathi NQ. 2014. Measuring and Valuing Social Capital: A Systematic Review. Network for Business Sustainability South Africa. Retrieved from: nbs.net/knowledge

Altieri MA. 1998. Ecological impacts of industrial agriculture and the possibilities for truly sustainable farming. Monthly Review; New York 50 (3), 60-71.

Arbuckle, J.G., 2013. Farmer Attitudes toward Proactive Targeting of Agricultural Conservation Programs. Soc. Nat. Resour. 26, 625–641. https://doi.org/10.1080/08941920.2012.671450

Armsworth, P.R., Acs, S., Dallimer, M., Gaston, K.J., Hanley, N., Wilson, P., 2012. The cost of policy simplification in conservation incentive programs. Ecol. Lett. 15, 406–414. https://doi.org/10.1111/j.1461-0248.2012.01747.x

Asche K, 2018. The State of Rural Minnesota 2018. Center for Rural Policy & Development. www.ruralmn.org

Aufiero F, Pentassuglia M. 2015. Il ruolo nutrizionale e terapeutico degli alimenti. Seconda edizione ampliata. Vis Sanatrix Naturae.

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., Field, R., Garnsworthy, P., Green, R., Smith, P., Waters, H., Whitmore, A., Broom, D.M., Chara, J., Finch, T., Garnett, E., Gathorne-Hardy, A., Hernandez-Medrano, J., Herrero, M., Hua, F., Latawiec, A., Misselbrook, T., Phalan, B., Simmons, B.I., Takahashi, T., Vause, J., zu Ermgassen, E., Eisner, R., 2018. The environmental costs and benefits of high-yield farming. Nat. Sustain. 1, 477–485. https://doi.org/10.1038/s41893-018-0138-5

Bauer SE, Tsigaridis K, Miller R. 2016. Significant atmospheric aerosol pollution caused by world food cultivation. Geophysical Research Letters, 43(10), 5394–5400. doi:10.1002/2016GL068354

Bocarsly ME, Powell ES, Avena NM, Hoebel BG. 2010. High-fructose corn syrup causes characteristics of obesity in rats: increased body weight, body fat and triglyceride levels. Pharmacology Biochemistry and Behavior, 97(1), 101–106.

Bourdieu P, 1986. The forms of capital. In J. G. Richardson (Ed.), Handbook of theory and research for the sociology of education (pp. 241-258). Westport, CT: Greenwood Press.

Bracmort, K., 2018. The Renewable Fuel Standard (RFS): An Overview, Congressional Research Service. https://doi.org/R43325

Bray GA, Nielsen SJ, Popkin BM. 2004. Consumption of high-fructose corn syrup in beverages may play a role in the epidemic of obesity. American Journal of Clinical Nutrition 79(4), 537–543.

Bryant H., Maisashvili A., Outlaw J. and Richardson J. (2016). Effects of Proposed Mergers and Acquisitions Among Biotechnology Firms on Seed Prices. Agricultural and Food Policy Center, Texas A&M University.

Burt RS, 1992. Structural holes: The social structure of competition. Cambridge, MA: Harvard University Press.

Buzby J, Wells H, Vocke G. (2006). Possible Implications for US Agriculture From Adoption of Select Dietary Guidelines. Washington, DC: US Dept of Agriculture Economic Research Service.

Cambardella, C.A., Delate, K., Jaynes, D.B., 2015. Water Quality in Organic Systems. Sustain. Agric. Res. 4, 60. https://doi.org/10.5539/sar.v4n3p60

Carbonell Isabelle (2016). The Ethics of Big Data in Big Agriculture. Film and Digital Media, University of California, Santa Cruz, United States of America. 31 Mar 2016.
DOI: 10.14763/2016.1.405

Cassidy, E.S., West, P.C., Gerber, J.S., Foley, J.A., 2013. Redefining agricultural yields: From tonnes to people nourished per hectare. Environ. Res. Lett. 8.
https://doi.org/10.1088/1748-9326/8/3/034015

Chazdon S, Allen R, Horntvedt J, Scheffert DR, 2013. Developing and Validating University of Minnesota Extension's Social Capital Model and Survey. University of Minnesota, Extension Center For Community Vitality.

Claassen, R., Ribaudo, M., 2016. Cost-Effective Conservation Programs for Sustaining Environmental Quality. Choices 31, 1–12. https://doi.org/10.2307/choices.31.3.04

Coleman JS, 1990. Foundations of social theory. Harvard University Press, Harvard.

Coleman JS. 1988. Social capital in the creation of human capital. American Journal of Sociology, 94, S95-S120.

CONABIO (2017) Ecosystems and agro-biodiversity across small and large-scale maize production systems. TEEB Agriculture & Food, UNEP, Geneva.

Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Daily GC, 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington DC.

Delbridge TA, Coulter JA, King RP, Sheaffer CC, Wyse DL. 2011. Economic performance of long-term organic and conventional cropping systems in Minnesota. Agronomy Journal 103:1372–82.

Dolan P, Fujiwara D, 2016. Happiness-Based Policy Analysis. The Oxford Handbook of Well-Being and Public Policy.

Dunn JB, Mueller S, Kwon H, Wang MQ. 2013. Land-use change and greenhouse gas emissions from corn and cellulosic ethanol. Biotechnology for Biofuels 6:51. doi:10.1186/1754-6834-6-51.

Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: An overview of the issues. Ecol. Econ. 65, 663–674. https://doi.org/10.1016/j.ecolecon.2008.03.011

EPA. 2007. Hypoxia in the Northern Gulf of Mexico: an update by the EPA Science Advisory Board. EPA-SAB-08-003. Washington D.C.: U.S. Environmental Protection Agency.

EPA. 2010. Nutrients in Estuaries: A Summary Report of the National Estuarine Experts

EPA. 2011. Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options. A Report of the EPA Science Advisory Board. EPA-SAB-11-013. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100DD0K.PDF?Dockey=P100DD0K.PDF

ETC and iPES Food (2017). Too Big to Feed: the Short Report. Mega-mergers and the Concentration of Power in the Agri-food Sector: how Dominant Firms have Become too Big to Feed Humanity Sustainably. ETC Group in cooperation with the International Panel of Experts on Sustainable Food Systems (iPES Food).

Fafchamps M, Minten B, 1998. Returns to social capital among trader, MSSD Discussion Paper No. 23. International Food Policy Research Institute, Washington DC.
FAO, 2014. Food Wastage Footprint: Full-Cost Accounting. Final Report. http://www.fao.org/3/a-i3991e.pdf

FAO, 2017. Methodology for Valuing the Agriculture and the wider food-system Related Cost of Health (MARCH). http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/MARCH.pdf

Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P., 2008. Land Clearing and the Biofuel Carbon Debt. Science (80-.). 319, 1235–1238. https://doi.org/10.1126/science.1152747

Finkelstein EA, Trogdon JG, Cohen JW, Dietz W. (2009). Annual medical spending attributable to obesity: payer- and service-specific estimates. Health Aff (Millwood). 2009;28(5):w822–w831.

Flora CB, 1995. Social Capital and Sustainability: Agriculture and Communities in the Great Plains and the Corn Belt. Research in Rural Sociology and Development: A Research Annual. 6: 227-246.

Flugge M, Lewandrowski J, Rosenfeld J, Boland C, Hendrickson T, Jaglo K, Kolansky S, Moffroid K, Riley-Gilbert M, Pape D, 2017. A Life-Cycle Analysis of the Greenhouse Gas Emissions of Corn Based Ethanol. Report prepared by ICF under USDA Contract No. AG-3142-D-16-0243. January 30, 2017.

Foley J., 2013. It's Time to Rethink America's Corn System. Sustainability. Scientific American. https://www.scientificamerican.com/article/time-to-rethink-corn/

Fujiwara D and Campbell R, 2011. Valuation Techniques for Social Cost-Benefit Analysis: Stated Preference, Revealed Preference and Subjective Well-Being Approaches. A discussion of the Current issues. HM Treasury. Department of Work and Pensions. July 2011.
Fukuyama F, 1996. Trust: The Social Virtues and the Creation of Prosperity. Harmondsworth: Penguin Books.

Good AG, Beatty PH. 2011. Fertilizing Nature: A Tragedy of Excess in the Commons. PLoS Biology 9(8):e1001124. doi:10.1371/journal.pbio.1001124

Goran MI, Ulijaszek Sj, Ventura EE. 2012. High fructose corn syrup and diabetes prevalence: A global perspective, Global Public Health, 8(1), 55-64, DOI: 10.1080/17441692.2012.736257

Gourevitch JD, Keeler BL, Ricketts TH. 2018. Determining socially optimal rates of nitrogen fertilizer application. Agriculture, Ecosystems and Environment, 254, 292–299. doi: 10.1016/j.agee.2017.12.002

Granovetter M, 1995. The economic sociology of firms and entrepreneurs, in A. Portes, ed., The Economic Sociology of Immigration: Essays on Networks, Ethnicity and Entrepreneurship. Russell Sage Foundation, New York.

Hansen, B., Alrøe, H.F., Kristensen, E.S., 2001. Approaches to assess the environmental impact of organic farming with particular regard to Denmark. Agric. Ecosyst. Environ. 83, 11–26. https://doi.org/10.1016/S0167-8809(00)00257-7

Hansen, L., Ribaudo, M., 2008. Economic Measures of Soil Conservation Benefits.
Interagency Working Group on Social Cost of Greenhouse Gases, 2016. Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.

Harb S. 2015. Natural Radioactivity Concentration and Annual Effective in Selected Vegetables and Fruits. Journal of Nuclear and Particle Physics 5(3), 70-73. http://article.sapub.org/10.5923.j.jnpp.20150503.04.html

Hoben JP, Gehl RJ, Millar N, GracePR, Robertson GP. 2011. Nonlinear nitrous oxide (N_2O) response to nitrogen fertilizer in on-farm corn crops of the US Midwest. Global Change Biology, 17: 1140-1152. doi:10.1111/j.1365-2486.2010.02349.x

iPES Food (2017). Too Big to Feed. A report of the International Panel of Experts on Sustainable Food Systems.

Jackson R.J., Minjares R., Naumoff K.S., Shrimali B.P and Martin L.K (2009). Agriculture Policy Is Health Policy. Journal of Hunger & Environmental Nutrition, 4:393–408, 2009 Copyright © Taylor & Francis Group, LLC ISSN: 1932-0248 print/1932-0256 online DOI: 10.1080/19320240903321367.

Jasinski D, Meredith J, Kirwan K. 2015. A comprehensive review of full cost accounting methods and their applicability to the automotive industry. Journal of Cleaner Production, 108, 1123 – 1139.

Johnson, J.M.F., Weyers, S.L., Archer, D.W., Barbour, N.W., 2012. Nitrous Oxide, Methane Emission, and Yield-Scaled Emission from Organically and Conventionally Managed Systems. Soil Sci. Soc. Am. J. 76, 1347. https://doi.org/10.1016/0304-8853(80)90845-8

Johnson, R., Monke, J., 2018. What Is the Farm Bill?, Congressional Research Service.
Jordan JL, Anil B, Munasib A. 2010. Community Development and Local Social Capital. Journal of Agricultural and Applied Economics 42, 143-159.

Kalcic, M., Prokopy, L., Frankenberger, J., Chaubey, I., 2014. An In-depth Examination of Farmers' Perceptions of Targeting Conservation Practices. Environ. Manage. 54, 795–813. https://doi.org/10.1007/s00267-014-0342-7

Keeler BL, Gourevitch JD, Polasky S, Isbell F, Tessum CW, Hill JD, Marshall JD. 2016. The social costs of nitrogen. Science Advances, 2(10), e1600219–e1600219. doi:10.1126/sciadv.1600219

Keeler, B.L., Wood, S.A., Polasky, S., Kling, C., Filstrup, C.T., Downing, J.A., 2015. Recreational demand for clean water: Evidence from geotagged photographs by visitors to lakes. Front. Ecol. Environ. 13, 76–81. https://doi.org/10.1890/140124

Kling, C.L., Arritt, R.W., Calhoun, G., Keiser, D.A., 2017. Integrated Assessment Models of the Food, Energy, and Water Nexus: A Review and an Outline of Research Needs. Annu. Rev. Resour. Econ. 9, 143–163. https://doi.org/10.1146/annurev-resource-100516-033533

Kool, A., Marinussen, M., Blonk, H., 2012. LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization.

Krupke et al., 2017. Planting of neonicotinoid-treated maize poses risks for honey bees and other non-target organisms over a wide area without consistent crop yield benefit. https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/1365-2664.12924

Krysel, C., Boyer, E.M., Parson, C., Welle, P., 2003. Lakeshore Property Values and Water Quality: Evidence From Property Sales in the Mississippi Headwaters Region.

Kuminoff, N.V., and A. Wossink. 2010. Why isn't more US farmland organic? J. Agric. Econ. 61:240–258. doi:10.1111/j.1477-9552.2009.00235.x

Kurenbach et al., 2017. Herbicide ingredients change Salmonella enterica sv. Typhimurium and Escherichia coli antibiotic responses. Microbiology Society Journals Online. http://mic.microbiologyresearch.org/content/journal/micro/10.1099/mic.0.000573

Lark, T.J., Salmon, J.M., Gibbs, H.K., 2015. Cropland expansion outpaces agricultural and biofuel policies in the United States. Environ. Res. Lett 10, 44003. https://doi.org/10.1088/1748-9326/10/4/044003

Lin N, 2001. Social capital: A theory of social structure and action. New York: Cambridge University Press.

Liu, X.J., Mosier, A.R., Halvorson, A.D., Zhang, F.S., 2005. Tillage and nitrogen application effects on nitrous and nitric oxide emissions from irrigated corn fields. Plant Soil 276, 235–249. https://doi.org/10.1007/s11104-005-4894-4

MARCH, 2017. Methodology for valuing the Agriculture and the wider food system Related Costs of Health (MARCH). Food and Agricultura Organization of the United Nations, Rome.

Mathews LG, Homans FR, Easter KW. 2002. Estimating the benefits of phosphorus pollution reductions: an application in the Minnesota River. JAWRA Journal of the American Water Resources Association, 38(5), 1217–1223. doi:10.1111/j.1752-1688.2002.tb04343.x

Mathijs E, 2003. Social capital and farmers' willingness to adopt countryside stewardship schemes. Outlook on Agriculture 32, 13-16.

McBride WD, Greene C, Foreman L, Ali M. 2015. The Profit Potential of Certified
Metzler-Zebeli et al., 2010. Dietary calcium phosphate content and oat β-glucan influence gastrointestinal microbiota, butyrate-producing bacteria and butyrate fermentation in weaned pigs. FEMS Microbiology Ecology, Vol. 75, Issue 3. https://onlinelibrary.wiley.com/doi/full/10.1111/j.1574-6941.2010.01017.x

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: General Synthesis. Island Press, Washington, DC.

Minnesota Department of Agriculture (2015). Minnesota Nitrogen Fertilizer Management Plan.

Minnesota Department of Agriculture (2018). 2017 Water Quality Monitoring Report: January – December 2017.

Minnesota Department of Agriculture, 2018. Proposed Permanent Rules Relating to Groundwater Protection.

Minnesota Department of Health website. Nitrate in Drinking Water. http://www.health.state.mn.us/divs/eh/water/contaminants/nitrate.html#MinnesotaWater (accessed in November 2018).

Minnesota Environmental Quality Board, 1999. Range of nutrients in manure from five species of livestock.

Minnesota Pollution Control Agency, 2014. The Minnesota Nutrient Reduction Strategy.
Minnesota Pollution Control Agency, 2018. Minnesota's Impaired Waters List [WWW Document]. URL https://www.pca.state.mn.us/water/minnesotas-impaired-waters-list (accessed 5.12.18).

Mohammed N., E. Chanai & M. Alkhorayef, 2016. The iMpact of Extensive Use of Phosphate Fertilizers on Radioactivity Levels in Farm Soil and Vegetables in Tanzania. Journal of Radioanalytical and Nuclear Chemistry, Vol. 307, Issue 3. Springer. https://link.springer.com/article/10.1007/s10967-015-4377-x

Montgomery J, 1991. Social networks and labor-market outcomes: Toward an economic analysis. American Economic Review 81, 1408-1418.

Mooney Pat (2018). Blocking the Chain. Industrial Food Concentration, Big Data Platforms and Food Sovereignty Solutions. ETC Group.

Morefield, P.E., LeDuc, S.D., Clark, C.M., Iovanna, R., 2016. Grasslands, wetlands, and agriculture: the fate of land expiring from the Conservation Reserve Program in the
Muller M, Tagtow A, Roberts SL, MacDougall E (2009). Aligning Food Systems Policies to Advance Public Health, Journal of Hunger & Environmental Nutrition, 4:3-4, 225-240, DOI: 10.1080/19320240903321193

Munasib ABA, Jordan JL, 2011. The effect of social capital on the choice to use sustainable agricultural practices. Journal of Agricultural and Applied Economics 43, 213-227.

Narayan D, 1999. Bonds and bridges social capital and poverty. Policy Research WP n. 2167. The World Bank, Washington DC.

Nyhan Jones V, Woolcock M, 2007. Using mixed methods to assess social capital in low income countries: A practical guide. Brooks World Poverty Institute Working Paper Series 1207, BWPI. The University of Manchester, Manchester.

OECD, 2001. The Well-being of Nations: The Role of Human And Social Capital. Centre for Educational Research and Innovation, Organisation for Economic Co-Operation and Development, France.

Organic Field Crop Production. USDA Economic Research Service Economic Research Report Number 188. https://www.ers.usda.gov/webdocs/publications/45380/53409_err188.pdf?v=42212

Ostrom E, 2000. Social capital: a fad or a fundamental concept? In P. Dasgupta and I. Serageldin, eds., Social capital. A multifaceted perspective. The World Bank, Washington DC.

Phalan, B., Green, R.E., Dicks, L. V, Dotta, G., Feniuk, C., Lamb, A., Strassburg, B.B.N., Williams, D.R., Ermgassen, E.K.H.J. z., Balmford, A., 2016. How can higher-yield farming help to spare nature? Science (80-.). 351, 450–451. https://doi.org/10.1126/science.aad0055

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., Seidel, R., 2005. Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. Bioscience 55, 573. https://doi.org/10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2

Portes A, 1998. Social Capital: Its Origins and Applications in Modern Sociology. Annual Review of Sociology 24: 1-24.

Pretty J. 2003. Social capital and the collective management of resources. Science, 302, 5652, 1912-4.

Putnam R, 1993. The prosperous community: Social capital and public life. The American Prospect, 13, 35-42.

Putnam RD, 1995. Bowling alone: America's declining social capital. Journal of Democracy 6, 65-78.

Putnam RD. 1993. Making democracy work: civic traditions in modern Italy. Princeton University Press: Princeton NJ.

Putnam RD, 2000. Bowling alone. The collapse and revival of American community. Simon Schuster, New York.

Rauch J, Casella A, 2001. Overcoming Informational barriers to international resource allocation: Prices and group ties. Economic Journal 113, 21-42.

Robertson, G.P., Paul, E.A., Harwood, R.R., Glover, J.D., Keeney, D., McCown, B.H., McIsaac, G., Muller, M., Murray, H., Neal, J., Pansing, C., Turner, R.E., Warner, K., Wyse, D., 2000. Greenhouse Gases in Intensive Agriculture: Contributions of Individual Gases to the Radiative Forcing of the Atmosphere. Science (80-.). 289, 1922–1925. https://doi.org/10.1126/science.289.5486.1922

Rossi JR, Woods TA, Allen JE, 2017. Impacts of a Community Supported Agriculture (CSA) Voucher Program on Food Lifestyle Behaviors: Evidence from an Employer-Sponsored Pilot Program. Sustainability 9, 1543; doi:10.3390/su9091543

Rostilla M, 2010. The Facets of Social Capital. Journal for the Theory of Social Behaviour 41:3 2010

Sawyer JE, Mallarino AP, 2014. Nutrient Considerations with Corn Stover Harvest. Extension and Outreach Publications. 84.

Scavia D. 2015. Industrial corn farming is ruining our health and polluting our watersheds. The Conversation April 6. https://theconversation.com/industrial-corn-farming-is-ruining-our-health-and-polluting-our-watersheds-39721

Schoonover H. and M. Muller (2006). Food Without Thought – How US Farm Policy Contributes to Obesity. Institute for Agriculture and Trade Policy. Environment and Agriculture Program. 20 Years IATP.

Schultz TW, 1962. Investment in Human Capital. The American Economic Review 51, 1-17.
Shortle, J., Horan, R.D., 2017. Nutrient Pollution: A Wicked Challenge for Economic Instruments. Water Econ. Policy 03, 1650033. https://doi.org/10.1142/S2382624X16500338

Shortle, J.S., Ribaudo, M., Horan, R.D., Blandford, D., 2012. Reforming agricultural nonpoint pollution policy in an increasingly budget-constrained environment. Environ. Sci. Technol. 46, 1316–1325. https://doi.org/10.1021/es2020499

Smil V. 2001. Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food. The MIT Press, Cambridge, UK.
Sociology, 94, S95-S120.

Sweetland SR. 1996. Human Capital Theory: Foundations of a Field of Inquiry. Review of Educational Research 66(3), 341-359.

TEEB, 2018. Scientific and Economic Foundations Report.

Tessum CW, Hill JD, Marshall JD. (2017). InMAP: A model for air pollution interventions. PLoS ONE, 12(4), e0176131–26. doi:10.1371/journal.pone.0176131

Thoma, G., Nutter, D., Ulrich, R., Maxwell, C., Frank, J., & East, C. (2011). National Life Cycle Carbon Footprint Study for Production of US Swine. National Pork Board.

Tilman D. 1999. Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. Proceedings of the National Academy of Sciences USA 96 (11), 5995-6000.

Tomer, M.D., Porter, S.A., Boomer, K.M.B., James, D.E., Kostel, J.A., Helmers, M.J., Isenhart, T.M., McLellan, E., 2015. Agricultural Conservation Planning Framework: 1. Developing Multipractice Watershed Planning Scenarios and Assessing Nutrient Reduction Potential. J. Environ. Qual. 44, 754. https://doi.org/10.2134/jeq2014.09.0386

U.S. Department of Agriculture Natural Resources Conservation Service, 2017a. Effects of Conservation Practices on Water Erosion and Loss of Sediment at the Edge of the Field.

U.S. Department of Agriculture Natural Resources Conservation Service, 2017b. Effects of Conservation Practices on Nitrogen Loss from Farm Fields.

U.S. Department of Agriculture Natural Resources Conservation Service, 2017c. Effects of Conservation Practices on Phosphorus Loss from Farm Fields.

U.S. Department of Agriculture, 2015a. 2015 Nation Resources Inventory: Minnesota Soil Erosion [WWW Document]. URL http://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/nri_crop_mn.html (accessed 10.31.18).

U.S. Department of Agriculture, 2015b. 2015 National Resources Inventory: Minnesota Cropland [WWW Document]. URL http://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/nri_eros_mn.html (accessed 10.31.18).

U.S. Department of Agriculture, 2018. National Agricultural Statistics Service QuickStats Ad-hoc Query Tool [WWW Document]. URL http://quickstats.nass.usda.gov/
U.S. Government Accountability Office, 2016. RENEWABLE FUEL Program Unlikely to Meet Production or Greenhouse Gas Reduction Targets.

UN. 1993. Integrated Environmental and Economic Accounting. UNSTATS.

UN. 2014. System of Environmental Economic Accounting 2012—Central Framework. United Nations, European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, The World Bank.

UNU-IHDP and UNEP (2014). Inclusive Wealth Report 2014. Measuring progress toward sustainability. Cambridge: Cambridge University Press.

US Dept of Agriculture Economic Research Service (2009). Sugars and sweeteners: recommended data. Available at: http://www.ers.usda.gov/Briefing/Sugar/ Data.htm.

USDA (2016). 2016 Certified Organic Survey: Minnesota.

USDA ERS, 2010. U.S. Farm Resource Regions. https://www.ers.usda.gov/webdocs/publications/42298/32489_aib-760_002.pdf?v=0
USDA ERS, 2014. Characteristics and Production Costs of U.S. Corn Farms, Including Organic, 2010. Linda Foreman. Economic Information Bulletin Number 128 September 2014. www.ers.usda.gov/publications/eib-economic-information-bulletin/eib128

USDA ERS, 2018. United States Department of Agriculture National Agricultural Statistics Service, Census of Agriculture (2012) and Farms and Land in Farms Summary. USDA Economic Research Service. https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=58268

USDA ERS, 2018b. Recent Trends in GE Adoption. https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption.aspx

USDA National Agricultural Statistics Service, 2018a. Farms and Land in Farms 2017 Summary. www.nass.usda.gov

USDA National Agricultural Statistics Service, 2018b. Farm Production Expenditures 2017 Summary. www.nass.usda.gov

USDA National Agricultural Statistics Service, 2018c. Historical prices of commodities. Summary. www.nass.usda.gov

Vasquez A, Sherwood NE, Larson N, Story M, 2016. Community-Supported Agriculture as a Dietary and Health Improvement Strategy: A Narrative Review. Journal of the Academy of Nutrition and Dietetics 117, 83–94.

WHO, 2015. International Agency for Research on Cancer. IARC Monograph Volume 112: Evaluation of Five Organophosphate Insecticides and Herbicides. WHO, 20 March 2015. http://www.iarc.fr/en/media-centre/iarcnews/pdf/MonographVolume112.pdf

Wisconsin Department of Natural Resources, 2012. Phosphorus reduction in Wisconsin water bodies: an economic impact analysis [WWW Document]. URL http://dnr.wi.gov/topic/SurfaceWater/documents/PhosphorusReductionEIA.pdf

Appendix A Uses of corn

Various uses of corn in food and industrial products (NCGA, National Corn Growers Association*; United States Department of Agriculture).*

Dextrose *(Food, Drug Uses)*				
Antibiotics	Baby Foods	Bakery products (biscuits, bread, crackers, fillings, icing, macaroons, pretzels, cookies, crackers, wafers, etc.)	Berries, canned and frozen	Beverages, brewed (beer, ale, etc.)
Beverages, carbonated	Breakfast foods	Caramel color	Cheese foods and spreads	Chewing gum
Chocolate products	Citric acid	Citrus juices	Coloring, pure food mix	Condensed milk
Confectionery	Cordials, liqueurs and brandy	Cream, frozen	Dairy products	Desserts
Dietetic preparations	Distillation products	Doughnuts (cake, yeast)	Drugs (fermentation process)	Eggs, frozen or dried
Fish, pickled	Flavoring extracts	Food acids (citric, etc.)	Fruit juices	Fruits and vegetables (canned)
Gelatin desserts	Ice cream, water ices and sherbets	Infant and invalid feeding	Jams, jellies, marmalades and preserves	Lactic Acid
Meat products (bacon, bologna, hams, sausage, frankfurters, mincemeat)	Medicinal preparations & intravenous (injections, pills, tablets, drugs, etc.)	Mixes, prepared (cake, icings and frostings, infant foods, pie fillings, toppings, etc.)	Peanut butter	Peas, canned
Pickles and pickle products	Prepared mixes	Powders (ice cream, prepared dessert, pudding, summer drinks, powders, etc.)	Sauces (catsup, tomato, etc.)	Seasoning mixes, dry
Sorbitol (in candies, toothpaste, etc.)	Soups, dehydrated	Spices and mustard preparations	Syrups (table, fomtain, medicinal, etc.)	Vinegar
Wine	Xanthan Gums	Yeast		
Dextrins *(Industrial Uses)*				
Adhesives (glues, pastes, mucilages, gums)	Bookbinding	Briquettes	Candles	Ceramics
Cord polishing	Core binder (castings, molds, etc.)	Cork products	Crayon and chalk (as a binder)	Dyes (dry, cake, etc.)
Envelopes	Fireworks	Inks, printing	Insecticides	Insulation, fiberglass
Labels	Leather	Linoleum	Magazines	Matches (on head and side of box)
Oil-well drilling	Ore-separation	Paints (cold-water, poster, etc.)	Paper and paper products	Plastics (molding)
Plywood	Sandpaper	Shoes (counter pastes, polish, etc.)	Silvering compounds	Soaps
Straws (drinking)	Textiles, sizing, finishing and printing	Twine (cord, string, etc.)	Wallboard and wallpaper	Window shades and shade cloth
Cornstarch *(Food, Drug and Cosmetic Uses)*				
Antibiotics	Aspirin	Baby Foods	Bakery products (breads, rolls, cakes,	Baking powder

			pies, crackers and cookies)	
Beverages, brewed (beer, ale, etc.)	Chewing gum	Chocolate drink	Confectionery	Cosmetics
Desserts (puddings, custards, etc.)	Drugs and pharmaceuticals	Flours, prepared (including prepared mixes)	Food and drug coatings	Gravies and sauces
Meat products	Mixes, prepared (pancake, waffle, cake, candy, etc.)	Mustard, prepared	Pie filling	Precooked frozen meals
Salad dressing	Soaps and cleaners	Soups	Sugar, powdered	Vegetables, canned
Corn Oil, Refined *(Food, Drug Uses)*				
Carriers for vitamins and other medicinal preparations in capsule form	Cooking Oil	Margarine	Mayonnaise	Potato chips
Salad dressing	Sauces, seasonings	Shortening	Soups	
Corn Syrup *(Industrial Uses)*				
Adhesives (plasticizing agent)	Chemicals	Dyes and inks	Explosives	Leather tanning (chrome process)
Metal plating	Paper, glassine and parchment	Plasticizer	Polish, shoe	Rayon (Viscose process)
Textiles, for finishing	Theatrical make-up	Tobacco and tobacco products		
High Fructose Corn Syrup *(Food Uses)*				
Bakery products	Canned fruits	Canned juices	Condiments	Confectionery products
Frozen desserts	Jams, jellies and preserves	Soft drinks	Wine	Yeast
Cornstarch *(Industrial Uses)*				
Abrasive paper and cloth	Adhesives (glues, mucilages, gums, etc.)	Batteries, dry cell	Binder or binding agents	Board (corrugating, laminating, solid fiberboard, cardboard)
Boiler compounds	Bookbinding	Briquettes	Ceramics (as clay binder)	Chemicals
Cleaners, detergents	Coatings on wood, metal and paper	Color carrier (in paper and textile printing)	Cord polishing, sizing	Cork products
Crayon and chalk (as a binder)	Dispersing and standardizing agent	Dressing, surgical	Dyes (as a bodying agent, carrier diluent, etc.)	Fermentation processes
Fiberglass size	Fireworks	Insecticide powders	Insulating material (glass, wool, rock wool, etc.)	Lubricating agents
Oilcloth	Oil-well drilling (drilling mud)	Ore refining (electrolytic reduction process, flotation process, etc.)	Paints (cleaning compounds, cold water and latex paints, poster, laquers, etc.)	Paper and paper products manufacture
Photographic films (antihalation powder)	Plastics (molded)	Plywood (interior)	Printing	Protective colloids (emulsions)
Textiles (warp sizing and finishing)	Tile, ceiling	Tires, rubber	Wallboard and wallpaper	Water recovery, industrial
Corn Syrup *(Food, Drug Uses) Liquid or Dried Form*				
Baby foods	Bakery products (bread, rolls, biscuits, doughnuts, pies,	Beverages, brewed (beer, ale, etc.)	Beverages, carbonated	Breakfast foods

	cakes, cookies, pretzels, etc.)			
Catsup, chili sauce, tomato sauce	Cereals, prepared	Cheese spreads and foods	Chewing gum	Chocolate products
Coffee whiteners	Condensed milk, sweetened	Confectionery	Cordials and liqueurs	Desserts
Eggs, frozen or dried	Extracts and flavors	Frostings and icings	Fruit butters and juices	Fruit drinks
Fruits (canned, candied, fillings, frozen, etc.)	Ice cream, water ices and sherbets	Jams, jellies, marmalades and preserves	Licorice	Malted products
Marshmallows and related products	Meat products (sausage, etc.)	Medicinal preparations (drugs, pharmaceuticals)	Mixes, prepared (cakes, infant foods, pie fillings, pudding powders, ice cream, etc.)	Peanut butter
Pickles and pickle products	Rice and coffee polish	Salad dressing	Sauces (seasoning, specialty, etc.)	Seafood, frozen
Soups, dehydrated	Syrups (table, chocolate, cocoa, fruit, medicinal, soda fountain, cordials, etc.)			

Appendix B Health externalities assessment

Data: The three main sources of data for this study are:

1) Gallup Daily tracking survey

Gallup conducts a daily survey administered to1,000 U.S. adults on topics pertaining to various demographic, political, economic, and well-being themes. For this study, we use 10 years of pooled cross-sectional microdata from the Gallup Daily Survey for the State of Minnesota from 2008 to 2017. The Gallup Daily Survey is designed to be representative at the state-level. It also includes a ZIP-code identifier for each individual which we use as a proxy for where they live.

2) Corn production data

We use the Cropland Data Layer (CDL)[3] published by the National Agricultural Statistics Service (NASS) to calculate land use intensity for corn and non-corn production which is calculated as the proportion of a survey respondents' surroundings used in corn and non-corn production. The CDL is satellite data which measures land use at a 30m by 30m scale for the years 2006-2017 for the entire state of Minnesota. We take ZIP code centroids[4], construct areas of varying radius around them (circular 'buffers') and then calculate the proportion of the buffer used for corn and non-corn production as a measure for the intensity of land use in corn and non-corn production in a person's surroundings. For example, a circular buffer of 5km radius (with an area of approximately 78km^2) around a ZIP code would be considered 10% corn if 7.8 kilometres of the buffer was used for corn production. This approach allows us to calculate land use intensity for corn and non-corn production (henceforth referred to as 'corn' and non-corn intensity') for all 863 ZIP codes in Minnesota. Merging the ZIP code measures of corn and non-corn intensity with the Gallup respondents' ZIP code and year of interview obtains the area used for corn, and the area used for all other crops in each buffer.

3) Organic corn production data

The CDL data set described is not able to distinguish between organic and non-organic corn.

Two further data sources offer the possibility of identifying areas where organic corn production takes place in Minnesota:

i. **List of all 519 certified organic corn farms in Minnesota** from the USDA Organic INTEGRITY Database. This database provides the ZIP code of each organic farm, meaning that it is possible to identify the number of organic corn farms that operate in the Gallup survey respondent's ZIP-code.

ii. **The Directory of Minnesota Organic Farms** which includes the zip code and total acreage of 160 organic corn farms in Minnesota. This data indicates that a typical organic farm produces a number of different crops and covers an average of 280 acres. If we assume that half of a typical organic farm's area is used for corn production, the total acreage of the 519 corn farms in Minnesota spans about 1.3% of total land used for corn production in this state. As the relative size of organic corn farming is very small, identifying the impact of organic corn production in our analysis presents a challenge.

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[3] National download for 2008-2017 is available here. The remaining data for 2006 and 2007 was downloaded from CropScape.

[4] A geographic centroid is the mean position of all the points within the area of the ZIP code.

Methodology

To measure the impact of corn production on health, we follow the Well-being Valuation (WV) method explained in MARCH (2017), which offers an alternative to the Quality-Adjusted Life Years (QALYs) approach of valuing the non-financial costs of health. To use this method, we first estimate the impact of a non-market good (in this case corn intensity), income, and other determinants of wellbeing on measures of subjective well-being (SWB), such as life satisfaction. Thus, as displayed in Figure 6, the WV method measures two effects: the impact of the non-market good on SWB (β_C) and the impact of income on SWB (β_M).

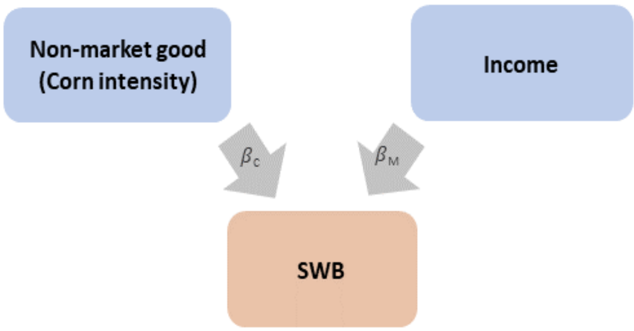

Figure Graphical representation of the WV method for valuing corn intensity as a non-market good.

Consequently, using the estimated impacts of income and the non-market good, we assess the monetary value of the non-market good. This monetary value shows how much an individual would have to be compensated to return their wellbeing to its original level (the status quo without the non-market good).

In this study, the non-market good being valued is corn intensity in the proximity of where individuals live and the measure of SWB is their life satisfaction[5]. The monetary value obtained through the WV method is the well-being effect of corn intensity through its impacts on health (see below on the two-stage procedure). This monetary value can also be interpreted as the (non-financial) costs of health associated with corn intensity. Note that the WV method does not account for any health impact caused by the consumption of products containing corn[6].

In order to implement the WV method in this case, we apply a two-stage procedure similar to MARCH (2017) to find β_C. We first estimate the impact of general health (GH), captured

[5] In the Gallup data, life satisfaction is measured by the Cantril ladder scale which poses the following question: "Please imagine a ladder with steps numbered from zero at the bottom to ten at the top. Suppose we say that the top of the ladder represents the best possible life for you and the bottom of the ladder represents the worst possible life for you. If the top step is 10 and the bottom step is 0, on which step of the ladder do you feel you personally stand at the present time?"

[6] As corn intensity can be assumed to be independent of the amount of corn consumed, not including corn consumption in the model does not bias our estimates.

by a 1-5 subjective scale (poor to excellent) on life satisfaction as a measure of SWB. We then multiply this estimated impact with the impact of corn intensity on general health to obtain an estimate of the impact of corn intensity on life satisfaction (β_C).

The impact of corn intensity on general health is estimated empirically through regression analysis based on the following model:

(1) $GH_i = f(C_i, NC_i, X_i)$

Where, GH_i denotes the general health of individual i. C_i and NC_i capture corn and non-corn intensity near individual i; and X_i is an index describing a range of demographic and socioeconomic characteristics of individual i.

Thus, the general health of individual i is assumed to be a function of a range of socioeconomic and demographic characteristics and corn and non-corn intensity.

The impact of corn intensity (C_i) on general health, which we call δ, is a key parameter for our analysis. If it is statistically significant and negative, it would imply that living near an area with higher corn intensity is associated with a reduction in an individual's wellbeing measured by their perception of their general health. To derive the impact from only corn production on general health, we also include in the model the proportion of land used for other agricultural products in a respondent's surrounding (NC_i). Thus, the derived effect of corn shows the change in health caused by corn intensity while holding non-corn intensity constant. C_i includes the land used for all types of corn including organic and non-organic farms. NC_i contains all other agricultural products in Minnesota. Key products include soybeans, wheat and alfalfa.[7]

The choice of buffer size (i.e., radius covered) around ZIP code centroids depends on the channels through which corn intensity affects health. Water and air pollution are likely channels for the impact of corn production on health, but without further analyses of these channels the choice of buffer is unclear. In the absence of theoretical evidence, we use a data-driven approach to investigate how the effect of corn production changes in differing buffers. Using this approach, we settle on buffer sizes of 5km and 10km. As a result, the corn intensity variable, C_i, represents corn intensity in 5 or 10 km buffers from the ZIP code centroid of each respondent. Given that the buffers are around ZIP code centroids, corn intensity measured within smaller buffers (e.g. 2km) would not be representative of the level of corn throughout the ZIP code area, especially for ZIP codes with larger areas. With very large buffers, and analysis in one state, the variation in associated corn intensity between individuals is reduced which renders the identification of health effects difficult.

In addition to corn intensity at the year of the interview, we use the previous year's data to calculate 5-year averages of land use in agricultural production. In the absence of panel data, we assume each respondent has lived at his current residence for 5 years, which is the average length of time spent in one's residence in the US (2017). This is a more robust estimation of the average area used for each agricultural product, as it is less affected by

[7] The list of all agricultural products included in NC_i is available in:
https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/metadata_mn17.htm

crop rotation and other short-term variations in the relative land use. As a result, using five-year averages is more appropriate to capture the long-term effects of corn production on health[8].

X_i includes all demographic and socio-economic characteristics of the respondents that are controlled for in the model. It is crucial that in seeking to identify the impact of corn intensity on health we adjust, where possible, for the impact of wider factors that are correlated with both corn production and health. In econometric terms, this means ensuring that we control for all observable confounding factors, which affect both general health and corn intensity. For example, living in areas with less population density is associated with higher corn production near an individual and may also drive wellbeing in and of itself. Thus, we need to control for population density in our model. In particular, we use the following variables suggested in Fujiwara and Campbell (2011):

- Age
- Gender
- Marital status
- Educational status
- Employment status and income
- Religious affiliation
- Number of children
- Geographic region
- Urbanization
- Local environment conditions
- Year

For geographic region, Gallup provides the ZIP code, county and congressional district of each respondent. A congressional district is an electoral constituency with an average population of 711,000. There are 8 congressional districts in Minnesota and we use these districts as a control for the impact of region-specific variables that may be correlated with both health and corn production. This is preferred to controlling for geographic regions at a more refined level such as counties, as the variation of corn production within each region will be very small. For local environment conditions, we control for a variable showing satisfaction with the city or area a respondent lives in.

To test the impact of organic production, we expand model (1) using location data on the full list of organic corn farms, as this ensures that we cover the full breadth of organic production in the region. Unlike the CDL data, this data set does not inform us as to the intensity of corn farmed in any given area. Thus, our analysis relies only on the number of organic corn farms per ZIP code. To account for the impact of organic corn we use model (2), which is a modification of the baseline model (1):

(2) $GH_i = f(C_i, NC_i, X_i, O_i, inter_i)$

[8] Our analysis shows that using the average or current year production does not affect the results greatly. This is expected as average and current production are strongly correlated with a correlation coefficient equal to 0.99.

In this model, O_i equals 1 if there is at least one organic farm in the ZIP code of individual i and 0 otherwise. The model also includes the variable $inter_i$ which is the interaction of corn intensity (C_i) with the dummy indicating existence of at least one organic corn farm in the ZIP code of respondent i (O_i). The coefficient on $inter_i$ shows how the impact of corn intensity differs based on whether a ZIP code contains at least one organic farm.

By using the WV method, we can estimate a monetary value for the non-financial health costs of relative land used for corn production. This is the amount of money needed to offset the impact from corn production in an individual's proximity on their general health. As general health is correlated with health conditions[9], the monetary value from the WV method also reflects the non-financial costs of different health conditions.

One of the key issues in the WV method is the correct estimation of the statistical models that underlie the value calculation. The values should be estimated based on causal estimates of the impacts of both income and the non-market good on well-being. In order to robustly estimate the impact of income, an instrumental variable (IV) model using lottery wins is used by Dolan and Fujiwara (2016). This model isolates changes in well-being due to lottery wins (which result in an increase in income that is not correlated with well-being). This method estimates a causal impact of income on well-being, which is higher compared with the models that do not consider exogenous changes in income.

As there is no information on lottery wins in our data set, we apply the ratio of the causal impact of income estimated in an instrumental variable (IV) framework to the ordinary Least square (OLS) impact obtained in Dolan and Fujiwara (2016). This implies that the impact of income on life satisfaction in our estimations is upscaled to reflect the effect of exogenous variations in income on well-being. The technical steps to obtain the causal impact of income using lottery wins are explained in Appendix 2 in MARCH (2017).

Health assessment

Secondary data is used to link subjective wellbeing and health status to production outcomes. Based on the data available, two main production outcomes could be valued, as outlined below:

1) Using county-level corn production data, we value the corn production system based on how wellbeing and subjective health status differs in intensity of corn production.
    a) As supplementary evidence to 1, we use the same data on corn production to link corn production systems to county-level disease incidence of diseases which have been linked to corn production systems.
2) Using zip-code level health survey data, and locations of farms, we value local health externalities from corn production. For example, we derive the effect of living within 10 kilometres of a farm producing corn.

To understand the wellbeing and health profile of the target population, we draw on data which elicits responses on life satisfaction or another comparable question which captures subjective wellbeing

[9] In our data set for example, the coefficient of correlation between general health and having had previously a heart attack is -0.17 and the correlation between general health and high blood pressure is -0.24. Both coefficients are statistically significant at 5% level.

When studying the effect of a production outcome on health and wellbeing in a statistical 'regression' framework, factors such as socio-economic characteristics are likely to bias the impacts of any outcome, given that these factors jointly determine both wellbeing (or health) and the likelihood of, for example, being exposed to a certain pollutant (In statistics, this is known as 'omitted variable bias'. When failing to control for relevant factors, the estimate of the effect of the production outcome would be biased given a correlation between the omitted variable and the production outcome, and the omitted variable and health/wellbeing). As such, the data we use will contain information on a number of socio-economic and demographic factors, such as age, gender, ethnicity, employment, education and income, so that these factors can be 'controlled for'.

With data on subjective-wellbeing (and health), production outcomes, and a broad range of controls, the WV approach is carried out as follows:

1. Estimate the impact of the production outcome on wellbeing (or health) in a regression framework incorporating controls.
   1a. In the case of health, estimate the impact of health on wellbeing in a regression framework incorporating controls. Take the estimate from 1 and multiply this with that from 1a to retrieve the impact of the outcome on wellbeing through health).
2. Estimate the causal effect of income on wellbeing in a quasi-experimental regression framework using instrumental variables.
3. Combine 1 and 2 to derive the compensating surplus to value the impact of corn production using the approach set out in Fujiwara, 2013.

The three steps above will yield a per-person, per-year value. This value tells us the monetary sum that would leave an individual who is exposed to the potential consequences of corn production at the same level of wellbeing should they no longer be exposed (the compensating surplus). This can be broadly interpreted as the willingness to accept the exposure.

As part of the WV approach, an estimate of the causal impact of income on subjective wellbeing is also required. To calculate this, we employ an instrumental variables (IV) approach using plausibly exogenous shocks to income. Given that wellbeing and income jointly determine one another (In statistics, this joint determination is known as 'Simultaneity'), an 'instrument' is needed which is correlated with income, but uncorrelated with wellbeing. An example of such an instrument is lottery wins, as these are determined by probability. This can be used to isolate the causal (and hence unbiased) effect of income.

Lastly, to value the (total) monetary impact of corn production in the population of interest, the per-person per-year values must be aggregated up to population levels. This will be done by estimating the proportion of individuals in the population who experience this particular outcome and multiplying this by the average monetary valuation as estimated from the WV approach.

Data requirements:

1) Locations of corn producing farms in Minnesota. For organic farms, we have data available here from the USDA's Agricultural Marketing Service.

2) Health survey data with ZIP-code level identifiers; CDC carries-out the health survey used to find out if this data can be accessed at ZIP code level.