Estimation of Dairy Manure-based Nutrient Supply-Demand Balances in Idaho, 1990 to 2022

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Xuejian Wang

Major Professor: Patrick Hatzenbuehler, Ph.D.
Committee Members: Alexander Maas, Ph.D.
Mario de Haro Martí, Ph.D.
Department Administrator: Christopher McIntosh, Ph.D.

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Abstract

The dairy industry in Idaho (ID) has expanded rapidly in the past 30 years. The expansion of the dairy industry has brought nutritious food and drinks across the U.S. and world and substantial agribusiness opportunities, especially in Southern ID. The dairy is, as of 2023, the largest industry regarding cash receipts in the ID agricultural economy. Development of the dairy sector has not only increased revenues for the direct participants in the dairy supply chain, but also aligned sectors such as production of feed crops, including alfalfa hay and corn silage.

Despite these benefits, the dairy industry also produces substantial amounts of dairy manure, and management of dairy manure is a considerable cost for dairy producers. Manure contains large amounts of nutrients, but the local demand for crops may not be able to absorb all of the supply, especially in major dairy producing regions in Southern ID. In addition, the increase in population and associated increase in land conversion for housing and other commercial development in some regions of ID in recent decades has led to reductions in cropland areas for feed and other crops, which has provided fewer outlets for distributing manure-based nutrients. The associated potential decrease in nutrient demand from cropland can intensify the oversupply of nutrients in some regions. An oversupply of manure can cause nutrients to accumulate in the local environment, which can contaminate soil, water, and air greenhouse gases. While the nutrient oversupply can be detrimental to the local environment, the extent of the impact regarding the total quantity and distribution of manure-based nutrients remains unclear.

In this thesis, dairy manure nutrient supply-demand balances in ID were quantified for the observation period of 1990 – 2022. The first set of quantification analyses is done at the state, region, and county-levels to determine the regional distribution of dairy manure in the state. A second analysis, which focuses on the more localized distribution of dairy manure and cropland, relies on a unique dataset from the Idaho State Department of Agriculture that allows for determination of the locations, sizes, and dates of establishment of ID dairies. In this more spatially targeted analysis, supply-demand balances were estimated at the census tract level for three major dairy producing counties in Southcentral ID (Gooding, Jerome, and Twin Falls) for the period of 2007 to 2022.

The results from the quantification analysis show that the state-level supply-demand balance has increased rapidly for all analyzed nutrients over the course of 1990 to 2022. In addition, the increase in nutrient balance has mainly occurred in Southcentral and Southwest ID, where most of the dairy farms have been established over this observation period. The spatial analysis demonstrates that the most acute increase in the manure-based nutrient supply has concentrated near rivers, including the Snake River, to a relatively higher degree than other census tracts. As time has passed, the number of dairies, and associated manure-based nutrients, further away from the Snake River has also increased. This has led to a substantial accumulation of nutrients in some areas that had previously not had much manure present. In some census tracts, as of 2022, the amount of nutrient accumulation was estimated at 10 times larger than in 2007. However, years of substantial amount of nutrient accumulation, and corresponding reduction in pace of dairy industry expansion, has caused nutrient accumulation to increase at a decreasing rate in more recent periods. Due to the chemical characteristics of liquid and solid manure, there has been greater increases in supply and accumulation of Nitrogen than Phosphorus and Potassium. Composting decreases Nitrogen relative to Phosphorus and Potassium, and dairies and industry partners currently compost about half of the dairy manure in Southern ID.

The main result of this thesis is that the substantial expansion of the dairy industry has led to a large accumulation of dairy manure nutrients in Southern ID. Further development of manure-based fertilizer product industries, which can implement value-added processes that extract the water and concentrate nutrient solids from liquid and solid dairy manure, and, hence, reduce the transportation costs to ship the manure-based nutrients away from the dairies, can help reduce the nutrient oversupply in the future. Such development can also potentially facilitate shipment of manure-based fertilizer across the Western U.S., helping both dairies via a diversified revenue stream as well as specialized manure processing businesses to generate profits from related businesses. This can also help remediate environmental issues, including reducing contamination of soil, water, and air and release of greenhouse gases. Reducing the environmental impact of the dairy industry can both ensure that agricultural productivity is sustained and help ensure that the ID agricultural economy remains vibrant in the future.

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I really appreciate the help from Dr. Patrick Hatzenbuehler, my major professor. He has put a lot of time and effort into this thesis project. He has helped me with the motivation, research design, organization, and implications of the thesis. He also provided many useful suggestions for improving the thesis as the project evolved. I also appreciate the help from Dr. Mario de Haro Martí. He has helped me achieve a more holistic understanding of the dairy sector in Idaho, especially the practices of dairy farmers and their real-world decisions. I also appreciate the help of Dr. Alexander Maas. He has helped me achieve a greater understanding of the economic and environmental linkages of the entities analyzed in the project. I also really appreciate the help from other faculty and classmates in the AERS department, who encouraged me when I faced difficulties.

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Chapter 1: Introduction

The dairy industry is the largest agricultural sector in Idaho (ID) (USDA, 2022a), and provides a substantial number of jobs in the state and nutritious food and drinks that are consumed throughout the U.S. and world. ID dairy producers primarily produce milk that is used in processing, especially for cheese (Idaho Farm Bureau Federation, 2019). The expansion of the dairy industry that has occurred over the past several decades has not only influenced conditions for entities that participate in the milk supply chains, but also has led to increases in the production of feed crops that were not widely grown in ID until recently like corn silage, providing additional nutrient demand for the sector. However, the dairy sector also competes with other agricultural sectors that are not direct participants in the dairy supply chain for water and land. Simultaneous increases in the ID population and associated expansion of urbanized areas have led to conversion of cropland to housing and other development. This decrease in available cropland has implications for the total usage of nutrients for crop production in the state.

In addition to the economic outputs by the dairy industry, it is also a substantial producer of manure. However, the nutrients from dairy manure, namely Nitrogen (N), potassium (K), and phosphorous (P), are presently not fully absorbed by the crops grown in ID for several reasons. These include existing practices by crop producers for usage of synthetic commercial fertilizers to provide nutrients for crops, as well as market structural issues such as high transportation costs for distributing manure from dairies to cropland. These issues imply that the current state is one in which there is an oversupply of manure. The oversupply situation is such that there is enhanced risk for environmental issues. Excess nutrients can contaminate water, air, and soil, which can further hurt the local ecosystem over the long term. For instance, manure with extra amount of P can increase growth of algae in the water, and their decomposition can absorb oxygen that fish need to breath (Brown & Griggs, 2009). This can change the colonization and number of fish in water bodies such as reservoirs, rivers, and streams (Kingsford, 1992). Some algae can also lead to fish mortality via direct toxicity (Lindholm et al.,1999). Furthermore, human consumption of water with excess nutrients can be harmful to health, and so is a concern among local policymakers (Condos, 2022). Interventions to remove nutrients and other chemicals and harmful matter from water can be costly. Thus, the effects of nutrient losses extend widely through the local ecosystem and economy, including directly impacting other economic sectors such as tourism (Condos, 2022; Gössling et al., 2015).

In addition to water and soil-related impacts, dairy production generates a substantial amount of greenhouse gases (GHG). GHG emissions from the sector have increased rapidly over the past several decades, increasing by 122 percent from 1990 to 2020 (EPA, 2022). The main relevant GHG for the dairy industry are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (Chen et al., 2022). Chen et al. (2022) estimate that dairy manure contributes 20% of GHG emissions, while the remainder are from enteric fermentation (cow belching during digestion) (EPA, 2023). Losses of N to the environment particularly notable. Manure-based N is commonly emitted as it interacts with air in its liquid and solid forms. Moore et al. (2015) and other experts estimate that around 80% of manure-based N can be lost between excretion and actions taken to manage the manure. The N that is lost through atmospheric interactions can enter the air and end up in water bodies and deserts around dairies.

To limit these environmental concerns, efforts among policymakers and researchers are underway to investigate manure management techniques that can reduce GHG emissions and other contamination. Technologies and practices that are presently not widely used by dairy farmers to manage manure can increase production costs with uncertain prospects for revenue. The potential for associated reductions in dairy industry profits can hinder future development of agricultural economy in ID. While the economic and environmental implications of the expansion of the dairy industry and related adjustments in cropland for feed and other crops in ID are well understood in many regards, the size of the impact on manure production and usage potential in ID is still unknown.

In this thesis, the gap of knowledge regarding quantifying the size of the manure management issue is filled through a series of data and expert-informed calculations of dairy manure supply-demand balances. Specifically, the dairy manure nutrient supply-demand balances are calculated at the state, region, and county levels using U.S. Department of Agriculture (USDA) data on cattle inventories and cropland acreage and conversion factors obtained from the literature. In implementation it was assumed, based on local expert consultation, that 50% of solid manure is composted. Additionally, for three major dairy producing counties, Gooding, Jerome, and Twin Falls, we use geographic information system (GIS) analysis and tools, as well as a unique farm level dataset from Idaho State Department of Agriculture (ISDA) to estimate nutrient supply-demand balances at the census tract level. This spatial analysis shows the geographical distribution of nutrient supply-demand balances and the associated implications for the development of the dairy sector and potential development of manure-based fertilizer products. There has been substantial concentration in the U.S. dairy industry in recent years (Feng et al., 2018). Small dairies are commonly unable to compete with large ones based on cost and product quality, so more small dairies are going out of business while large ones increase in size (Feng et al., 2018). This phenomenon applies in ID as well and has important economic environmental implications. Specifically, if the dairy industry were less concentrated, then the manure produced would also be less concentrated. Distribution of raw manure from dairies to cropland would be less costly, on net, if dairies were less concentrated more evenly distributed. Lastly, the accumulation of nutrients over time was calculated using the calculated supply-demand balances in the analyzed counties.

The results from the analysis show that ID manure-based nutrient supply-demand balances have increased considerably over the past 30 years. However, there are differences in the extent of increases across nutrients. Specifically, increases in N are about 30% larger than K and P. However, composting can decrease the amount of N relative to K and P. At the regional level, the results demonstrate that the manure-based nutrient increases have been concentrated in Southern ID, especially in major dairy counties such as Gooding, Jerome, and Twin Falls counties. The results from the census tract level GIS analysis show that there have been relatively more nutrient supply increases in the census tracts nearest to the Snake River. However, increases in dairy establishment and expansion in areas further away from the river have been observed over time. Considering accumulation, calculated nutrient accumulations over the full observation period were up to 10 times greater than the annual nutrient balance for 2022. While accumulation has remained positive over time, the speed of nutrient increases has declined in recent years.

The quantification of dairy manure-based nutrient balances in this thesis contributes to the literature on the impacts of dairy industry development and expansion on local economies and the environment. First, the estimates regarding accumulation of excess manure that is concentrated in certain locations provide insights regarding both environmental risks and economic opportunities for manure-based nutrient product development. Second, the analysis provides baseline estimates regarding the potential opportunities for reducing GHG emissions by changing manure management practices. Since dairy manure is one of major sources of CH_4 N_2O, both of which have higher global warming potential than carbon dioxide CO_2 (EPA, 2022), efforts to reduce such emissions will plausibly be increasingly of interest for policymakers. Regulations are not the only concern for dairy producers regarding the environmental effects, however, since over half of U.S. consumers have expressed concerns regarding the environmental impacts associated with dairy products they buy (Schiano et al., 2020).

In addition, the quantification of nutrient supply-demand balances provides insights regarding the potential economic impact of manure-based fertilizer products and technology development. Industry stakeholders and policymakers have identified several relevant innovations and underutilized practices in manure management. The specific advances pertain to processes that utilize machines that can isolate and aggregate manure nutrients and extract the liquid so that they are more substitutable for synthetic fertilizer-based nutrients in crop production (Chen and Tejeda, 2020). The set of value-added nutrient products created from manure are from innovative techniques commonly referred to as manure-based fertilizer (MBF). Some specialized firms in this industry in other parts of the world are creating “pellets” out of separated manure solids, and the pellets have specified nutrient components and can be spread using existing fertilizer spreaders (e.g., Yushunxin Fertilizer, 2022). However, the development of the MBF industry in the U.S. remains far below its potential, especially in ID. Further development of the MBF industry could plausibly generate substantial economic and environmental benefits and enhance the overall sustainability and performance of the ID dairy industry. The actual impact of MBF is dependent on the quantification of the supply-demand balance of manure-based nutrients, which this thesis provides.

Chapter 2: Current Manure Supply Chain Structure, “Value Added” Processes, and Technologies

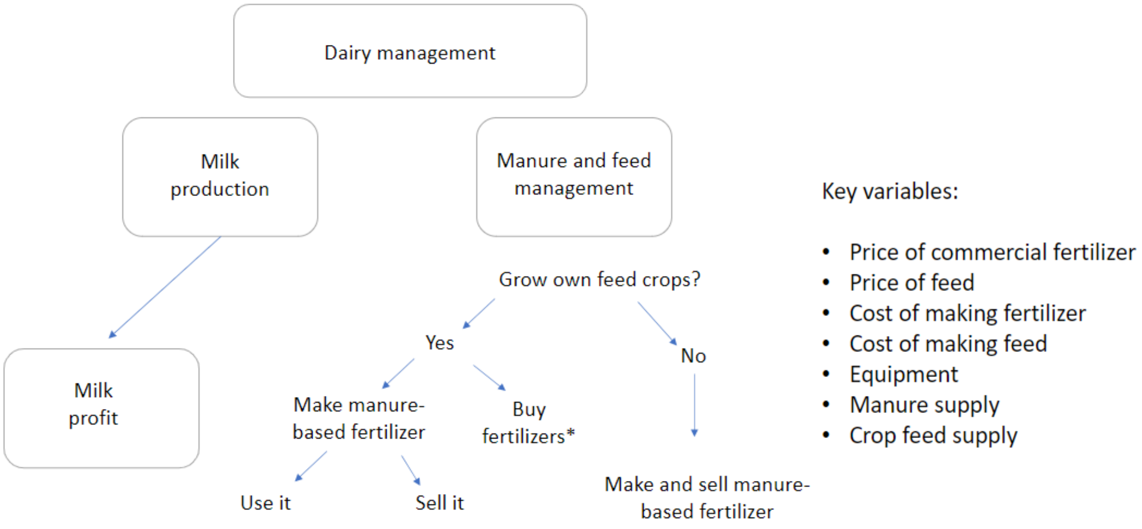
This chapter provides a background characterization of the current dairy manure supply chain in Southern ID. The first portion of the chapter describes the market structure. Specifically, the major agents that participate in the market are introduced, and then descriptions are provided regarding their interactions with each other in the supply and demand of dairy manure. Next, information is provided for value-added processes and techniques that have been developed to transform dairy manure into products that can be sold more easily and across greater distances. Such value-added processes impact nutrient content, cost of production and distribution, and potential usage of dairy manure as a nutrient source among nutrient demand sources such as crop farmers.

Current Dairy Manure Supply Chain Structure

The manure supply chain is comprised of economic agents that produce, gather, and utilize manure for crop fertilization. In the dairy manure supply chain, there are 2 main agents at the beginning and end of the chain: dairies and crop farms. There are also intermediary firms that gather manure from dairies for composting, and their produced compost is then sold to crop farms.

Dairy farms produce manure as a biproduct of milk production (figure 2.1). Raw liquid and solid manure can be processed into manure-based fertilizer (MBF) products, which are typically subproducts that are formed based on liquid and/or solid components of raw manure and re-organized into different forms (e.g., pellets). The processing requires specialized machinery to separate liquids from solids and such processing generates substantial organic residues (Prado et al., 2022).

Crop farms use nutrients, both manure-based and synthetic commercial N, P, and K, for feed and other crop production (figure 2.2). Dairies can use raw manure and/or MBF produced by themselves, depending on their own cropland assets and capacities to produce MBF. They can also buy raw manure, compost, MBF, and synthetic commercial fertilizers from specialized firms.



* Fertilizers include manure-based fertilizers and commercial fertilizers

Figure 2.1 Stylized decision-making framework for dairy managers

Source: Author

Focusing specifically on the interactions among the agents in the dairy supply chain, the feed crops grown on dairies and other farms absorb nutrients from either manure-based or synthetic commercial fertilizer, and dairy cows eat feed crops (figure 2.1). The choices of whether to produce, buy, or sell synthetic commercial fertilizer, MBF, and/or feed crops depends on the relative prices of these products and the production capacity for both producing MBF and feed crops on the dairies.

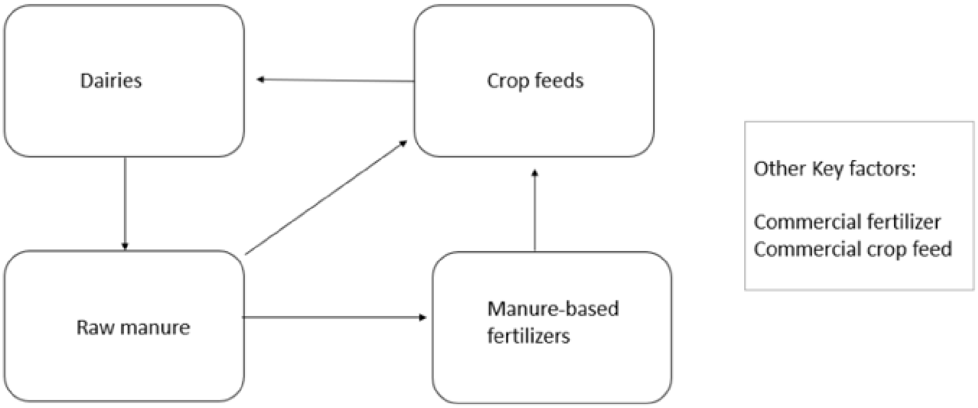


Figure 2.2 Stylized representation of the manure-based fertilizer supply chain

Source: Author

The choice of whether to use synthetic commercial fertilizer price or produce or buy MBF has become increasingly more important in recent years as the prices of synthetic commercial fertilizer have increased dramatically between 2017 and 2022 (table 2.1). This implies that the manure-based nutrients are becoming more valuable. The increases in prices have been particularly pronounced for urea, used to produce N, and potassium chloride, used to produce K. However, the cost of MBF may still be higher than commercial fertilizer, depending on the production capacity of a dairy or specialized firm. To process manure, need to invest in equipment, specialized labor to operate it, and adjustment costs associated with adopting new processes. Equipment needed to produce MBF is likely relatively high given that current technologies are relatively undeveloped, and usage of commercial fertilizers have been commonplace for many years.

Technology and manure-based nutrient separation

There is the production process of MBF (Figure 2.3). Raw manure needs to first be separated into solids and liquid, and then a centrifuge separator can be used to isolate the solids into their primary components (Chen and Tejeda, 2020). The separated solids can be used to produce either compost and manure pellets, which require an additional pelletizer machine (Chen and Tejeda, 2020).

Implementing these processes to produce MBF may be costly. There are fixed and variable costs to consider in the production process. Fixed costs are mainly machinery investments. For a large-scale operation company producing pelletized MBF, a firm would need several separate machines including a fermentation tank, mixture agitator, mechanized sieve, molding machine, dryer, and mechanized packager (abc Machinery, 2022). Investments in this portfolio of machines can be substantial, and range anywhere from $11,000 to $550,000 (Yushunxin Fertilizer, 2022). The variable cost or the manufacturing cost is around $0.03/kg (Hara, 2001). The variable costs primarily consist of machinery depreciation, machinery repairs and maintenance, electricity, labor, and bagging materials (Hara, 2001). Overall, firms typically spend a minimum of $165 per dry ton of pelletized MBF (Hills et al., 2021).

Table 2.1 Commercial fertilizer prices on global markets from 2017 to 2022

Year	**Phosphate rock**	**Urea**	**Potassium chloride**
	($/mt)	($/mt)	($/mt)
2017	89.69	213.88	218.23
2018	87.90	249.45	215.50
2019	87.96	245.28	255.50
2020	76.05	229.10	241.07
2021	123.21	483.21	542.81
2022	266.16	700.02	863.42

Source: World Bank Commodity Price Data. Unit: nominal US dollars

Despite the costs, there are several benefits associated with processing manure. First, processing can change the nutrient composition, so that it is more predictable regarding the content. Specifically, the composting process decreases the amount of N relative to P and K (Lorimor et al., 2004; Butler et al., 2006), and manure solid separation can result in further isolation of individual nutrients. Second, the value-added processes for separating nutrients and pelletizing them allows them to be spread in the crop field more efficiently, and this can reduce nutrient losses (Van Horn et al., 1994). The processed manure is also lighter because there is less water. Pellets are also easier to ship and sell manure over longer distances than raw manure, which can help increase their marketability and business generating potential.

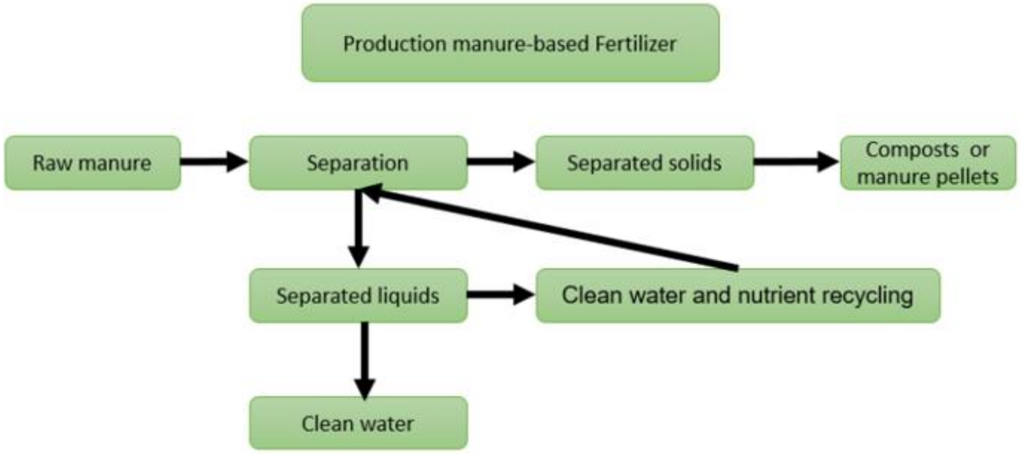


Figure 2.3 Stylized production process for manure-based fertilizer

Source: Author

Chapter 3: Objective, Hypotheses, Methods, and Data

Given the background of a somewhat underdeveloped MBF industry, but increasing value of manure-based nutrients, the objective of this paper was to quantify the supply-demand balance of nutrients for dairy manure in ID in order to provide insights regarding the potential economic and environmental opportunities associated with enhanced development of the MBF industry and such development effects on the current manure supply chain. Prior to implementing the quantification of supply-demand balances for nutrients, several other frameworks were considered for providing a more thorough characterization of the manure supply chain.

There are several methods that were considered, and these included the Huff model (Huff, 1963) and Von Thünen model (see, for example, Altaweel, 2020). The Huff model was considered because it can help demonstrate the relative attractiveness of businesses to attract customers based on their geographical location and size. Specifically, the Huff model was initially developed to estimate the likelihood that potential customers in a given region will patronize a store (Huff, 1963). Alternatively, the Von Thünen model was developed to describe the special distribution of economic activities, the determinants of the value of land, and the associated enterprises that are undertaken on such land areas. In the Von Thünen framework, the land rental rate is determined by the price of land itself, transportation costs, and the relative extent of presence of different industries that are in the region of analysis (Altaweel, 2020). The model is particularly useful for characterizing the geographical distribution of various industries in urban and rural areas.

Given these designs, the Huff and Von Thünen models could potentially be applied to the current case of manure distribution in Southern ID. Specifically, the Huff model could provide estimates of the likelihood of that manure is distributed on surrounding cropland based on the locations of dairies and surrounding cropland, given sufficient data. Dairies that are located closer to crop farmers are more likely a to interact and trade manure with them. In addition, the Von Thünen model can help explain the regional distribution of dairies, cropland, and other land based on land prices, transportation costs of manure and other products, and the locations of other related industries.

However, while relevant and worthwhile to consider, versions of the Huff and Von Thünen models were not developed to characterize the manure supply chain in Southern ID for the purposes of this thesis for several reasons. First, the Huff model is not fully suitable because the choice to use manure by crop land farmers is more complex than whether to visit a store. Thus, estimation of likelihoods of manure trade based solely on distance would not provide accurate estimates of manure trade flows. Additionally, the Von Thünen model works better for describing where industries decide to locate for production rather than for distribution of goods among industries (e.g., exchange of manure between a dairy and crop farm).

Objective

Since other existing frameworks were not viewed as ideal fits for characterizing the manure and compost market in Southern ID, especially in light of existing data limitations, the method employed in this thesis was to obtain baseline quantified supply and demand for manure-based nutrients using local livestock inventory and cropland data and parameters from the literature.

Hypothesis

The background information provided a basic overview of the current state of affairs in the dairy manure supply chain. To summarize, on the supply side, the dairy industry has increased rapidly in the past 30 years in ID. There are many more dairy cattle in ID as of 2022 than in the early 1990s. There are also more cattle, on average, per dairy. The rapid increase in the dairy inventory has greatly increased the associated supply of manure. Meanwhile, nutrient demand by crops may likely have decreased due to changes in cropland, and especially the changes associated with conversion of cropland to other land uses such as housing or commercial development as the population has increased.

Hypothesis 1: Supply-demand balances of manure-based nutrients have increased in ID from 1990 to 2022.

While the dairy cow inventories in ID have kept increasing in the past 30 years, rate of inventory has slowed (figure 3.1). The speed of increase was particularly high before 2007, but has gradually decreased in more recent years.

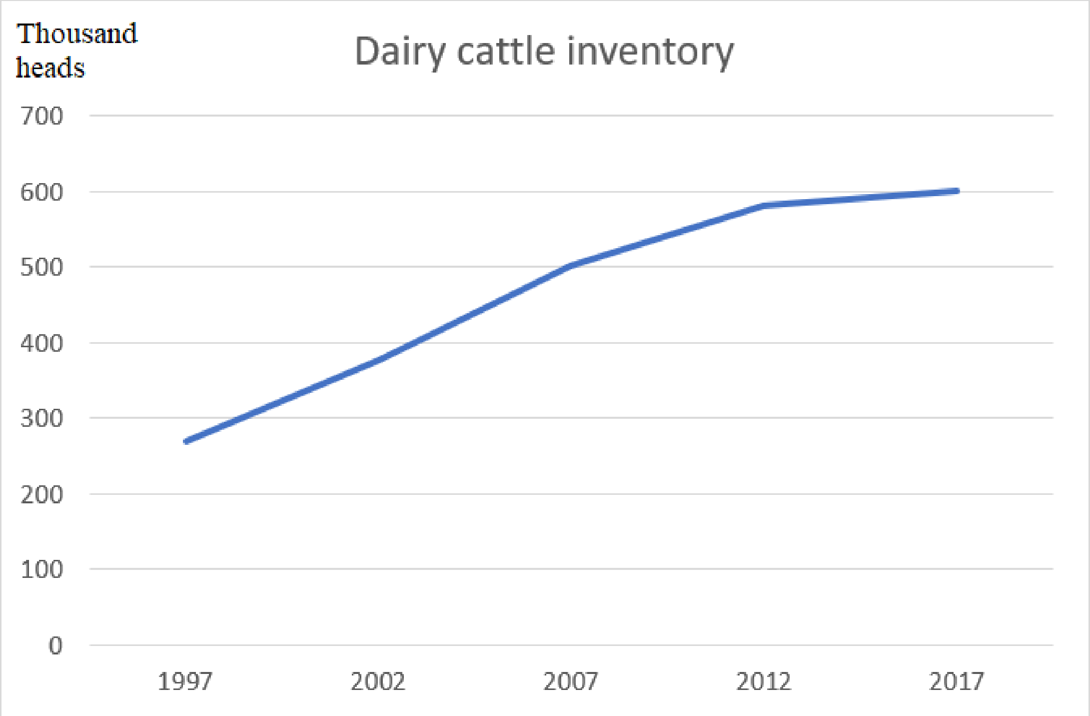


Figure 3.1 Inventory of dairy cattle in Idaho from 1997 to 2017

Source: U.S. Department of Agriculture - National Agricultural Statistics Service

In addition, accumulation over time makes the base number of manure supply-demand balance increase in size, and this change in baseline lead the rate of nutrient accumulation to decline.

Hypothesis 2: Manure nutrient accumulation in ID has increased between 1997 and 2017, but at a decreasing rate.

Method

The quantification method employed in this thesis had several steps. First, the total supply of N, P, and K from manure in ID was estimated for the observation period of 1990 to 2022. Next, demand for N, P, and K as used by crops in ID was estimated for this same period. Then we calculated the supply-demand balances, which are the differences between supply and demand. These calculations are done at the state, region, and county levels.

Additionally, to better discern the regional distribution of manure supply and demand, a more targeted analysis was conducted at the census tract level for 3 major dairy producing counties in Southcentral ID for 1997 – 2017. This spatial analysis utilized GIS and associated calculation tools.

To obtain an understanding of the extent to which manure-based nutrients are used or remain in the environment, the last element of the analysis included estimation of manure-based nutrient accumulation for the same 3 counties and observation period.

Data

The data on the inventory of dairy cows and cattle on feed were obtained from the USDA National Agricultural Statistics Service (NASS). Specifically, for the state level analysis the state-level survey data from 1990 to 2022. We use region and county-level USDA Census data, which are available every five years, to implement the quantification at those analysis levels from 1997 to 2017. To implement the GIS analysis, a unique dataset on dairy farms from ISDA was used. These data include cattle inventory, dairy location, and year of establishment.

To calculate the amount of manure produced per dairy cow, and the associated nutrients per unit of manure, estimates from Lorimor et al. (2004) and Butler et al. (2006) were used.

To calculate nutrient demand, cropland data for the major crops in ID, alfalfa hay, barley, corn silage, corn grain, potato, sugar beets and wheat, were obtained from the USDA. Specifically, state-level survey cropland harvested data were obtained from USDA NASS for 1990 to 2022. The analogous crop area data were also gathered from the USDA Census for 1997 to 2017 for region and county levels. To implement the GIS analysis, crop area data were collected from the USDA CropScape dataset. Since cropland area estimates were needed at census tract level, census tract geographical information from the U.S. Census Bureau were combined with the USDA CropScape data. In addition, N, P, and K demand for each crop is obtained from University of Idaho Enterprise budgets and other Extension bulletins (Eborn & Greenway, 2022, Westerhold, 2019a, 2019b, 2019c, 2019d, 2019e, 2019f).

Summary Statistics for Manure Supply and Demand in ID

Summary statistics of nutrient supply for 1997 to 2017 are included in table 3.1. It is observed that the number of dairy cattle has more than doubled from 1997 to 2017. The inventory of cattle on feed increased at the beginning part of the observation period, but then decreased toward its original level. The inventory of dairy cattle is double the cattle on feed inventory by 2017. The number of replacement cows, which are the cows that are on dairies and are being fed but are not yet counted in USDA statistics, are estimated based on expert consultation. Specifically, replacement dairy cow numbers are equal to 80 percent of total inventory. Replacement cattle on feed are 50 percent of total inventory. The difference in replacement cows is larger than inventory.

Manure nutrient supplies from dairy cattle are different than those from cattle on feed. Dairy cattle produce more nutrients per unit than do cattle on feed. Similarly, compost from dairy cattle contains more nutrients than that from cattle on feed. Lastly, nutrients from manure contain relatively less N and more P and K.

Table 3.2 shows the nutrient demand for major crops in ID from 1997 to 2017. Cropland area for most crops was stable during the period, with corn being the notable exception. Cropland area for corn silage and corn grain has more than doubled over the observation period. In addition, nutrient demand per acre is similar for most crops, but potatoes demand relatively more nutrients than the other crops.

Table 3.1 Summary statistics of manure and compost sources in ID from 1997 to 2017

	Cattle on feed inventory	Cattle on feed replacement	Dairy cattle inventory	Dairy cattle replacement
Number of cattle (thousand heads)				
1997	270	135	268	214
2002	335	168	377	302
2007	265	133	502	402
2012	240	120	581	465
2017	270	135	600	480
Manure nutrient per cattle (lbs. per day)				
	Cattle on feed		**Dairy**	
N from manure	0.35		0.87	
P from manure	0.18		0.45	
K from manure	0.29		0.49	
Manure per cattle	92		133	
Compost nutrient per cattle (lbs. per day)				
	Cattle on feed		**Dairy**	
N from compost	0.23		0.53	
P from compost	0.51		0.60	
K from compost	0.64		0.70	

Source: The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. Replacement cattle on feed are 50 percent of inventory. Manure production and nutrient data are from Lorimor et al., (2004). Compost nutrient data is from Butler et al., (2006), which is estimated by manure production per cattle, and weight of composts decreases 50% from raw manure (Keena, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

Table 3.2 Summary statistics of area harvested and nutrient needs for major crops in ID from 1990 to 2017

	Alfalfa	Barley	Corn silage	Corn grain	Sugar beet	Wheat	Potato
Harvest area (thousand acres)							
1997 harvest area	1000	750	80	43	197	1430	398
2002 harvest area	1170	710	140	45	210	1090	373
2007 harvest area	1150	550	210	105	167	1175	349
2012 harvest area	1040	600	220	135	182	1243	344
2017 harvest area	1060	510	220	115	166	1109	310
Nutrient demand per acre (lbs. per year)							
Demand for N per acre	20	90	75	70	125	150	310
Demand for P per acre	95	45	30	30	80	50	285
Demand for K per acre	55	0	50	50	65	0	255

Source: The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Chapter 4: Estimates of Nutrient Supply, Demand, and Supply-Demand Balances at the State, Regional, and County-Levels

In this chapter, the calculation method for obtaining nutrient supply-demand balance estimates is described. Next, an assessment was made regarding the usability of the cattle on feed data for as part of manure nutrient supply based on differences in the nature of the cattle on feed data. The final portion of the chapter includes estimates of nutrient supply, demand, and supply-demand balances at the state, region, and county-level.

Calculation Method of Nutrient Supply and Demand

To calculate total annual nutrient supply, the total nutrient supply was first divided into manure and compost supply. Equation (1) demonstrates how manure or compost nutrient supply was estimated. It is equal to the daily nutrient supply per cattle times cattle number and other coefficients. Daily data is transformed into annual by multiplying the daily values by 365. Cattle inventory multiplied by 1.8 adjusts for cattle replacements, as was determined based on expert opinions. Separate calculations were implemented for N, P, and K, respectively. It was assumed that the ratio of manure and compost is 1:1, also based on expert opinion. The final step in the supply calculation was to add nutrient supply from manure and compost together to get total supply.

$$Annual\ nutrient\ supply = \frac{Daily\ nutrient}{cattle} * \ Cattle\ inventory\ * \ 365 * 1.8 \tag{1}$$

To calculate total annual nutrient demand, nutrient demand for each crop per acre were obtained. These annual nutrient demand per crop area values were then multiplied by the annual crop area estimates (equation 2). This calculation was implemented for each of N, P and K for each of the major crops in ID: alfalfa, barley, corn silage, corn grain, sugar beets, wheat, and potato. Total annual demand for each nutrient is equal to the summation of the individual nutrient demand values for each of the major crops.

$$Annual\ nutrient\ demand = \frac{Annual\ nutrient}{crop\ area} * \ Crop\ area \tag{2}$$

Measurement of Dairy Nutrient Supply and Demand

In this thesis, manure nutrient supply from dairy cattle emerged as the primary focus, in part due to data issues with other sources of manure. Specifically, the analysis was initiated with the prospects to include data for all Concentrated Animal Feeding Operations, including both dairy cattle and cattle on feed. However, several issues emerged.

First, there is no data for county-level cattle on feed in the 1997 census. Thus, to make estimates for cattle on feed manure supply for 1997 required an assumption that the ratio of dairy cow and cattle on feed was constant between 1997 and 2002. Additionally, and more prominently, in some counties, there are some missing values for cattle on feed values. This is likely the case because the number of observations was too small for the USDA to report.

These data issues caused there to be large differences between state-level survey data and county-level census data for cattle on feed inventories. Table 4.1 shows the difference between survey and census data in cattle on feed and dairy cattle. The difference in cattle on feed is around 150 thousand head, which is more than half of the inventory (table 3.1). In contrast, the difference in dairy cattle is relatively small.

Thus, if the number of cattle on feed inventory data for implementation of the calculation of manure supply in equation 1, there would be large differences in nutrient supply estimates between those obtained from the state-level survey data and summation of county-level census data.

Therefore, the cattle on feed data were excluded from the analysis, and focus is placed on manure supply dairy cattle only.

Table 4.1 Difference in inventory of dairy cows and cattle on feed between state-level survey data and summation of county-level Census data

Year	Cattle on feed (thousand head)	Dairy cattle (thousand head)
1997	172	4
2002	205	-12
2007	133	-33
2012	128	4
2017	164	0

Source: The data of cattle inventory is from USDA-NASS.

Similar data quality checks were implemented for nutrient demand data, and there is little difference identified from the data sources. One technical note, however, is that the nutrient demand coefficients for soft white winter wheat were used rather than spring wheat due to data availability.

Table 4.2 shows the difference in nutrient demand between state-level survey data and the summation of county-level census data. Most values of the difference between survey data and census data are non-negative. However, in 2017, differences in N and P are negative. Overall, the absolute value difference in 2017 is quite small. In general, the impact of the difference in usage of state or county level estimates for nutrient demand is limited, and so the demand side analysis proceeded as initially planned.

Table 4.2 Percentage difference in N, P, and K demand between state-level survey data and summation of county-level Census data

Year	N	P	K
1997	0%	2%	10%
2002	0%	6%	15%
2007	4%	9%	19%
2012	6%	8%	19%
2017	-4%	-2%	4%

Source: The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

State-level Dairy Nutrient Supply and Demand

At the state-level, ID dairy manure nutrient supply has increased rapidly over the past 30 years. Table 4.3 shows the state-level annual average supply nutrients. The total amount of nutrient supply increased over the full period. By the end of the observation, the manure supply more than doubled. Annual N supply is near 300 million pounds at the state level by 2022.

Table 4.4 shows the annual average demand of nutrients. It is observed that, in contrast to supply, state-level nutrient demand has decreased slightly in the past 30 years. The decrease is about 15% of the total demand. The demand for N is below 400 million pounds per year at the state level, while it was over 400 million pounds per year between 1990 and 1994.

Table 4.3 State-level annual average supply of dairy manure, compost, and their associated N, P, and K from 1990 to 2022

Period	N supply (million lbs.)	N available for crops (million lbs.)	P supply (million lbs.)	K supply (million lbs.)
1990-1994	84	17	62	71
1995-1999	121	24	90	102
2000-2004	171	34	128	145
2005-2009	229	46	171	194
2010-2014	262	52	195	222
2015-2019	274	55	204	232
2020-2022	296	59	221	251

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al., (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al., (2004). Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs. N available for crops is equal to 80% of total N supply based on Moore et al. (2015) and expert opinions.

Table 4.4 State-level annual average demand for N, P, and K from 1990 to 2022

Period	N demand (million lbs.)	P demand (million lbs.)	K demand (million lbs.)
1990-1994	445	327	185
1995-1999	455	339	193
2000-2004	414	326	191
2005-2009	399	308	179
2010-2014	410	306	178
2015-2019	382	292	174
2020-2022	377	286	171

Source: The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

This can be the result of changes in agricultural structure in ID. On the one hand, the increase in the number of dairy cows has influenced the composition of cropland and portfolio of crops grown in ID, with more corn and less alfalfa hay. These changes in crops grown have impacted the nutrient demand. In addition, the growth in the urban area and population also requires cropland conversion to land for housing and other industries. The reduction in planted cropland translates into a direct reduction in nutrient demand.

When the nutrient supply and demand estimates are different (table 4.5), the obtained nutrient supply-demand balances show that there has been a shift from negative toward positive in the past 30 years. The balances are substantially negative for N and P in the 1990s but have moved toward zero in recent years. The balance for K was negative in 1990, but because positive by the early 2000s. The obtained supply-demand estimates that are either less negative or more positive from between the beginning to the end of the observation period is consistent with the observed increase in the N, P, K supply and decrease in demand. This implies that, at least in theory, ID could meet its full demand for K and nearly all its demand for N and P from dairy manure nutrients.

Table 4.5 State-level annual average dairy supply-demand balances for N, P, and K from 1990 to 2022

Period	N supply-demand balance (million lbs.)	P supply-demand balance (million lbs.)	K supply-demand balance (million lbs.)
1990-1994	-362	-265	-114
1995-1999	-334	-248	-90
2000-2004	-243	-199	-46
2005-2009	-170	-137	14
2010-2014	-148	-111	44
2015-2019	-109	-87	58
2020-2022	-80	-65	80

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

The next portion of the analysis includes more detailed estimates of nutrient demand for each individual crop. Table 4.6-4.14 shows nutrient demand for alfalfa, barley, corn silage, corn grain, potatoes, sugar beets, and wheat, respectively. Demand for N is highest for wheat and potatoes. Demand for P and K is greatest for alfalfa and potatoes. In a broad sense, nutrient demand for most crops has not changed much in the past 30 years. The main exceptional case is corn for which nutrient demand has tripled over the observation period. However, the absolute amount of nutrients demanded by corn is still relatively small and so is not large enough to substantially impact overall supply-demand balances for total nutrients.

Table 4.6 State-level annual average demand for N, P, and K for alfalfa hay from 1990 to 2022

Period	N demand (million lbs.)	P demand (million lbs.)	K demand (million lbs.)
1990-1994	20	94	55
1995-1999	21	102	59
2000-2004	23	110	64
2005-2009	23	107	62
2010-2014	22	102	59
2015-2019	20	97	56
2020-2022	20	96	56

Source: The data of crop land is from USDA-NASS. Alfalfa nutrient demand data comes from Westerhold, (2019a).

Table 4.7 State-level annual average demand for N, P, and K for barley from1990 to 2022

Period	N demand (million lbs.)	P demand (million lbs.)	K demand (million lbs.)
1990-1994	68	34	0
1995-1999	66	33	0
2000-2004	63	31	0
2005-2009	50	25	0
2010-2014	49	25	0
2015-2019	49	25	0
2020-2022	46	23	0

Source: The data of crop land is from USDA-NASS. Barley nutrient demand data comes from Westerhold, (2019d).

Table 4.8 State-level annual average demand for N, P, and K for corn grain from 1990 to 2022

Period	**N demand (million lbs.)**	**P demand (million lbs.)**	**K demand (million lbs.)**
1990-1994	3	1	2
1995-1999	3	1	2
2000-2004	4	2	3
2005-2009	5	2	4
2010-2014	8	3	6
2015-2019	8	3	6
2020-2022	8	4	6

Source: The data of crop land is from USDA-NASS. Corn grain nutrient demand data come from Westerhold, (2019c).

Table 4.9 State-level annual average demand for N, P, and K for corn silage from 1990 to 2022

Period	**N demand (million lbs.)**	**P demand (million lbs.)**	**K demand (million lbs.)**
1990-1994	5	2	3
1995-1999	6	2	4
2000-2004	10	4	7
2005-2009	15	6	10
2010-2014	17	7	11
2015-2019	17	7	11
2020-2022	18	7	12

Source: The data of crop land is from USDA-NASS. Corn silage nutrient demand data come from Westerhold, (2019b).

Table 4.10 State-level annual average demand for N, P, and K for potatoes from 1990 to 2022

Period	N demand (million lbs.)	P demand (million lbs.)	K demand (million lbs.)
1990-1994	122	112	100
1995-1999	125	115	103
2000-2004	114	105	94
2005-2009	101	93	83
2010-2014	99	91	81
2015-2019	98	90	81
2020-2022	94	86	77

Source: The data of crop land is from USDA-NASS. Potato nutrient demand comes from Eborn and Greenway, (2022).

Table 4.11 State-level annual average demand for N, P, and K for sugar beets from 1990 to 2022

Period	N demand (million lbs.)	P demand (million lbs.)	K demand (million lbs.)
1990-1994	25	16	13
1995-1999	25	16	13
2000-2004	24	16	13
2005-2009	20	13	10
2010-2014	22	14	11
2015-2019	21	13	11
2020-2022	21	14	11

Source: The data of crop land is from USDA-NASS. Sugar beet nutrient demand data come from Westerhold, (2019e).

Table 4.12 State-level annual average demand for N, P, and K for wheat from 1990 to 2022

Period	N demand (million lbs.)	P demand (million lbs.)	K demand (million lbs.)
1990-1994	203	68	0
1995-1999	208	70	0
2000-2004	175	58	0
2005-2009	186	62	0
2010-2014	194	65	0
2015-2019	170	56	0
2020-2022	169	56	0

Source: The data of crop land is from USDA-NASS. Wheat nutrient demand data comes from Westerhold, (2019f).

Region-level Dairy Nutrient Supply and Demand

The state-level analysis does not reflect the substantial regional differences in agriculture in ID. The dairy industry is concentrated in Southcentral and Southwest ID. There are relatively few dairy farms in North ID and Eastern ID. Thus, manure nutrient supply can be much higher in Southcentral and Southwest ID than other parts of the state. Meanwhile, the trend for demand can be different due to different cropping systems. Additionally, the Rocky Mountain region in the central part of the state separates into different regions, and not much agricultural production occurs there. Thus, it is expected that there are substantial regional differences in manure nutrient supply and demand.

Table 4.13 shows region-level supply-demand balances between 1997 and 2017. It is observed that the nutrient balances in East and North ID have not changed much over this period. However, the nutrient balances in Southcentral and Southwest ID increased a great amount. Southwest and Southcentral ID shifted from being net demanders to suppliers for N and P. The differences in the regional balances imply that North and East ID could potentially “import” manure-based nutrients from South Central and Southwest ID to meet the nutrient demand in those regions.

In North and East ID, the nutrient supply-demand balances increased slightly between 1997 and 2017. In East ID, supply-demand balances for N increased from -215 to -189 million pounds. In North ID, supply-demand balances for N increased from -71 to -58 million pounds. Changes in P and K are smaller than those for N.

In contrast, for Southcentral ID and Southwest ID, the nutrient balance increases were quite large. Supply-demand balances for N in Southcentral ID increased from -32 million pounds in 1997 to 113 million pounds in 2017. The increase in N supply-demand balance in Southwest ID increased from -19 to 20 million pounds from 1997 to 2017. The positive balances for N in Southcentral and Southwest ID are close to the N demand from other parts of ID. As was the case for the other regions, the change in P and K in Southcentral and Southwest ID is smaller than N.

Table 4.13 Region-level dairy supply-demand balances for N, P, and K from 1997 to 2017

Year	Region	N supply-demand balance (million lbs.)	P supply-demand balance (million lbs.)	K supply-demand balance (million lbs.)
1997	EAST	-215	-155	-74
2002	EAST	-189	-146	-74
2007	EAST	-166	-129	-62
2012	EAST	-184	-139	-66
2017	EAST	-189	-146	-74
1997	NORTH	-71	-30	-3
2002	NORTH	-69	-29	-2
2007	NORTH	-76	-30	-2
2012	NORTH	-69	-28	-3
2017	NORTH	-58	-25	-3
1997	SOUTH CENTRAL	-32	-27	16
2002	SOUTH CENTRAL	26	10	52
2007	SOUTH CENTRAL	81	49	92
2012	SOUTH CENTRAL	100	67	112
2017	SOUTH CENTRAL	113	74	120
1997	SOUTHWEST	-19	-23	-6
2002	SOUTHWEST	5	-10	6
2007	SOUTHWEST	23	5	22
2012	SOUTHWEST	24	9	26
2017	SOUTHWEST	20	5	23

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

County-level Dairy Nutrient Supply and Demand

Although the regional level estimates were insightful, more detailed information from county-level data can provide insights regarding the extent of concentration of either manure supply or nutrient demand in each region. Such estimates can be particularly important for demonstrating the impact on nutrient supply and demand for counties that have a substantial amount of dairy production.

Table 4.14 shows county-level average annual supply-demand balance in East Idaho for 1997 to 2017. It is observed that the average nutrient supply-demand balance is negative or around 0 for most counties for the full observation period. However, there are some substantial nutrient deficits in some counties, including Bingham, Bonneville, Caribou, Fremont, Jefferson, Madison, and Power counties. The N supply-demand balance in some counties was negative 20 million pounds per year. These relatively large negative values can be explained by a substantial amount of crop production with relatively little dairy production. On the other hand, nutrient supply-demand balance in other counties is around 0, including Clark and Custer counties. These counties are predominantly comprised of mountainous and rangeland areas.

In North ID, the average nutrient supply-demand balance in some counties is negative, and it is around 0 for other counties (Table 4.15). Counties with substantial nutrient demand include Latah, Lewis, Nez Perce, and Idaho counties, which are prominent wheat producing states. The N supply-demand balance in some counties was below negative 10 million pounds per year. The absolute values of the estimated nutrient balances in North Idaho were smaller than those for Eastern ID. This is explained in part by nutrient demand being smaller in North ID compared with Eastern ID. In addition, the balance values for P and K are smaller than those for N. The balance for K is near 0. In addition, nutrient supply-demand balance in other counties is around 0, even for N, for several counties including Bonner and Shoshone. These counties are near nationally protected wilderness areas.

Table 4.14 Average dairy supply-demand balance for N, P, and K for counties in Eastern Idaho from 1997 to 2017

Year	County	N supply-demand balance (million lbs.)	P supply-demand balance (million lbs.)	K supply-demand balance (million lbs.)
1997-2017	BANNOCK	-7	-5	-2
1997-2017	BEAR LAKE	-1	-3	-1
1997-2017	BINGHAM	-43	-32	-19
1997-2017	BONNEVILLE	-24	-16	-8
1997-2017	BUTTE	-3	-4	-2
1997-2017	CARIBOU	-13	-8	-2
1997-2017	CLARK	-1	-1	0
1997-2017	CUSTER	0	-2	-1
1997-2017	FRANKLIN	1	0	2
1997-2017	FREMONT	-19	-13	-7
1997-2017	JEFFERSON	-15	-15	-7
1997-2017	LEMHI	0	-1	0
1997-2017	MADISON	-19	-13	-7
1997-2017	ONEIDA	-6	-4	-1
1997-2017	POWER	-27	-15	-8
1997-2017	TETON	-5	-4	-1

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

In contrast to North and Eastern ID, there is substantial heterogeneity in Southcentral ID regarding supply-demand balances across counties (Table 4.16). In some counties the average nutrient supply-demand balance is far above 0, while in others they are around 0.

The major nutrient supplying counties are Cassia, Gooding, Jerome, Lincoln, and Twin Falls. Gooding County is especially notable with an annual average supply-demand balance for N above 50 million pounds. The large positive values are associated with the development of the dairy industry in the counties over the observation period. In contrast, in other counties such as Blaine and camas, nutrient supply-demand balance is around 0. These counties have a larger amount of mountain and forest areas and less cropland and fewer dairies.

Table 4.15 Average dairy supply-demand balance for N, P, and K for counties in North Idaho from 1997 to 2017

Year	**County**	**N supply-demand balance (million lbs.)**	**P supply-demand balance (million lbs.)**	**K supply-demand balance (million lbs.)**
1997-2017	BENEWAH	-5	-1	0
1997-2017	BONNER	0	0	0
1997-2017	BOUNDARY	-2	-2	0
1997-2017	CLEARWATER	-1	0	0
1997-2017	IDAHO	-12	-5	-1
1997-2017	KOOTENAI	-2	-1	0
1997-2017	LATAH	-15	-5	0
1997-2017	LEWIS	-13	-4	0
1997-2017	NEZ PERCE	-16	-5	0
1997-2017	SHOSHONE	0	0	0

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

In Southwestern ID, the average nutrient supply-demand balances are slightly above 0 in some counties, while the number is around 0 in other counties (Table 4.17). Positive nutrient supply-demand balances are observed for Ada, Canyon, and Owyhee counties. The supply-demand balances for N are near 5 million pounds per year in these counties. While the dairy sector provides more nutrient supply in the counties, the scale of supply is relatively smaller than was observed in Southcentral ID. In addition, in other counties such as Boise and Gem, estimated nutrient supply-demand balances were around 0, including Boise County and Gem counties. These counties are comprised of mountainous areas that do not have much crop production.

Table 4.16 Average dairy supply-demand balances for N, P, and K for counties in Southcentral Idaho from 1997 to 2017

Year	County	N supply-demand balance (million lbs.)	P supply-demand balance (million lbs.)	K supply-demand balance (million lbs.)
1997-2017	BLAINE	-1	-2	-1
1997-2017	CAMAS	-2	-5	-2
1997-2017	CASSIA	-8	-4	5
1997-2017	GOODING	52	38	45
1997-2017	JEROME	19	13	19
1997-2017	LINCOLN	6	3	6
1997-2017	MINIDOKA	-20	-15	-8
1997-2017	TWIN FALLS	12	6	14

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

While the previous analysis of the averages over the course of the full period from 1997 to 2017 was helpful for describing differences across counties, some counties have undergone substantial changes in their supply-demand balances over time. Table 4.18 shows county-level supply-demand balances for several counties, including Cassia, Gooding, Twin Falls, Elmore, and Owyhee, for which changes were particularly notable from 1997 to 2017. It is observed that all counties shifted from net nutrient demanders to suppliers, except for Gooding County which remained a net for the full period. The N supply-demand balance in Gooding County was estimated to be above 70 million pounds in 2012. In some countries, supply-demand balances increased by over 40 million pounds during the observation period. This reflects how substantial expansion of the dairy industry in some counties has greatly increased the amount of manure-based nutrient, and also that the largest changes in manure supply-demand balances have occurred in relatively few counties where dairy industry concentration has been observed.

Table 4.17 Average dairy supply-demand balances for N, P, and K for counties in Southwest Idaho from 1997 to 2017

Year	**County**	**N supply-demand balance (million lbs.)**	**P supply-demand balance (million lbs.)**	**K supply-demand balance (million lbs.)**
1997-2017	ADA	5	3	5
1997-2017	ADAMS	0	-1	0
1997-2017	BOISE	0	0	0
1997-2017	CANYON	3	2	6
1997-2017	ELMORE	-1	-3	0
1997-2017	GEM	0	-1	0
1997-2017	OWYHEE	3	0	2
1997-2017	PAYETTE	2	1	2
1997-2017	VALLEY	0	0	0
1997-2017	WASHINGTON	-2	-3	-2

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data are from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

Table 4.18 Dairy supply-demand balances for N, P, and K for counties with major change in Idaho from 1997 to 2017

Year	**County**	**N supply-demand balance (million lbs.)**	**P supply-demand balance (million lbs.)**	**K supply-demand balance (million lbs.)**
1997	CASSIA	-29	-19	-8
2002	CASSIA	-23	-15	-5
2007	CASSIA	-4	-3	8
2012	CASSIA	6	6	15
2017	CASSIA	8	8	18
1997	GOODING	20	13	18
2002	GOODING	47	34	40
2007	GOODING	57	41	48
2012	GOODING	72	54	63
2017	GOODING	67	50	57
1997	TWIN FALLS	-7	-6	2
2002	TWIN FALLS	8	3	11
2007	TWIN FALLS	18	11	18
2012	TWIN FALLS	15	9	17
2017	TWIN FALLS	27	17	25
1997	ELMORE	-9	-8	-5
2002	ELMORE	-7	-8	-6
2007	ELMORE	1	-2	1
2012	ELMORE	5	2	5
2017	ELMORE	2	0	4
1997	OWYHEE	-4	-6	-3

cont. Table 4.18

2002	OWYHEE	1	-2	1
2007	OWYHEE	6	2	5
2012	OWYHEE	6	2	5
2017	OWYHEE	6	1	5

Source: Manure nutrients are estimated by cattle inventory, replacement, and unit nutrients of manure and compost. The data of cattle inventory is from USDA-NASS. The replacement cows are estimated based on expert consultation. Replacement dairy cows equal to 80 percent of inventory. We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). The data of crop land is from USDA-NASS. We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cow with 1000 and 1400 lbs.

Chapter 5: Calculate Supply-Demand Balance at Census Tract Level from 2007 to 2022

This chapter includes more detailed descriptions of the method and scope of the GIS-based analysis used for estimation of manure nutrient supply-demand balances at the census tract level. A background map was constructed, which shows the evolution of dairy industry development in 3 major dairy producing counties: Gooding, Jerome, and Twin Falls. Lastly, maps and tables were constructed to show how the manure nutrient supply-demand balances differ across space (maps) and have changed over time from 2007 to 2022 (tables). Lastly, there is a summary discussion regarding the potential implications of the analysis.

GIS Analysis of Supply-Demand Balance at the census tract level

To start with, we defined the scope of census tract level supply-demand balances to include several counties that are nearby in geography but that have different characteristics regarding agricultural production. We focus on Gooding, Twin Falls, and Jerome counties. Gooding County is the largest dairy producing county in ID. We also include its neighbors, Twin Falls and Jerome counties, which also have a substantial amount of dairy and crop production. In the counties, cropland and dairy production data are combined and analyzed at the census tract level.

The GIS analysis of calculating the manure supply-demand balances at the census tract level was done via the following steps. The first step was to locate dairy farms by the longitude/latitude coordinates that corresponded with the address information included in the ISDA dairy dataset. One dairy farm was dropped from the analysis because the coordinates associated with its address were outside the county borders per Google maps. Once the dairies locations were specified, their associated census tracts were identified. Next, since the utilized dataset had information on the year of establishment, it was possible to determine the inventory of dairy cattle in each census tract for each year of analysis of 2007, 2012, 2017, 2022. After the data were aligned within the census tracts, the calculation method described in chapter 4 was employed to obtain estimates of nutrient supply for N, P, and K. For demand, the CropScape data set, which are spatial area estimates of cropland, were combined with the census tract data. Next, an area harvested estimate was obtained for each crop and census tract combination. Lastly, by the method described in chapter 4, the area estimates were multiplied by nutrient demand per acre for each crop. Note that the USDA CropScape data includes only a composite “corn” layer, but that there are slightly different nutrient demand coefficients for corn silage and corn grain in the calculation method in chapter 4. Thus, we choose to use the coefficients for corn silage because more corn silage is grown than corn grain . To obtain the supply-demand balances in each census tract, we sum up the nutrient demands across all crops then and subtract those from the calculated supplies.

Background of Supply-Demand Balance at Census Tract Level Analysis

A background map of the GIS analysis region is included in figure 5.1. It shows the spatial distribution of dairy farms and cropland in Gooding, Jerome, and Twin Falls counties in 2007. It is observed that dairy farms are concentrated near the Snake River, which can provide water that animals can consume and that can be used for crop irrigation.

In addition, dairy farms are more concentrated in Gooding than in the other counties. Some dairies have are larger with over 1000 cows, while others are smaller with around 100 cows. Cropland was divided into 5 major categories in the area: potatoes, sugar beets, corn, alfalfa hay, and small grains (including wheat and barley). There is a substantial amount of corn and alfalfa hay, which are primary feed crops, grown in the acreage near the dairy farms. However, other crops, such as potatoes and sugar beets, are grown relatively further away from the dairies and the Snake River.

As described earlier, the dairy industry grew rapidly between 2007 and 2022 statewide. The differences in figures 5.1 and 5.2, which is the analogous one to 2007 for 2002, show that this is also the case in the GIS research area. The number of dairy farms increased substantially in all 3 counties. In addition, dairy farms are much larger in 2022 than in 2007. Most dairy farms are still located near the Snake River as of 2022, but there are also more that are relatively far from the river. In addition, there is a little change in cropland, but some increases in corn and small grain were observed.

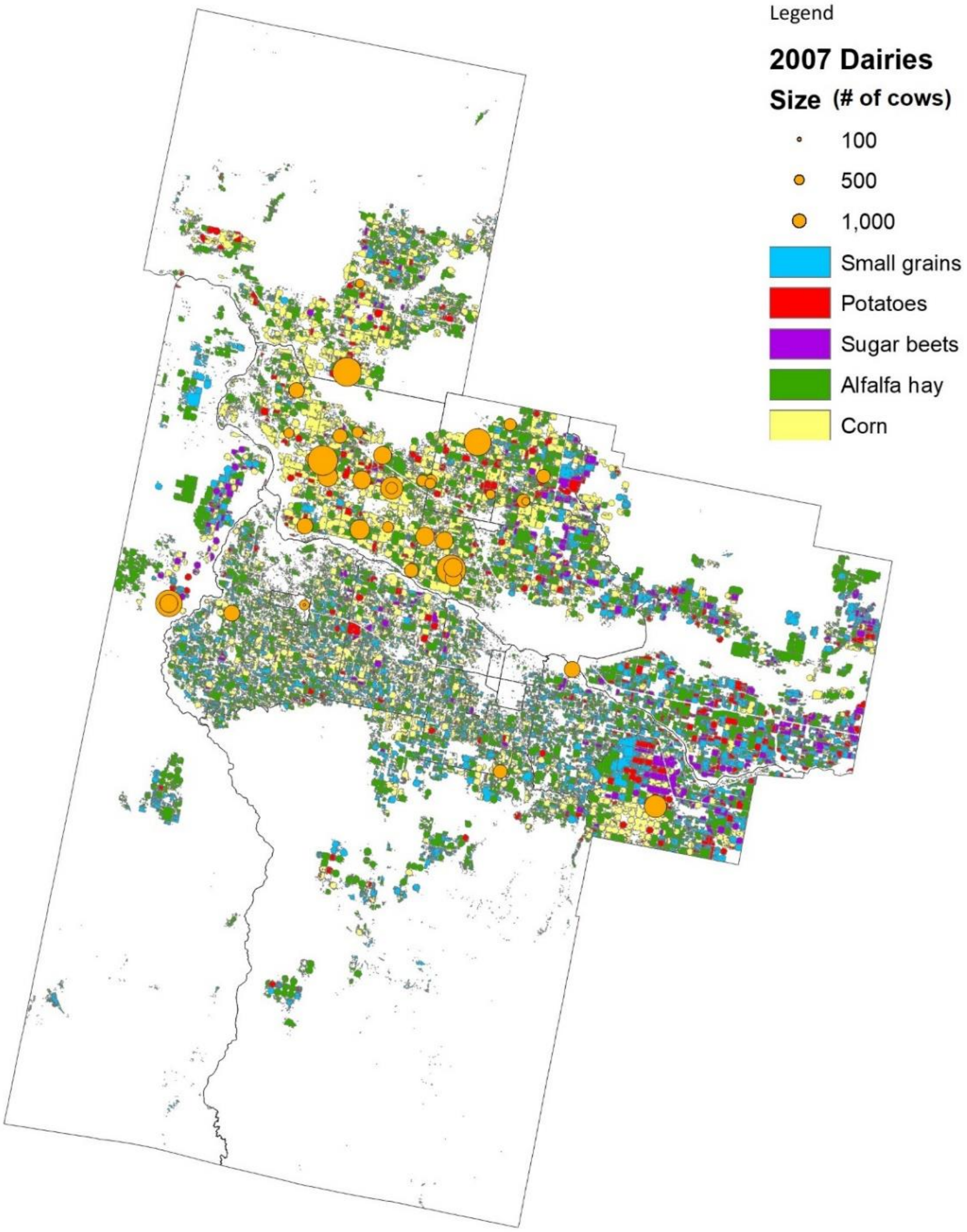


Figure 5.1 Map of dairy farms and cropland in Gooding, Jerome, and Twin Falls Counties in 2007

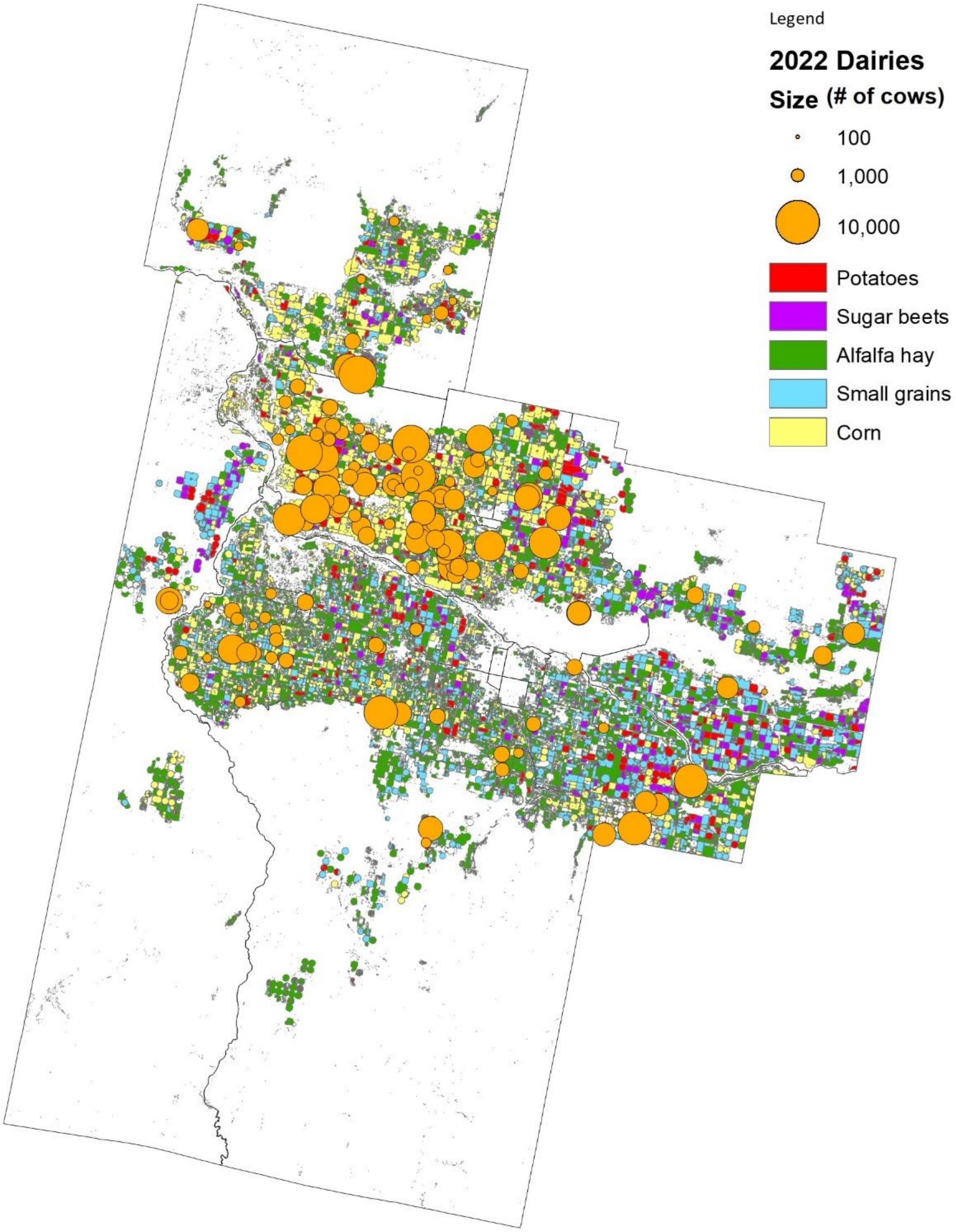


Figure 5.2 Map of dairy farms and cropland in Gooding, Jerome, and Twin Falls Counties in 2022

Supply-Demand Balance for N at Census Tract Level from 2007 to 2022

The nutrient supply-demand balances in the census tracts were mapped within GIS using the "Symbology" toolset. The spatial distributions and evolution in the balances over time for the different show similar distribution patterns for P and K, so N and P were used as examples. Figure 5.3 shows the supply-demand balance for N in 2007. The red color represents a nutrient surplus, or relatively high positive supply-demand balance, while the green color is indicative of a nutrient deficiency or negative balance. The yellow color is associated with the nutrient supply-demand balances near zero.

Figure 5.3 shows that there are major differences in the N supply-demand balance in these census tracts. To start, red colors are concentrated near the middle of the map. This shows that there is a large N surplus along the Snake River where dairy farms are located. In addition, there are large green areas in the south and east part of the map, where farmers grow other crops but there are relatively few dairies. Other areas are yellow, which means that they are more balanced between dairy nutrient supply and crop demand.

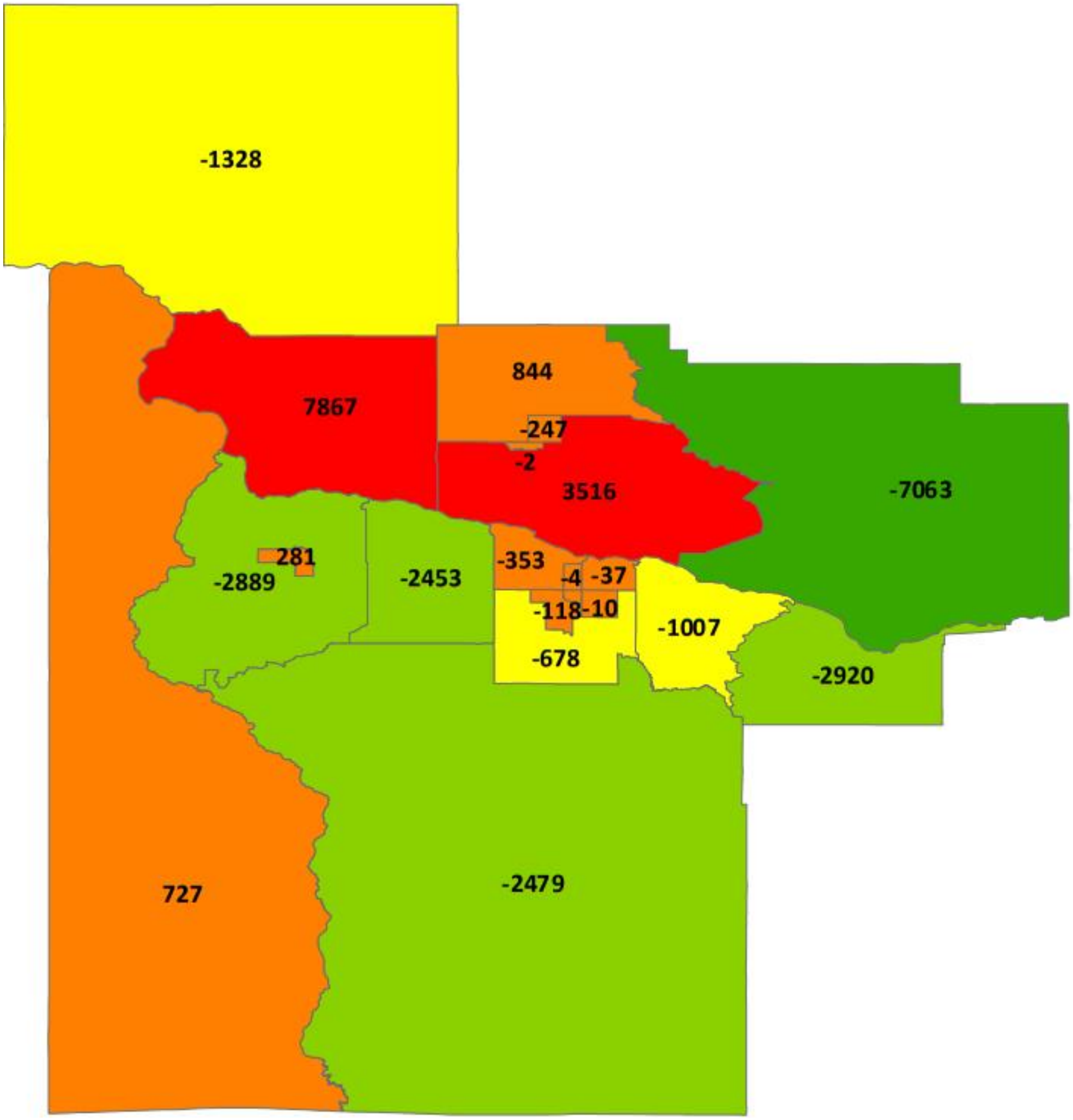


Figure 5.3 Nutrient supply-demand balance for N for census tracts in Gooding, Jerome, and Twin Falls Counties in 2007

Figure 5.4 shows the analogous map for 2012. It is observed there was a large increase in nutrient surplus between 2007 and 2012, and the increases were not evenly distributed (comparing figures 5.3, 5.4). Increases in some census tracts were more than 3 times. The largest increases were observed in census tracts along the Snake River. In the east and south parts of the map, the nutrient balance did not change much.

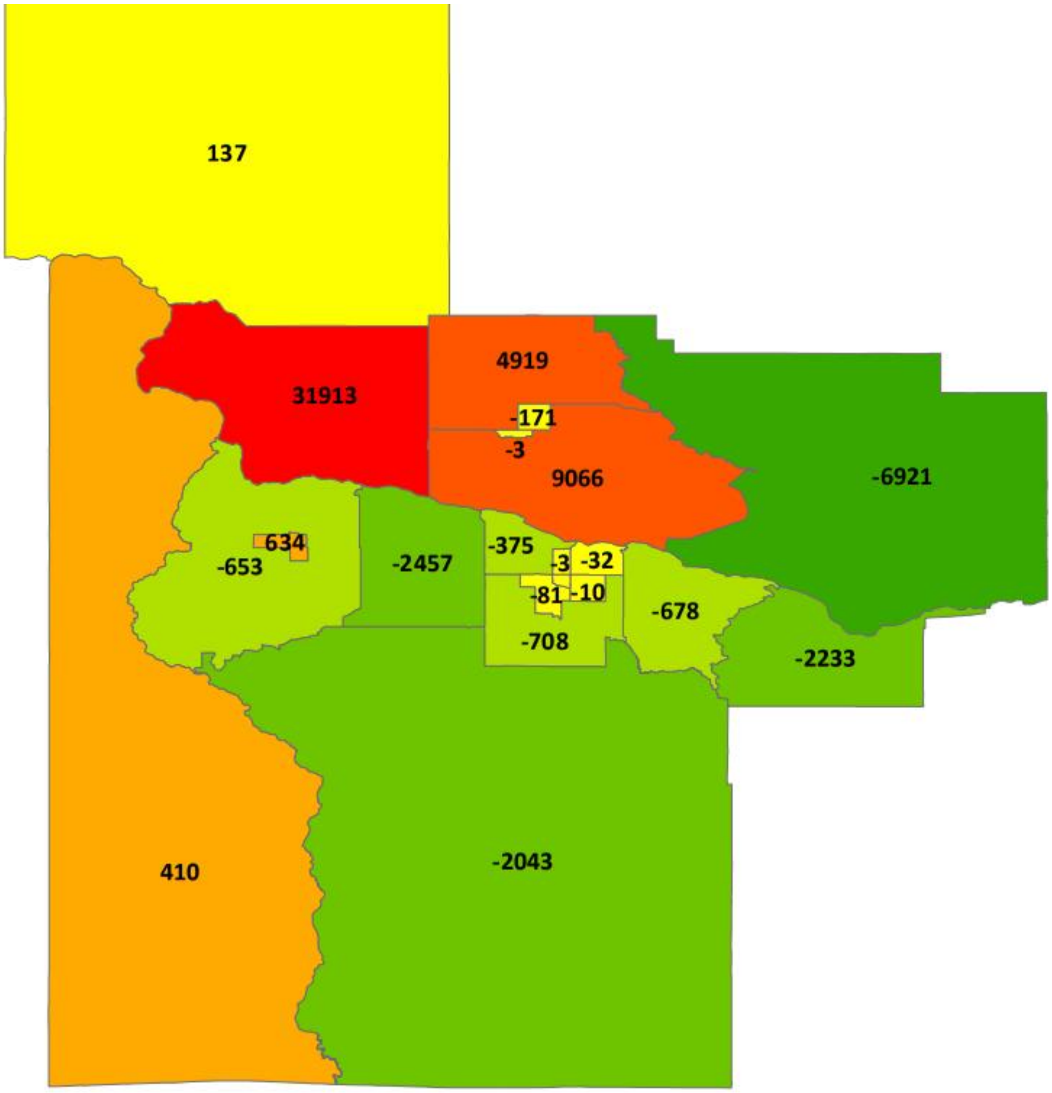


Figure 5.4 Nutrient supply-demand balance for N for census tracts in Gooding, Jerome, and Twin Falls Counties in 2012

Nutrient surplus also increased greatly from 2012 to 2017, but the increase was more widely distributed (comparing figure 5.4, 5.5). The continued increase in N supply made the surplus reach ever higher levels in 2017. The N surplus N in some tract was above 40 million pounds per year in one census tract. The census tracts with the highest nutrient balances remained along the Snake River. In addition, nutrient balances in eastern and southern parts of the map also increased greatly. Some census tracts shifted from net demanders to net suppliers.

However, there are a few census tracts for which their N supply-demand balance did not change much. These census tracts are those that are nearest to more urbanized areas.

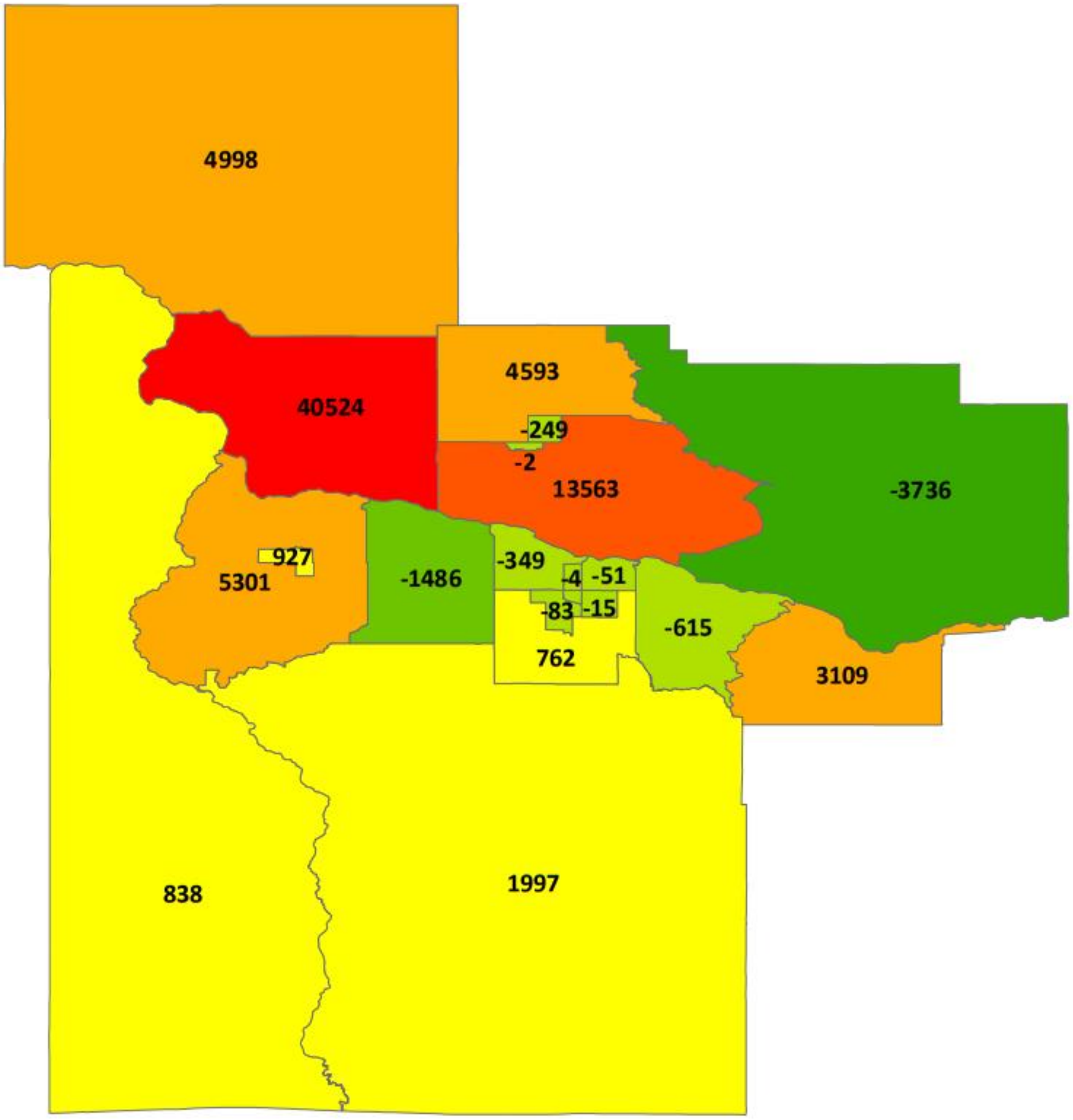


Figure 5.5 Nutrient supply-demand balance for N for census tracts in Gooding, Jerome, and Twin Falls Counties in 2017

The increase in nutrient balance continues from 2017 to 2022, and the increase is still widespread among the 3 counties (figure 5.5, 5.6). Nutrient surplus in some census tracts is very high in 2017, and nutrient surplus of N can proceed 50 million pounds per year. In addition, the increase in nutrient balance happens in most census tracts in the map. However, the increase rate can be lower compared with previous periods.

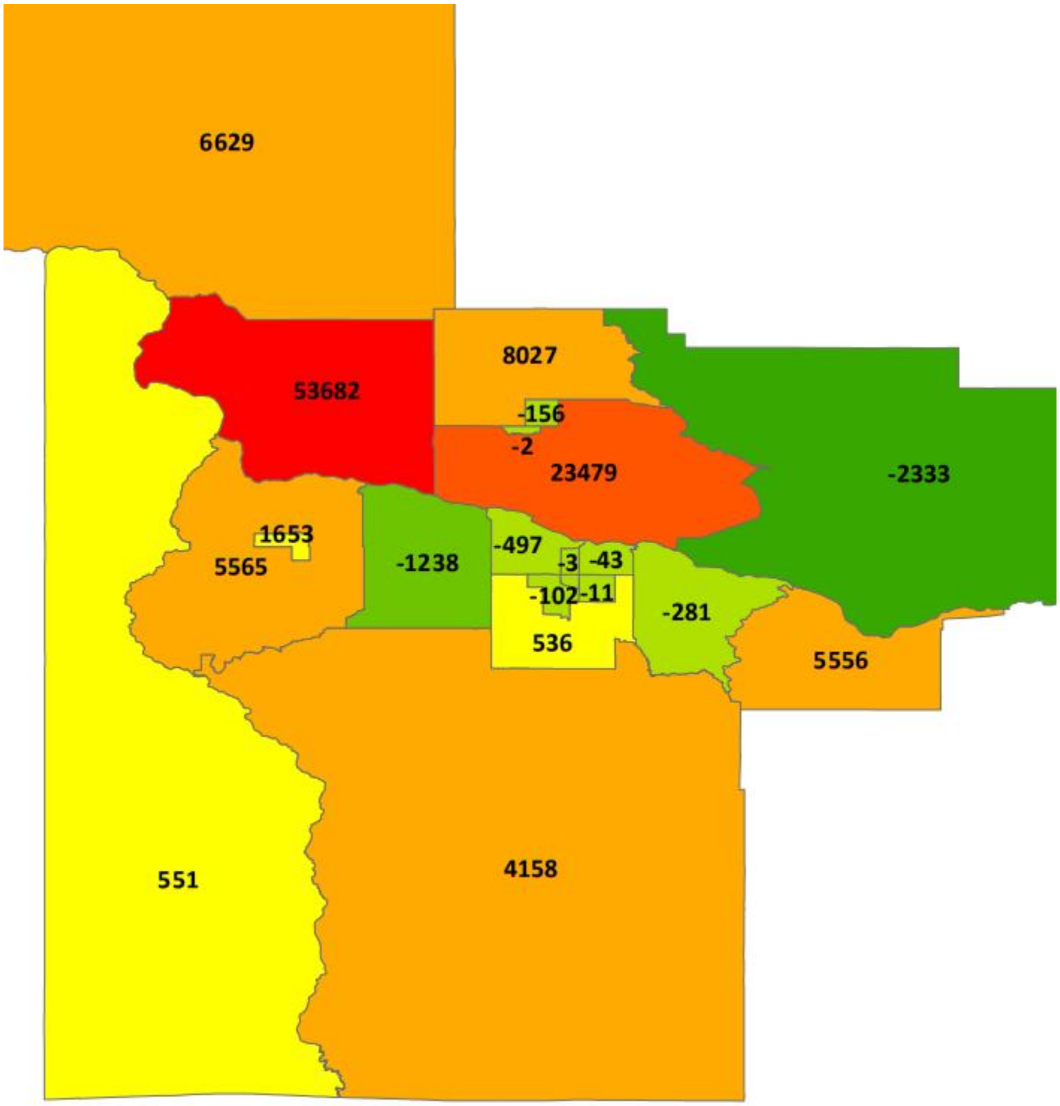


Figure 5.6 Nutrient supply-demand balance for N for census tracts in Gooding, Jerome, and Twin Falls Counties in 2022

The P supply-demand balances were also mapped in a similar manner to the N maps for 2007 to 2022 and are shown in figures 5.7-5.10 representing 5-year intervals, respectively. The broad trend of distribution of P is like the distribution of N. However, the P balances are relatively smaller than the N balances. This is particularly noticeable in the areas with more dairies. This is because the dairy manure contains more N than P. In contrast, in areas with fewer dairies, the difference between N and P is not as stark.

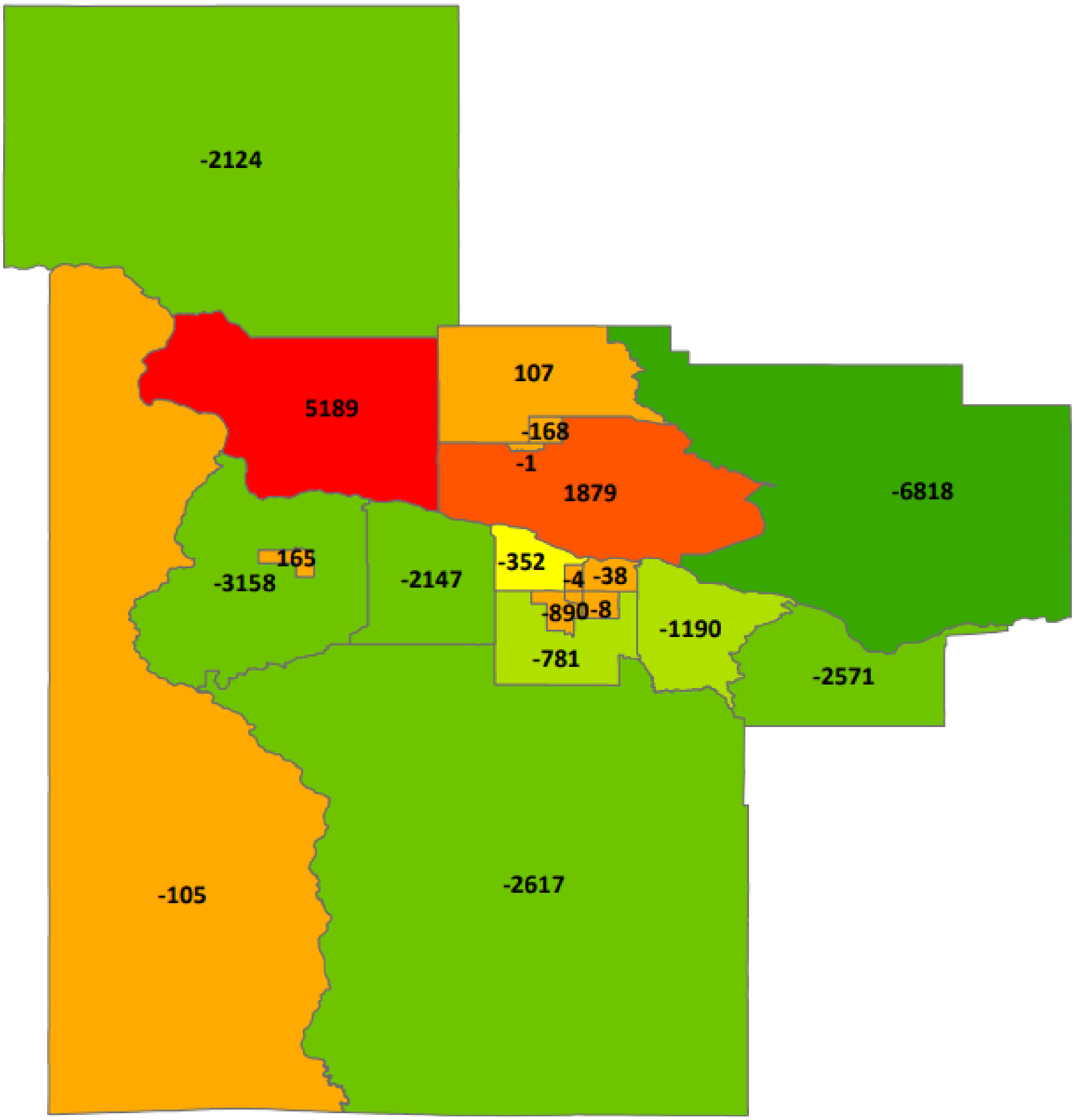


Figure 5.7 Nutrient supply-demand balance for P for census tracts in Gooding, Jerome, and Twin Falls Counties in 2007

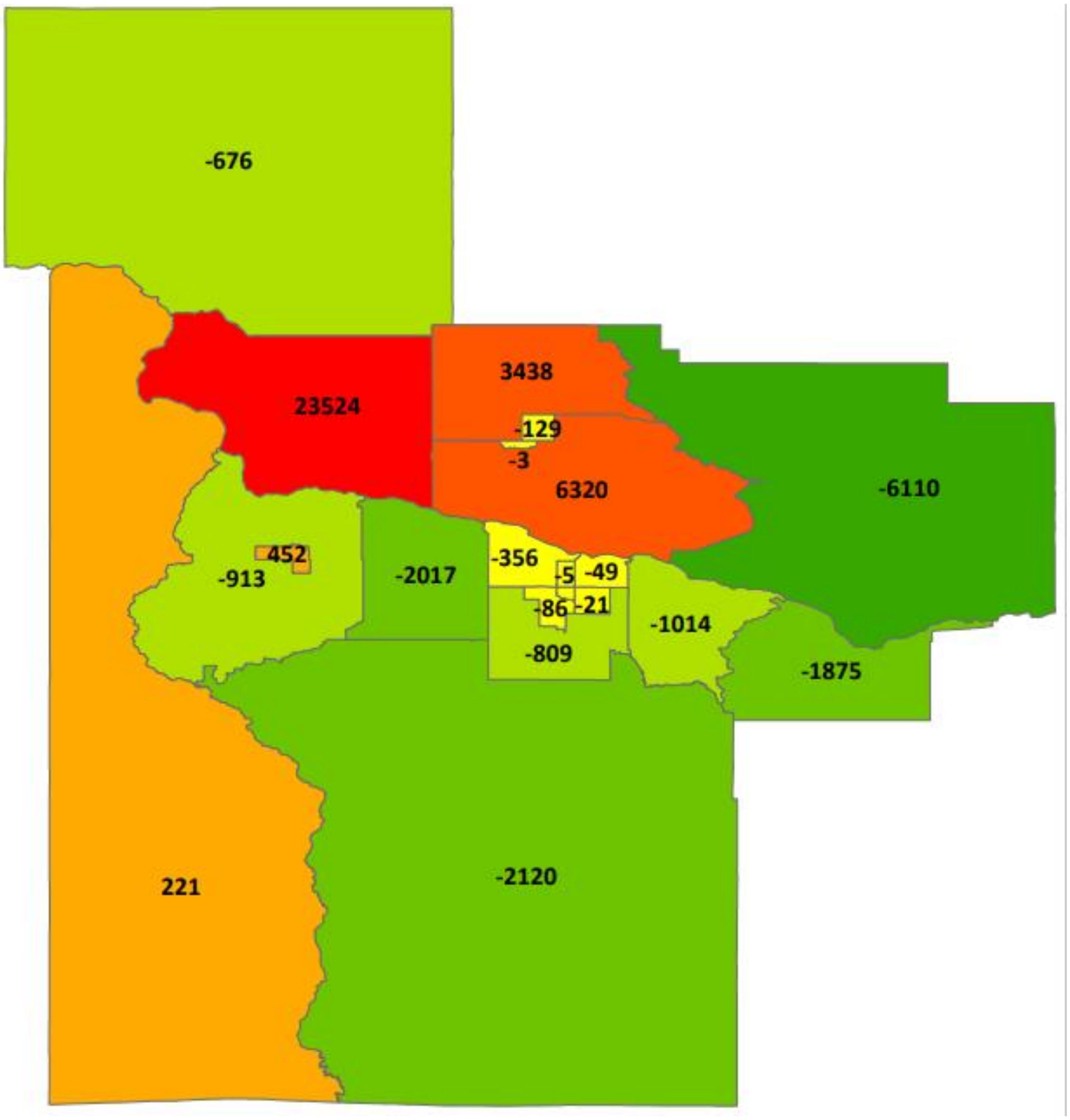


Figure 5.8 Nutrient supply-demand balance for P for census tracts in Gooding, Jerome, and Twin Falls Counties in 2012

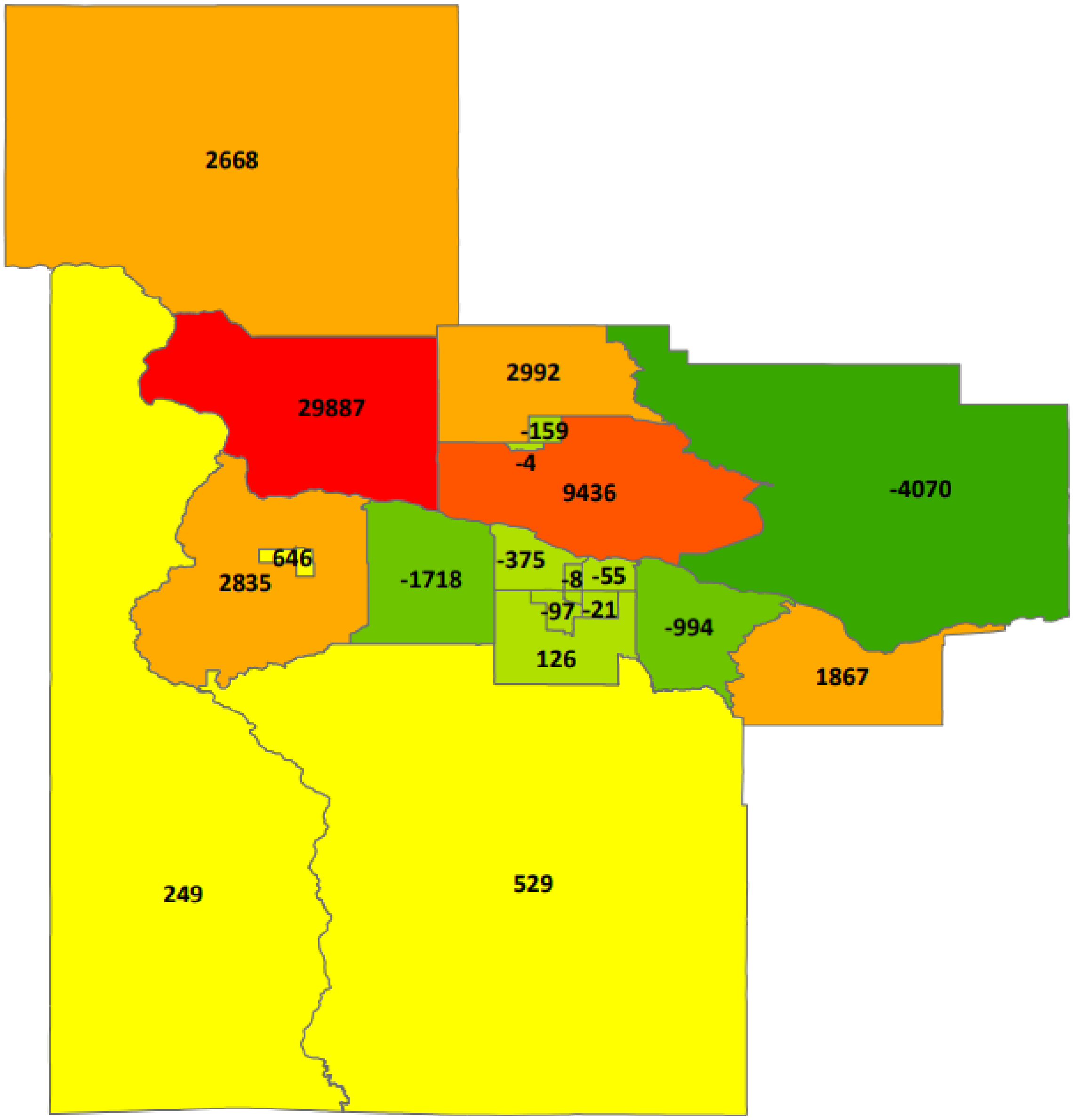


Figure 5.9 Nutrient supply-demand balance for P for census tracts in Gooding, Jerome, and Twin Falls Counties in 2017

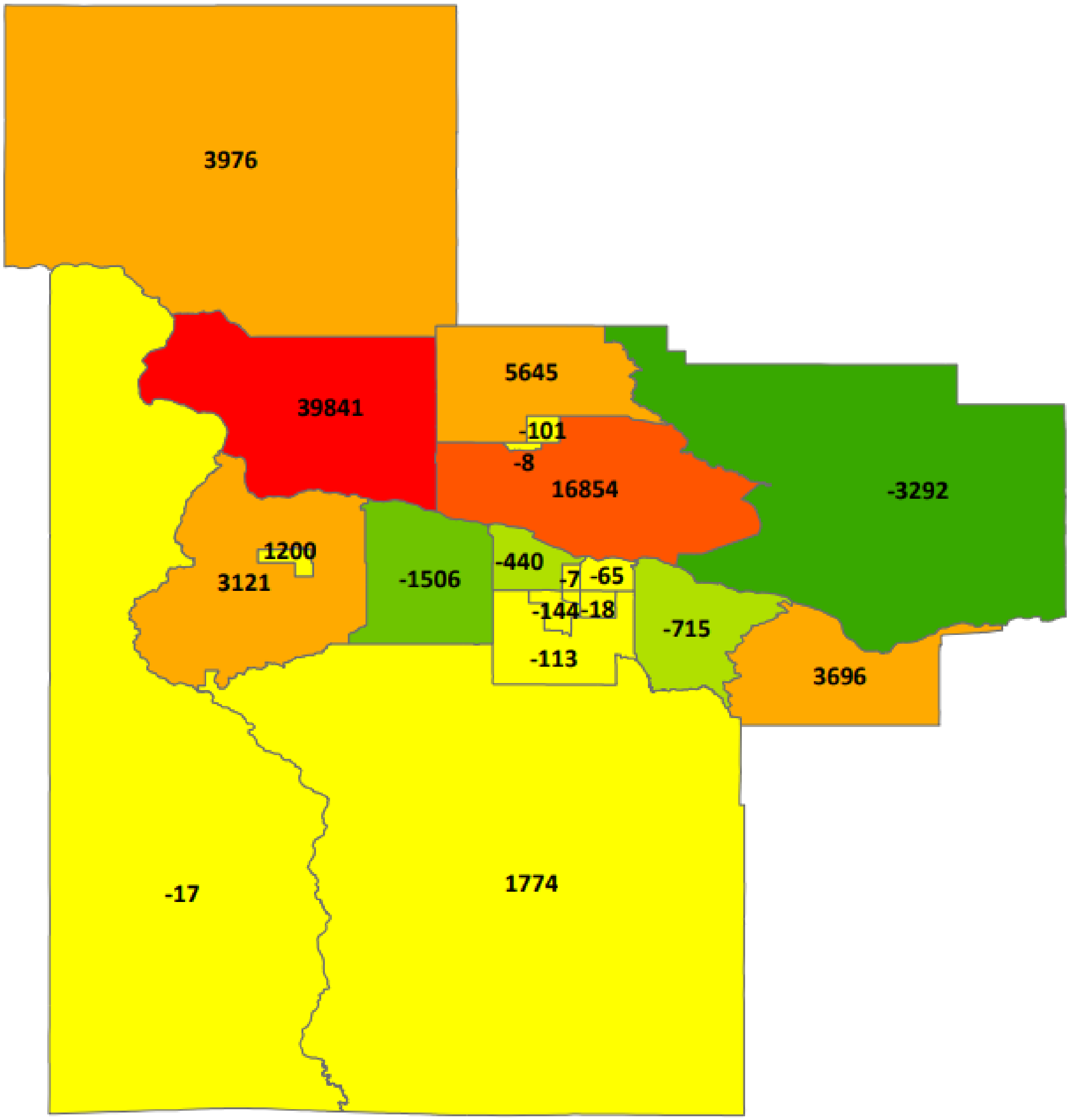


Figure 5.10 Nutrient supply-demand balance for P for census tracts in Gooding, Jerome, and Twin Falls Counties in 2022

Census tract level estimates for the nutrient supply-demand balances that were discussed in the context of figures 5.1 – 5.10 for N and P, respectively, as well as those for K, can be found in table 5.1. While representation of the estimates in figure form can help with visual representation of the spatial distribution of nutrient balances, including them in tabular form can be helpful for achieving greater understanding of the extent of the changes in the supply-demand balances over time.

Table 5.1 Dairy supply-demand balance for N, P, and K for census tracts in Gooding County, Jerome County, and Twin Falls County from 1997 to 2017

Year	County	Census tract	N supply-demand balance (thousand lbs.)	P supply-demand balance (thousand lbs.)	K supply-demand balance (thousand lbs.)
2007	Gooding	960100	-1328	-2124	-1209
2012	Gooding	960100	137	-676	423
2017	Gooding	960100	4998	2668	4321
2022	Gooding	960100	6629	3976	6048
2007	Gooding	960200	7867	5189	6661
2012	Gooding	960200	31913	23524	27292
2017	Gooding	960200	40524	29887	34433
2022	Gooding	960200	53682	39841	45773
2007	Jerome	970100	-7063	-6818	-4645
2012	Jerome	970100	-6921	-6110	-3846
2017	Jerome	970100	-3736	-4070	-1648
2022	Jerome	970100	-2333	-3292	-214
2007	Jerome	970200	844	107	960
2012	Jerome	970200	4919	3438	4696
2017	Jerome	970200	4593	2992	4194
2022	Jerome	970200	8027	5645	7152
2007	Jerome	970300	-247	-168	-178
2012	Jerome	970300	-171	-129	-108
2017	Jerome	970300	-249	-159	-144
2022	Jerome	970300	-156	-101	-82
2007	Jerome	970400	-2	-1	-1
2012	Jerome	970400	-3	-3	-1
2017	Jerome	970400	-2	-4	-2
2022	Jerome	970400	-2	-8	-5

cont. Table 5.1

2007	Jerome	970500	3516	1879	3225
2012	Jerome	970500	9066	6320	8164
2017	Jerome	970500	13563	9436	11742
2022	Jerome	970500	23479	16854	20279
2007	Twin Falls	980100	727	-105	1022
2012	Twin Falls	980100	410	221	1095
2017	Twin Falls	980100	838	249	1023
2022	Twin Falls	980100	551	-17	924
2007	Twin Falls	980200	-2479	-2617	-1639
2012	Twin Falls	980200	-2043	-2120	-1325
2017	Twin Falls	980200	1997	529	1918
2022	Twin Falls	980200	4158	1774	3648
2007	Twin Falls	980300	-2889	-3158	-1980
2012	Twin Falls	980300	-653	-913	285
2017	Twin Falls	980300	5301	2835	4862
2022	Twin Falls	980300	5565	3121	5356
2007	Twin Falls	980400	281	165	219
2012	Twin Falls	980400	634	452	531
2017	Twin Falls	980400	927	646	765
2022	Twin Falls	980400	1653	1200	1388
2007	Twin Falls	980500	-2453	-2147	-1693
2012	Twin Falls	980500	-2457	-2017	-1423
2017	Twin Falls	980500	-1486	-1718	-933
2022	Twin Falls	980500	-1238	-1506	-513
2007	Twin Falls	980600	-678	-781	-354
2012	Twin Falls	980600	-708	-809	-378
2017	Twin Falls	980600	762	126	740
2022	Twin Falls	980600	536	-113	598

cont. Table 5.1

2007	Twin Falls	980700	-353	-352	-250
2012	Twin Falls	980700	-375	-356	-252
2017	Twin Falls	980700	-349	-375	-248
2022	Twin Falls	980700	-497	-440	-308
2007	Twin Falls	980800	-4	-4	-3
2012	Twin Falls	980800	-3	-5	-4
2017	Twin Falls	980800	-4	-8	-5
2022	Twin Falls	980800	-3	-7	-4
2007	Twin Falls	980900	-37	-38	-21
2012	Twin Falls	980900	-32	-49	-27
2017	Twin Falls	980900	-51	-55	-40
2022	Twin Falls	980900	-43	-65	-40
2007	Twin Falls	981000	-10	-8	-5
2012	Twin Falls	981000	-10	-21	-12
2017	Twin Falls	981000	-15	-21	-12
2022	Twin Falls	981000	-11	-18	-10
2007	Twin Falls	981100	0	0	0
2012	Twin Falls	981100	0	0	0
2017	Twin Falls	981100	-1	0	0
2022	Twin Falls	981100	0	0	0
2007	Twin Falls	981200	-118	-89	-59
2012	Twin Falls	981200	-81	-86	-66
2017	Twin Falls	981200	-83	-97	-64
2022	Twin Falls	981200	-102	-144	-94
2007	Twin Falls	981300	-1007	-1190	-399
2012	Twin Falls	981300	-678	-1014	-322
2017	Twin Falls	981300	-615	-994	-266
2022	Twin Falls	981300	-281	-715	315

cont. Table 5.1

2007	Twin Falls	981400	-2920	-2571	-1504
2012	Twin Falls	981400	-2233	-1875	-885
2017	Twin Falls	981400	3109	1867	3431
2022	Twin Falls	981400	5556	3696	5692

Sources: Author’s calculations use cropland data from USDA-CropScape. The ISDA data include cattle inventory and dairy location. In addition, we use manure amount per dairy cow and beef cattle obtained from Lorimor et al. (2004). We use nutrients per manure and compost unit obtained from literature (Lorimor et al., 2004; Butler et al., 2006). We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cows between 1000 and 1400 lbs.

Chapter 6: Model and Estimation of Manure Nutrient Accumulation from 2007 to 2022

So far in this thesis, estimates have been provided such that they represent annual values. While useful, the reality is that if nutrients are not utilized by crops, then they remain released into the soil, water, and/or air. Thus, in this chapter, a storage model of manure accumulation is introduced to describe the extent to which nutrients have been compile over time. An overview of the basic model is described first and then estimates of nutrient accumulation in Gooding, Jerome, and Twin Falls counties for 2007 to 2022 are provided and discussed.

Storage Model of Manure Accumulation over Time

To quantify the extent to which positive supply-demand balance of manure carry over from year-to-year a stocks accounting model adapted from Wright (2011) was developed. The framework is such that in year *t*, the available stock of manure is A_t. Manure usage is u_t. The change of stock, x_t, is equal to the difference between available stock from the previous year (A_{t-1}) and manure used,

$$x_t = A_{t-1} - u_t. \tag{3}$$

Stock carried over in the current year is x_t. Dairy cows also generate manure g_t in year *t*. Available stock of manure in year *t* is equal to the sum of the previous stock and newly generated manure. minus manure used this year. The stock carried from one year to the next is non-negative.

$$A_t = g_t + x_t = A_{t-1} + g_t - u_t, \qquad x_t \geq 0 \tag{4}$$

Estimation of manure and compost accumulation in Gooding, Jerome, and Twin Falls counties

We use the previously described stock accumulation model to estimate the amount of nutrient stock that has accumulated in Gooding, Jerome, and Twin Falls counties between 2007 and 2022. The calculations utilize the census tract level manure nutrient supply-demand estimates from chapter 5.

Specifically, the nutrient supply-demand balances (equation 3) are first calculated for each census tract and year. To calculate the accumulation, we need to make sure that supply-demand balance is non-negative. So, if the value of supply-demand balance is negative, the accumulation value was set to 0. In addition, it was assumed that nutrient accumulation during the 2007-2011 period was the same as in 2007 because data are not available for every year. Similarly, accumulation during the 2012-2016 period was assumed as the same in 2012, and the same assumption was made for the periods of 2017 – 2021 and 2017 – 2022.

The results for the accumulation estimates are included in table 6.1. It is observed that the dairy manure nutrient stocks increased rapidly from 2007 and 2022, and that the increase is not evenly distributed The stock for N was estimated as near 500 million pounds in some census tracts by 2022. This estimate is 10 times higher than the supply-demand balance in 1 year. In contrast, there are many census tracts with 0 accumulation from year-to-year. This means that the nutrient demand is higher than or exactly equal to nutrient supply. In such cases, crop farmers can use synthetic commercial fertilizers if there is little nutrient stock. This also applies to areas with little agricultural activities.

In addition, the increase rate of nutrient accumulation decreased in most census tracts from the beginning to the end of the observation period. Specifically, from 2007 to 2012, the average rate of increase decreased from around 300% to around 100%. The average rate of increase decreased further from 2017 to 2022.

The decrease in nutrient accumulation rate can be explained by there being a relatively higher baseline stock value carried over from one year to the next. Specifically, in 2007, the average accumulation was around a few million pounds. However, in 2022, the accumulation was above 100 million points. In addition, the general expansion rate of dairy inventories is decreasing in ID, and so the associated increase in dairy manure production is decreasing.

Table 6.1 Accumulation of supply-demand balance at census tract level in Gooding County, Jerome County and Twin Falls County

Year	**County**	**Census tract**	**N supply-demand balance (thousand lbs.)**	**N supply-demand balance increase rate %**	**P supply-demand balance (thousand lbs.)**	**K supply-demand balance (thousand lbs.)**
2007	Gooding	960100	0	.	0	0
2012	Gooding	960100	683	.	0	2114
2017	Gooding	960100	25675	3659%	13338	23720
2022	Gooding	960100	32304	26%	17314	29768
2007	Gooding	960200	39335	.	25943	33307
2012	Gooding	960200	198899	406%	143564	169769
2017	Gooding	960200	401518	102%	292999	341933
2022	Gooding	960200	455201	13%	332841	387705
2007	Jerome	970100	0	.	0	0
2012	Jerome	970100	0	.	0	0
2017	Jerome	970100	0	.	0	0
2022	Jerome	970100	0	.	0	0
2007	Jerome	970200	4220	.	537	4802
2012	Jerome	970200	28817	583%	17729	28281
2017	Jerome	970200	51784	80%	32690	49250
2022	Jerome	970200	59811	16%	38335	56402
2007	Jerome	970300	0	.	0	0
2012	Jerome	970300	0	.	0	0
2017	Jerome	970300	0	.	0	0
2022	Jerome	970300	0	.	0	0
2007	Jerome	970400	0	.	0	0
2012	Jerome	970400	0	.	0	0
2017	Jerome	970400	0	.	0	0
2022	Jerome	970400	0	.	0	0

cont. Table 6.1

2007	Jerome	970500	17578	.	9395	16126
2012	Jerome	970500	62908	258%	40993	56946
2017	Jerome	970500	130725	108%	88171	115657
2022	Jerome	970500	154204	18%	105025	135936
2007	Twin Falls	980100	3637	.	0	5111
2012	Twin Falls	980100	5686	56%	1106	10588
2017	Twin Falls	980100	9877	74%	2349	15701
2022	Twin Falls	980100	10428	6%	2349	16625
2007	Twin Falls	980200	0	.	0	0
2012	Twin Falls	980200	0	.	0	0
2017	Twin Falls	980200	9983	.	2643	9592
2022	Twin Falls	980200	14140	42%	4417	13240
2012	Twin Falls	980300	0	.	0	1427
2017	Twin Falls	980300	26505	.	14175	25736
2022	Twin Falls	980300	32070	21%	17296	31093
2007	Twin Falls	980400	1404	.	825	1096
2007	Twin Falls	980300	0	.	0	0
2012	Twin Falls	980400	4576	226%	3084	3754
2017	Twin Falls	980400	9212	101%	6316	7580
2022	Twin Falls	980400	10864	18%	7516	8969
2007	Twin Falls	980500	0	.	0	0
2012	Twin Falls	980500	0	.	0	0
2017	Twin Falls	980500	0	.	0	0
2022	Twin Falls	980500	0	.	0	0
2007	Twin Falls	980600	0	.	0	0
2012	Twin Falls	980600	0	.	0	0
2017	Twin Falls	980600	3812	.	629	3702
2022	Twin Falls	980600	4348	14%	629	4299

cont. Table 6.1

2007	Twin Falls	980700	0	.	0	0
2012	Twin Falls	980700	0	.	0	0
2017	Twin Falls	980700	0	.	0	0
2022	Twin Falls	980700	0	.	0	0
2007	Twin Falls	980800	0	.	0	0
2012	Twin Falls	980800	0	.	0	0
2017	Twin Falls	980800	0	.	0	0
2022	Twin Falls	980800	0	.	0	0
2007	Twin Falls	980900	0	.	0	0
2012	Twin Falls	980900	0	.	0	0
2017	Twin Falls	980900	0	.	0	0
2022	Twin Falls	980900	0	.	0	0
2007	Twin Falls	981000	0	.	0	0
2012	Twin Falls	981000	0	.	0	0
2017	Twin Falls	981000	0	.	0	0
2022	Twin Falls	981000	0	.	0	0
2007	Twin Falls	981100	0	.	0	0
2012	Twin Falls	981100	0	.	0	0
2017	Twin Falls	981100	0	.	0	0
2022	Twin Falls	981100	0	.	0	0
2007	Twin Falls	981200	0	.	0	0
2012	Twin Falls	981200	0	.	0	0
2017	Twin Falls	981200	0	.	0	0
2022	Twin Falls	981200	0	.	0	0
2007	Twin Falls	981300	0	.	0	0
2012	Twin Falls	981300	0	.	0	0
2017	Twin Falls	981300	0	.	0	0

cont. Table 6.1

2022	Twin Falls	981300	0	.	0	315
2007	Twin Falls	981400	0	.	0	0
2012	Twin Falls	981400	0	.	0	0
2017	Twin Falls	981400	15545	.	9333	17153
2022	Twin Falls	981400	21101	36%	13029	22845

Sources: Author’s calculations use cropland data from USDA-CropScape. The ISDA data include cattle inventory and dairy location. In addition, we use manure amount per dairy cow and beef cattle obtained from Lorimor et al. (2004). We use nutrients per manure and compost unit obtained from literature (Lorimor et al. 2004; Butler et al., 2006). We assume 50 percent of manure is composted. Compost nutrient data is from Butler et al. (2006), and weight of composts decreases 50% from raw manure (Keena, 2022). Manure production and nutrient data are from Lorimor et al. (2004). We use the nutrient demand data for alfalfa (Westerhold, 2019a), corn silage (Westerhold, 2019b), field corn (Westerhold, 2019c), barley (Westerhold, 2019d), sugar beets (Westerhold, 2019e), wheat (Westerhold, 2019f), and potato (Eborn & Greenway, 2022).

Note: The nutrients of dairy cows are the average of lactating cows between 1000 and 1400 lbs.

Chapter 7: Conclusions and Implications

Conclusions

This thesis demonstrated that there have been substantial increases in dairy manure nutrient supply-demand balances in ID from 1990 to 2022. Associated with the growth of the dairy industry, the increase in nutrient supply has more than tripled in the past 30 years. The increase in N is about 30% larger than P and K. The increase is most prominent in Southern ID, which has several prominent dairy producing counties including Gooding, Jerome, and Twin Falls counties. Dairies, and their associated manure nutrients, are concentrated spatially near the Snake River. In addition, dairy manure nutrient supply-demand balances being larger have led to ever greater nutrient accumulation. However, since the baseline value of nutrients carried over from year-to-year has continued to increase, the increase rate of dairy manure nutrient accumulation has decreased over time.

The results from state level estimates of manure nutrient supply-demand balances show that dairy manure can meet much of the total nutrient demand from major crops in ID. For instance, the total nutrient supply-demand balance for N in Gooding, Jerome, and Twin Falls counties was estimated at 105 million pounds in 2022. This is about 30% of total N demand for N by major crops in the full state of ID.

The nutrient supply-demand balances are associated with a rapid increase in nutrient supply associated with both the rapid development of the ID dairy industry as well as by other changes outside of the dairy sector such as increases in population and expansion of urban areas that use more land and water. The relative decrease in demand nutrient demand for crop production in ID would have caused there to be positive manure nutrient supply-demand balances even without the expansion of the dairy industry.

The increases in manure nutrient supply-demand balances have mainly occurred in Southcentral and Southwest ID. This is the region where the ID dairy industry is concentrated. While there are many positive aspects to the development of the dairy industry in ID, but nutrient surpluses that are concentrated in certain regions can also cause environmental issues that are of concern to policymakers and.

Qualifications

Calculations in the thesis may not be fully accurate because there are many other factors that were omitted. First, not all the manure is being used by the crops, especially for N, for which all N in the initial excretion is not available for usage by the crop by the time manure is distributed on the soil. Thus, the nutrient supply estimates are likely overestimated. Thus, the estimated supply-demand balances can be best thought of as “upper bounds”. Additionally, the actual supply-demand balances may also be larger than those calculated in this analysis, because the actual demand by the crop producers is likely lower than the demand estimates in the analysis since the manure and/or compost cannot be transported over long distances and producers may prefer synthetic commercial fertilizer relative to manure.

Implications

In the future, if farmers can better process the manure and ship it to further areas than is the case today, then meeting the demand of nutrients across the Western U.S. with manure-based products may be possible. Other manure sources, including cattle on feed, can make the supply even larger. Additionally, dairy farmers or specialized firms can produce MBF for economic profit if the MBF industry is further developed. The potential benefits to dairy producers and others in the manure supply chain are substantial. For instance, if nutrient surplus in 3 dairy producing counties of Gooding, Jerome, Twin Falls was completely converted to fertilizer, N surplus alone would be worth 33 million dollars based on 2022 N prices. Similarly, P and K will be worth 8 and 37 million dollars, respectively. This is a total manure nutrient value from just 3 counties of nearly 80 million dollars.

This demonstrates that MBF can potentially substitute substantial amounts of synthetic commercial fertilizer, including Phosphate rock, Urea, and Potassium chloride. The increase in manure-based fertilizer supply can decrease the price of synthetic commercial fertilizer. This can decrease the cost of buying fertilizers for crop growers, increase the profitability of crop production, and, thus, enhance crop farmer economic sustainability. If feed crop farmers reinvest some profits into productivity enhancing activities, then the resultant increase in feed crop supply can decrease the feed crop price. Such reductions in feed crop prices can reduce feed costs for dairies and enhance their own profitability. Thus, increased adoption of MBF can enhance overall economic performance and sustainability among both dairies and crop farmers.

On the other hand, the current relatively high cost of MBF technology can limit technology adoption, making future development of the MBF sector unclear. Thus, more research regarding development of MBF technologies and processes is needed. Future research needs to use more data sources about MBF and GHG. Farm-level data can help provide more accurate estimates.

Quantification of GHG and effects of increased usage of “value added” processes and technologies on GHG would be a useful next step. GHG emissions from dairy has presented challenges to sustainable development to the dairy industry. Dairy is one of the major sources of GHG emissions, especially for methene and nitrous oxide (EPA, 2022). While GHG are emitted from the whole production system (Rotz et al., 2012), the main sources of GHG during dairy production are enteric fermentation and manure management (Rotz et al., 2012). The potential to limit GHG from enteric fermentation is not very large given current technologies since these result from the natural digestive process of cows. However, there is potential to limit GHG from manure by processing it in various ways that limit emissions as it moves from excretion to storage, transport, and usage. Making efforts to reduce GHG emissions from manure is important because over half of consumers have expressed concerns regarding the environmental impact of dairy products (Schiano, 2020). Policymakers may also likely consider new regulations for regulating GHG within and outside of the dairy industry (Rabe, 2023).

Thus, in the future, the government can design policies to help to develop new technologies and processes to reduce the environmental impact from dairy manure. First, the U.S. government can provide more research funds to help to develop MBF technology and processes. Second, agencies such as the USDA can also give more farmers more incentive (e.g., financial discounts) to adopt and use newly developed technologies. Such efforts can include subsidies for purchase of specific MBF technology as well as discounted loans. Lastly, more education and extension programs can help farmers to increase their awareness regarding the benefits and costs of MBF technologies and processes, which can help farmers to make their decisions regarding enhanced usage of manure-based fertilizer supply and usage.

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