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A County-Level Assessment of Manure Nutrient Availability Relative to Crop Nutrient Capacity in Iowa: Analysis of Spatial and Temporal Trends

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Abstract. During the twentieth century, agricultural production strived to achieve increased food production in order to satisfy both local and export demands. In many cases, this led to increased farm sizes and an operational separation of crop and livestock production. Society fears that the trend of increasing centralization and industrialization of agriculture, specifically animal agriculture, has resulted in concentration of waste products associated with their production (manures, wash-down water, process waters, etc.) over relatively small geographic regions that are spatially segregated from crop production areas. Since the distance that manure can be economically hauled for land application has practical limits, this could lead to over-application, of manures near animal feeding facilities, potentially increasing nutrient losses to ground and surface waters. A statewide analysis of crop and animal production in Iowa suggests that about 25% of current nitrogen and phosphorus requirements for crop production could be supplied from manures and litters, while around 40% of the required potassium could be provided. However, neither livestock nor crop production is uniformly distributed across all counties. This unequal distribution suggests that a more disaggregated analysis of crop nutrient requirements and manure nutrient supply is necessary to estimate the risks of excess nutrient loss to the environment. Results indicated that in general all counties had sufficient nutrient utilization capacities to value manure as a resource; however, counties in Northwest Iowa are becoming progressively more manure rich, while counties in Southwestern and Central Iowa are becoming progressively more manure poor. This separation of crop and livestock production is becoming more pronounced, indicating that solids separation and nutrient (especially phosphorus) recovery systems that can concentrate manure nutrients for transport could become more important to help counties maintain nutrient balance and to return manure nutrients to the soil if these trends persist.

Keywords. *Manure production, manure use, crop production, nutrient capacity, excess manure*

Introduction:

Driven by world-wide population increases, growing incomes, and increased urbanization, society has experienced a marked and rapid dietary transformation (Smil, 2002). Specifically, there has been an increase in per capita demand for animal proteins (meat, milk, and eggs). Future forecasts of global meat demands generally expect an increase of 50% over the next two generations (due mostly to changes in developing countries). In an effort to meet societal demands of food and fiber agriculture has experienced numerous changes over the years. One of these being the use of mineral fertilizers, which allowed decoupling of crop and animal production systems, as for the first time crop production was no longer limited to the use of animal wastes, green manures, and natural soil fertility to support crop production. In many cases, this change led to increased farm sizes (more acres per farm or animals per farm), an operational separation of crop and livestock production as farms became more specialized (Naylor et al., 2005), and an increased use of animal confinement facilities as pasture systems gave way to confinement facilities and row-crops production as the growth of higher-value crop commodities could be supported by the readily available mineral fertilizers.

Society fears that the trend of increasing demand for meat and livestock products and the associated growth of the animal production industry will result in greater amounts of manure, in many cases beyond the ability of the soil around the facility to utilize it (Karlen et al., 2004). Additionally, it has been suggested that intensification and industrialization of agriculture, specifically animal agriculture, has resulted in concentration of waste products associated with their production (manures, wash-down water, process waters, etc.) over relatively small geographic regions that are spatially segregated from crop production areas. Since the distance that manure can be economically hauled for land application has practical limits, the public fears that this spatial separation between crop and animal production areas could lead to over-application of manure nutrients, i.e., in excess of crop nutrient demand, near animal production facilities, and thus potentially increase transport of nutrients to ground and surface waters.

Moreover, it has been recognized for years that manures are a valuable soil amendment due to their potential contribution to improved soil quality. As stated by Drinkwater et al. (1998), as compared with senescent-crop residues, a larger proportion of manure-derived carbon is retained in the soil. The return of manure to the soil is thought to improve soil structure, tilth, and water relations (holding capacity, available water content, and conductivity). Additionally, the use of manures as a fertilizer is well accepted as there are numerous macro- and micro-nutrients it provides to support crop growth. More recently it has been suggested that the return of manure to the land can be an important component of sustainable agriculture systems. Specifically, Sulc and Tracy (2007) identified four positive factors associated with livestock being integrated into cropping enterprises, these were: (i) crops can be used to feed livestock minimizing the import of outside feed stuffs, (ii) livestock manure can serve as a source of nutrients for crop production, (iii) livestock can serve as a sink for agricultural by-products, and (iv) ruminant livestock encourage the establishment of perennial grass and legume forages as a feedstuff.

This dichotomy, manure as either a waste or a resource, has long defined the issue of manure management. The debate has only intensified as demand for animal protein and agricultural sustainability has increased. Opinions on how to achieve this improved sustainability vary greatly with some arguing that animal production needs to be minimized or eliminated completely (due to the inherent inefficiency in conversion of plant energy and protein to animal energy and protein), while others argue for the encouragement of animal production as part of organic systems where the manure serves as the main fertilizer source for crop production. Even opinions over the types of animals that should be raised varies, with the argument for poultry and pork based on better feed conversion efficiencies of these species compared to cattle and the argument for cattle based on the fact that as ruminants they can convert grasses and forages into human consumable proteins. These issues illustrate that understanding manure nutrient availability and crop nutrient demands is an important component in evaluating agricultural sustainability. Moreover, comparisons of manure nutrients to crop nutrient demand provides a sense of the “value of the manure,” i.e., whether it will be treated as a waste or resource in different regions.

Specifically, the intensification of animal agriculture has led many to question whether different agricultural areas have sufficient land to utilize the manure being produced (Smil, 2002), such as Iowa. An aggregated analysis (statewide) of crop and animal production in Iowa suggests that about 25% of the nitrogen and phosphorus requirements, and 40% of the potassium, for crop production could be supplied from manures and litters generated from livestock production. However, a more interesting question is how this varies spatially throughout the state, i.e., are there areas where manure nutrient production is greater than crop demand, and how has this changed temporally. Thus, our objective is to explore if animal production in Iowa is intensifying to such a degree that in certain areas of the state manure will not be viewed as a resource, but instead a waste that the animal production facility must find a way of disposing of, and to examine if/how this has changed over time, i.e., are these issues becoming more frequent. I hope that this work can be utilized to evaluate where manure treatment strategies that partition and remove nutrients may be most practical, or even necessary, to implement (areas where the manure nutrients cannot be utilized) and also to identify locations where more manures could be desired (to reduce the reliance on synthetic fertilizers). Specifically, I (1) quantify the extent to which livestock production has become more spatially concentrated by determining the production of animal manure and manure nutrients on a statewide and county basis, (2) quantify the extent to which the production of manure nutrients may exceed the capacity of crop land to assimilate the nutrients, (3) identify counties that are more likely to have animal waste utilization problems and be in need of innovative manure treatments, and (4) to quantify how these issues have evolved over time. Future work on these issues could evaluate how changes in animal production strategies (pasture versus containment based facilities) and crop rotation choices (continuous corn, corn-soybean, small grains, or increased alfalfa hay) impact these nutrient balances and the extent to which manure is being viewed as a resource or waste.

Materials and Methods:

Data from the census of agriculture were used to make estimates of crop and livestock populations and production. The census of agricultural producers is conducted periodically (approximately every 5 years) by the USDA National Agricultural Statistics Service (NASS). Electronically published censuses (www.agcensus.usda.gov/Publications/index.php) were utilized for data collection; censuses from 2007, 2002, 1997, 1992, 1987, 1982, 1978, 1974, 1969, 1964, 1959, 1954, 1950, 1945, 1940, 1935, 1930, and 1925 were utilized. Classifications of animals and crops have varied slightly over the years; the distinctions and how these changes were handled will be discussed individually for each animal type and where applicable crop production type. In the following sections the method of estimating crop nutrient assimilative capacity of the crop land will first be described, followed by estimation of animal manure production and nutrient content. In addition to these data, crop production data was also supplemented using data from the Iowa Agricultural Statistics which is produced annually.

Estimating the nutrient assimilative capacity of crop land

The assimilative capacity is an estimate of the amount of nutrients that could be applied to land available for manure application without building up nutrient levels in the soil over time, i.e., at agronomic rates. Specifically, our definition will only include an estimate of the amount of nutrient contained in the harvested portion of the removed biomass, and as such is a low estimate of the actual nutrient application that would be required to support these production levels as some nutrient would inevitably be lost to erosion, surface runoff, leaching, gaseous emissions, fixation by the soil, and possibly harvest of additional portions of the crop residue. The extent to which nutrients are lost to each of these mechanisms is dependent on the specific nutrient, the conditions of the field and soil, the weather conditions of a particular year, the method, timing, and rate of nutrient application, as well as the timing of field tillage, planting, and harvesting practices, and all their interactions. The calculated estimate of assimilative capacity includes all farms within the, not just those with livestock, and thus assumes that these operations would be willing use manure as a fertility source.

It should be recognized that this estimate of assimilative capacity is for actual assimilative capacity during the particular year of the census. This is impacted by both the crop choice during the given year and the growing conditions specific to that year and in many cases may be below the assimilative capacity estimated by the producer determining appropriate nutrient application rates. In general this isn’t an issue of concern as most census years were representative of crop production in the year immediately preceding and following the census year; however, crop yields in 2012 were reduced as compared to other recent years due to drought conditions prevalent throughout much of the state and thus provide a low estimate of the potential nutrient utilization capacity the producer would have estimated.

Estimates of the kilograms of nitrogen, phosphorus, and potassium per unit of crop yield were obtained from the USDA NRCS nutrient content of crops database (available at http://plants.usda.gov/npk/main). These estimates were multiplied by the production (either in bushels or metric tons) for each of the crops (corn grain, corn silage, soybeans, alfalfa hay, other hay, oats, wheat, barley, and rye). In this analysis, I assumed that the nitrogen removed with soybeans and alfalfa hay was obtained entirely by nitrogen fixation, i.e., no manure, soil, or synthetic nitrogen was utilized by these crops. This again is a conservative estimate as research has generally supported that if mineral nitrogen is present in the soil the plant will utilize this to support their growth and development. Moreover, the harvest of crop biomass (wheat, oat, barley, and rye straw, corn stover, and soybean residue) was not considered a part of the nutrient assimilative capacity. This assumption was made as on a statewide basis these residues typically aren’t harvested in significant quantities; however, these residues could be harvested for use as bedding materials at some animal operations. In these cases the residues would then be returned with the manure application. More recent use of corn stover to support bioethanol production could alter this production practice and make accounting for nutrients removed with stover harvest necessary.

Table 1. Nitrogen, phosphorus, and potassium contents of the harvested portion of corn, oats, soybean, wheat, barley, rye, alfalfa, corn silage, and grass/clover hay.

Crop	kg N/bushel	kg P/bushel	kg K/bushel
Corn-Field, for grain	0.36	0.07	0.08
Oat, for grain	0.27	0.05	0.06
Soybean, for grain	1.61	0.16	0.38
Wheat-Durum, for grain	0.58	0.10	0.12
Barley, for grain	0.44	0.07	0.09
Rye, for grain	0.48	0.08	0.12
	kg N/metric ton	kg P/metric ton	kg K/metric ton
Alfalfa, for hay	25.2	2.36	19.1
Corn-Field, for silage (dough stage)	3.56	0.53	3.00
Grass and Red Clover, for hay	20.1	2.03	12.6

Estimating Animal Production

Data from the census of agriculture was used to make estimates of livestock populations in each county. Unfortunately, the census of agriculture does not report the average number of animals on a farm during the year, which is needed to estimate manure nutrient production. However, the census typically reports inventory (population currently on hand) and sales data (sold at some point during the year) on the number of head of beef, dairy, swine, and poultry for the census year. These values were used to estimate livestock and poultry populations within the calendar year, which was the basis for estimating total manure production.

Hog and pig production information was obtained from three categories from the census of agriculture. These were an end-of-year inventory of hogs and pigs used for breeding, an end-of-year inventory of other hogs and pigs, and the number of hogs and pigs sold in the calendar year. Using these numbers I calculated the number of pig fattening places as the sum of number of pigs sold plus the end-of-year inventory of other pigs. This sum was divided by three to estimate finishing spaces (this assumes 2.2 to 2.5 turns per year, i.e., that using these number each pig space would be counted three times, once from each turn). A ratio of 20 sows to 1 boar was used to partition the breeding stock into categories of boars and sows. In this analysis I assumed a sow gestation period of 114 days and a farrowing/weaning period of 35 days (76.5% of time in gestation and 24.5% of time farrowing/weaning) to estimate manure production. Prior to 1969 breeding stock inventory wasn't provided. I assumed that breeding stock accounted for 14.7% of total inventory prior to this based on the ratio of breeding stock to total stock in the 1974 census. This ratio was used for every individual county as I anticipated that as I move further back in history there was less pig transfer from county-to-county, i.e., that before this year most swine operations were farrow-to-finish as compared to the specialized farm typical of the modern swine industry. Prior to 1964 only the number of pigs sold was provided. The current fattening inventory was estimated to be about 54.7% (based on the 1969 census) of that sold with breeding stock still 14.7% of total live inventory. Again these estimates were utilized for each county.

End of year beef and dairy cow numbers were provided in the census of agriculture. I assumed that this value represented the average population of dairy and beef cows within each county for that particular year. In many cases the number of dairy and beef heifers was also provided; sometimes this value was divided into categories of less than one year and over a year of age; however, this wasn't always this case. When this data wasn't broken down by age I assumed that ½ of the heifers were less than one year of age and the others were between one and two years of age. If the number of replacement calves wasn't provided it was estimated as a fraction of the other cattle category, which includes steers, calves, and bulls. The number of steers was estimated as the number of cattle on feed. The number of bulls was estimated at 5% of the beef cow inventory. After subtracting the number of bulls and steers from the other cattle category, the remainder was assumed to be replacement heifers which were partitioned into beef and dairy replacements based on the percentage of dairy and beef cows within the county during the census year. In estimating the average population of beef steers (finishing spaces) I summed the end-of-year inventory of cattle on feed with the number of cattle on feed sold. This total was divided by three to determine an average population (this assumes there will be 2.2 grow-outs per year on a farm).

The final animal category considered was poultry. I considered three species of poultry operations, these included turkeys, layers, and broilers. Turkeys were divided into those kept for laying (reproduction) and market turkeys. The population of laying turkeys was reported in the census of agriculture as the year-end-inventory, this was assumed constant for the year. The number of turkeys sold and the current market turkey inventory were reported. These two values were summed and divided by three to determine the number of market turkey spaces in each county. I assumed that half of the market turkeys were hens and that the other half was toms. The year-end-population of laying hens was provided in the census of agriculture. I assumed this value represented the average population for that year, i.e., that sale of laying hens were balanced with replacements. Typically only the sales of broiler chickens were provided and this value was divided by six to determine the average broiler population during the given year, i.e., six turns of broilers would be produced per year.

Estimating Manure Production and Manure Nutrient Content

The quantity of manure was estimated on both an *as excreted* and an *available for land application* basis. The as excreted value would represent the total mass of nutrient the animals would excrete and does not account for the fraction that isn't recoverable (for example if an animal spends time on pasture manure excreted would not be collected). The available for land application basis estimates the nutrient content of the manure after storage and the percent of the manure that would be collected. The as excreted estimate centered on using the number of animal spaces and type of animals produced in each county as described in the previous section and then utilizing the ASABE manure production standard to estimate the quantity and nutrient content individual animals would contribute. In all cases I took the ASABE standard and converted manure and nutrient excretion rates into a per day statistics (shown in table 3).

Table 3. Manure and nutrient excretion rates

Animal Species	Mass kg/head-day	N Excretion kg/head-day	P Excretion kg/head-day	K Excretion kg/head-day
Beef - Cow	31	0.19	0.044	0.14
Beef - Growing Calf	22	0.13	0.025	0.09
Finishing Cattle	27	0.15	0.020	0.10
Beef Bulls	31	0.19	0.044	0.14
Dairy Cow	63	0.41	0.070	0.11
Dairy - Calf - 150 kg	8.5	0.063	0.0105	0.046
Dairy - Heifer - 440 kg	22	0.12	0.020	0.09
Swine - Boar - 200 kg	3.8	0.028	0.0097	0.018
Swine - Sow	6.6	0.044	0.0128	0.029
Swine - Finisher	3.9	0.033	0.0053	0.014
Poultry - Turkey (females)	0.16	0.0025	0.00070	0.0010
Poultry - Turkey (male)	0.27	0.0041	0.00120	0.0020
Layers	0.09	0.0016	0.00048	0.0006
Broilers	0.10	0.0011	0.00033	0.0006

In the case of beef production animals were classified into one of four categories, beef cows, beef calves, finishing cattle, and bulls. Manure excretion is provided in the ASABE standard for beef cows, finishing cattle, and growing calves, but not bulls. I assumed that the excretion from beef bulls would be the same as a beef cow. In determining manure production from growing calves (< 1 year) the number of replacements was divided by two before multiplying by the manure production rate, this assumes that the birth of calves is uniformly distributed throughout the year, no correction was made for replacements heifers over one year of age as this value represents heifers that would have been present on the farm every day of the year. Estimating manure production from dairy cattle was done in a similar manner. I assumed that a cow would be in milk for 305 days in the lactation and dry the remaining 60 days of the year. Swine manure production estimates follow directly from the estimated animal numbers and the manure excretion rates provided in table 3. Similarly, manure production estimates for layers and broilers follows from their estimate of animal numbers. Manure production was based on an estimate that half of market turkeys were toms and the other half hens, with manure excretion from laying turkeys assumed to occur at the rate to turkey hens.

One concern with this methodology is that it assumes that the composition of as excreted manure has not changed from 1924 through the present. At first glance this assumption is certainly questionable. However, using UDSA data Smil (2002) has shown that, with the exception of meat birds (broilers and turkeys) which showed drastic improvement, that feed conversion efficiencies have remained relatively unchanged. This would suggest that assuming relatively similar as excreted manure composition to be a reasonable initial estimate if diet remained constant. A similar sentiment is provided by Coffey (1996) who states “from a global perspective, swine production has not been a source of increased manure nutrient production,” going so far as to suggest that improvements in nutrient use efficiency has even reduced nutrient excretion on a per pig basis. Specifically, Coffey (1996) states that feed conversion efficiently of grow-finish pigs has changed from 4 to less than 2.85 in top-producing pig herd, which on its own would result in nutrient excretion decreases of around 35%. However, animal diets have often changed dramatically over the last 100 years, often leading to significant improvements in animal performance, i.e., growth rates. Much of this improvement in animal growth would appear to be due to changes in diet that increased the quantity of feed the animal consumed, i.e., improved digestibility from smaller grind sizes and changes to more nutrient dense feed stocks. This change to greater nutrient density probably reduced the impact feed efficiency improvements had had on nutrient excretion as greater quantities of nitrogen and phosphorus were feed. More recently, improved understanding of the nutritional needs of the animal and the fraction of available nutrients within the feedstock have allowed nutritionists to better balance farm rations. Innovations such as phase feeding, the incorporation of industrial amino acids to improve nitrogen retention, as well as the inclusion of the enzyme phytase to increase phosphorus digestion have shown the potential to reduce nutrient excretion. Given these changes in animal feeding practices an increase in nutrient excretion from the animals would have been expected as the animals are confined and feed more nutrient rich feed stuffs; however, given the improvements realized in feed conversion efficiency and faster growth overall changes to nutrient excretion would have been minimized.

A second analysis where the manure was adjusted to an as applied basis by correcting for the percent of manure collected, nutrient losses during storage, and nutrient availability was also conducted. In this analysis it was assumed that swine manure would be stored in deep pits storages, beef feeder cattle would be raised on open feedlots, dairy farms would use a slurry manure system, turkeys and broilers would be raised on litter, and that layers would be housed in high rise facilities where manure collects below the cages and is stored until land application. I also assumed that beef cows, calves, and bulls would be raised on a mixture of open lots (30% of the time) and pasture (70% of the time), dairy calves and yearling were assumed to be on lots all the time, and swine boars and sows were assumed to use pit manure storage systems.

The first step in estimating manure production and nutrient content was to correct for nutrient and mass changes during storage. The percent loss that I estimated for different manure systems is shown in table 4. This table was calculated using the ASABE Manure Production standard for as excreted manure and the table of as removed production and characteristics table found at the end of the standard. No data was provided in the standard for beef cows, growing calves, bulls, dairy heifers and yearlings, or swine sows and boars. In these cases percent loss was assumed to be according to manure storage system. For example, since I assumed beef cows, calves, and bulls as well as dairy heifers and yearlings would be raised on open lots they were assumed to have the same mass and nutrient losses as finishing cattle raised on lots did (note, this does not account for the fact that beef cows, calves and bulls would only be on the lot 30% of the time). A similar approach was followed for swine sows and boards assuming they would have similar nutrient losses as swine finisher manure. The change in mass and nutrient loss was then multiplied by the daily excretion value and the percent of manure that would be captured to estimate amounts available for land application. This is summarized in table 5. Nutrient availability was estimated based on Sawyer and Mallarino (2008) which suggested that all phosphorus and potassium would be available (based on soil test conditions) and that 50% of nitrogen in dairy and beef cattle (sum of three year availability – 35, 10, and 5% availabilities in 1st, 2nd, and 3rd years respectively, which takes nitrogen credits for subsequent years), 100% of swine manure (100% in first year), and 60% of poultry litter (55 and 5% in 1st and 2nd years respectively) N would be available.

Clearly, many approximations were needed to make these assumptions. In particular, animal housing and manure storages have evolved over time. Specifically, prior to 1974, when rapid installation of confinement animal operations was occurring, these assumptions are suspect. Prior to this the percent of manure expected to be captured would have changed drastically as operations moved from pasture based system to confinement housing, altering manure capture for land application. Specifically, pasture systems were a common part of both dairy and swine prior to the 1960s; this would have significantly reduced the percent of manure that was recoverable in some cases to almost 0% in summers as animals would be almost continuously out on pasture. Additionally, the alternative manure management systems would have different nutrients losses than those assumed in table 4.

Table 4. Manure mass and nutrient percent losses during storage.

Animal Species	Mass % Loss	TKN % Loss	P % Loss	K % Loss
Beef - Cow	72.2	41.0	0.0	6.3
Beef - Growing Calf	72.2	41.0	0.0	6.3
Finishing Cattle	72.2	41.0	0.0	6.3
Beef Bulls	72.2	41.0	0.0	6.3
Dairy Cows	-6.2	51.4	0.0	0.0
Dairy Calf	72.2	41.0	0.0	6.3
Dairy Heifer	72.2	41.0	0.0	6.3
Swine - Boar - 200 kg	0.0	14.5	7.7	30.7
Swine - Sow	0.0	14.5	7.7	30.7
Swine- Finisher	0.0	14.5	7.7	30.7
Turkey Litter	48.8	27.3	61.8	9.8
Layer Manure	65.9	65.3	24.4	32.2
Broiler Litter	80.0	32.2	63.6	54.3

Table 5. Manure and nutrient values after storage.

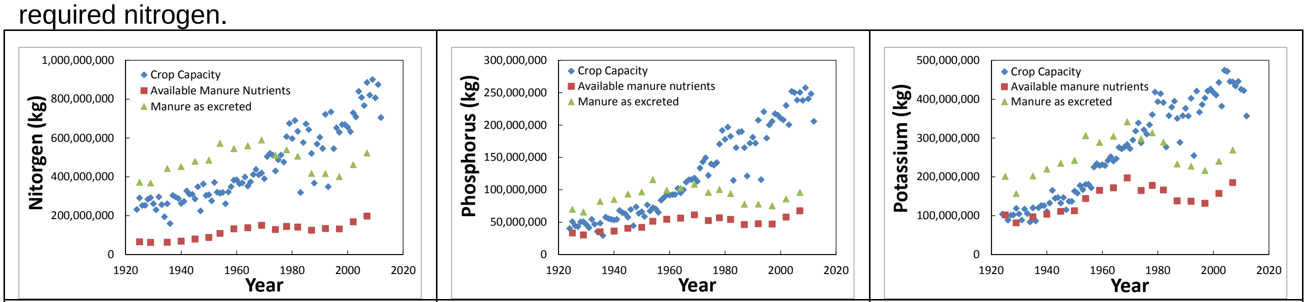
Animal Species	Mass kg/head-day	N Excretion kg/head-day	P Excretion kg/head-day	K Excretion kg/head-day
Beef - Cow	2.6	0.034	0.013	0.039
Beef - Growing Calf	1.8	0.023	0.0075	0.025
Finishing Cattle	7.5	0.089	0.020	0.094
Beef Bulls	2.6	0.034	0.013	0.039
Dairy Cow	67	0.20	0.070	0.110
Dairy - Calf - 150 kg	2.4	0.037	0.011	0.043
Dairy - Heifer - 440 kg	6.1	0.071	0.020	0.084
Swine - Boar - 200 kg	3.8	0.024	0.0090	0.012
Swine - Sow	6.6	0.038	0.012	0.020
Swine - Finisher	3.9	0.028	0.0049	0.010
Turkeys	0.11	0.0024	0.00036	0.0014
Layers	0.031	0.00056	0.00036	0.00041
Broilers	0.020	0.00075	0.00012	0.00027

Results and Discussion:

The first part of this analysis focuses on how manure excretion, manure nutrient availability for application, and crop nutrient demand has changed over time within Iowa (figure 1). Crop nutrient demand has increased greatly since 1924 (by approximately 4x, 6x, and 4x for N, P, and K respectively). The demand increased approximately linearly until around the 1960s when demand exploded, corresponding to increasing use of synthetic fertilizers. Demand continued to increase rapidly until around 1980 where it remained steady for approximately 20 years. Starting in the early 2000's demand again showed a steady increase for nitrogen and phosphorus, but demand for potassium remained relatively unchanged. One other trend of note in the nutrient utilization data is the four years where crop production was greatly reduced; these were 1983, 1988, 1993, and 2012. In three of these cases the reduced yields were due to drought like conditions (1983, 1988, and 2012) throughout much of the state and in 1993 it was due to flooding conditions. Similarly, reduced nutrient demands were seen in 1934 and 1935 (drought conditions) and in 1947 and 1956. However, nutrient utilization was much more volatile during the more recent adverse growing years than in the pre-1970's years. This is most likely due to the loss of crop diversity making nutrient demand much more dependent on a few crops and as a result more susceptible to adverse weather conditions during critical growth periods. Historically, nitrogen demand was about 50% from corn production with the other 50% split relatively evenly between small grain and grass hay production (figure 2a). However, corn now accounts for more than 90% of the nitrogen demand. Similar trends were seen for phosphorus and potassium demand (figure 2b and c); however in these cases nutrient demand is now dominated by the combination of corn and soybean demand.

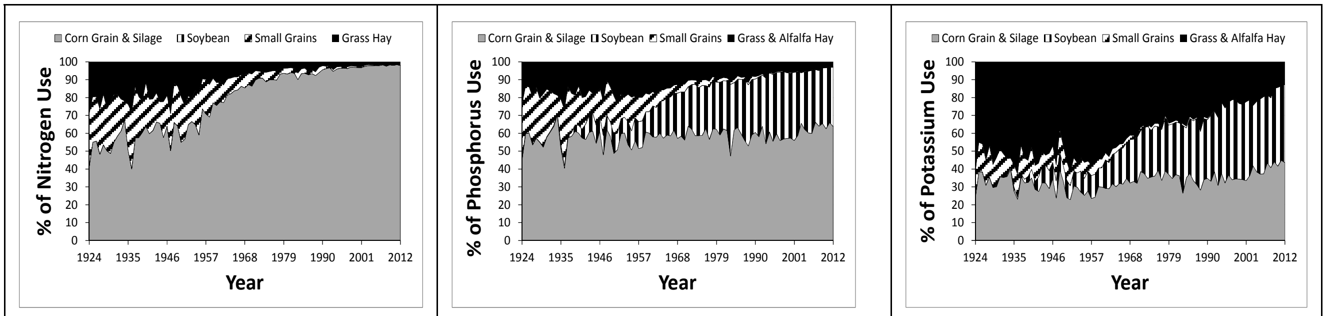
Manure production throughout the years has been less variable (nutrient excretion increased by a factor of about 1.4x for all nutrients, while available nutrients increased by 3x, 2x, and 2x for N, P, and K). Nitrogen excretion exhibited a slow and steady climb, peaking around the 1970's. It then declined back to approximately 1924 levels, bottoming out in the 1990s. More recently nitrogen excretion has once again been on the rise. Available manure nitrogen has risen relatively consistently, corresponding to changes from beef and dairy production to swine production, leading to better capture of the manure and reduced nitrogen losses during storage. Phosphorus and potassium excretion and available for application showed similar patterns to that of nitrogen, a first peak in the 1970s and then an increasing trend over the last 15 years. This peak in the 1970s corresponds to peaking of beef steer production in Iowa, where as the more recent increases corresponds to growth in the swine industry.

In general, I estimate that available nitrogen from manures has always been below the crop nutrient demand. This ratio actually peaked in the 1960s (when approximately 40% of N could be obtained from manure) and then decreases rapidly until the 1980s (approximately 22% of N could be obtained from manure). This change occurred due to the greatly increased demand for nitrogen for crop production. Since the 1980s this ratio has hovered around 22%. Similarly, phosphorus and potassium availability from manure has increased, but they too provide a lower percent of the nutrient demand required to support crop growth. As can be seen in figure 1 prior to 1970 I estimate that nitrogen, phosphorus, and potassium excretion in manures was actually greater than that the amounts harvested. This could occur if the animals were receiving a significant portion of the nutrients to support their growth from crops not accounted for in this analysis, presumably grasses while on pasture in these cases. In general, both available phosphorus and potassium initially trended closely with the amounts estimated to be harvested. Available nitrogen was significantly lower, indicating that crop production was either mining soil nitrogen or that green manures (plowing under of nitrogen fixing crops or cover crops) and the inclusion of legumes (alfalfas, clovers, field peas) in the rotations was supplying the required nitrogen.



(a) (b) (c)

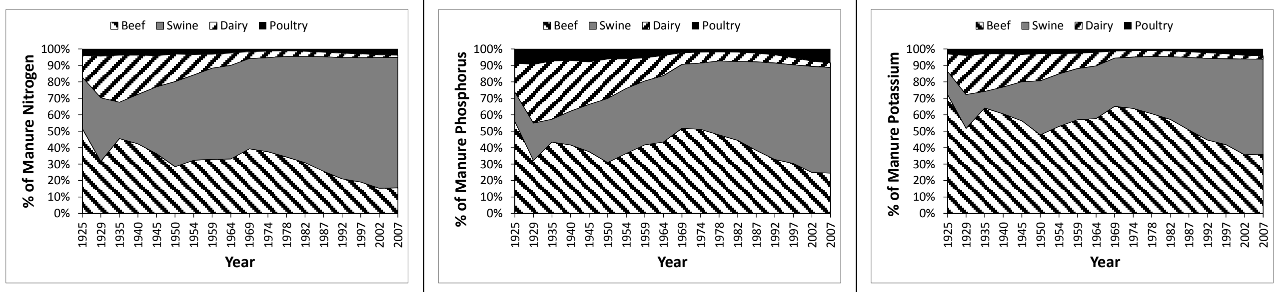
Figure 1. Trends in the crop nutrient utilization capacity and manure nutrients available for land application for (a) nitrogen, (b) phosphorus, and (c) potassium.



(a) (b) (c)

Figure 2. Estimated percent of crop nutrient for (a) nitrogen, (b) phosphorus, and (c) potassium for corn, soybean, small grains, and grass hay.

Another important aspect of evaluating changes in manure excretion and nutrient availability that is important to consider is how the contribution of available nutrients from different animal species has changed over time (figure 3). Dairy manure nutrients have consistently been a declining faction of the manure nutrients available for crop production. Similarly, manure nutrients available from beef cattle manures, although constant or even slightly increasing percent of all manure nutrients through the 1970s, has shown a steep decline ever since. This has allowed swine manure to become an ever increasing percentage of the manure available for crop production. As a result, there has been an increase in the percent of nutrients that are captured and available for crop production despite the fact that overall nutrient excretion beyond would have been expected from the change in nutrient excretion.

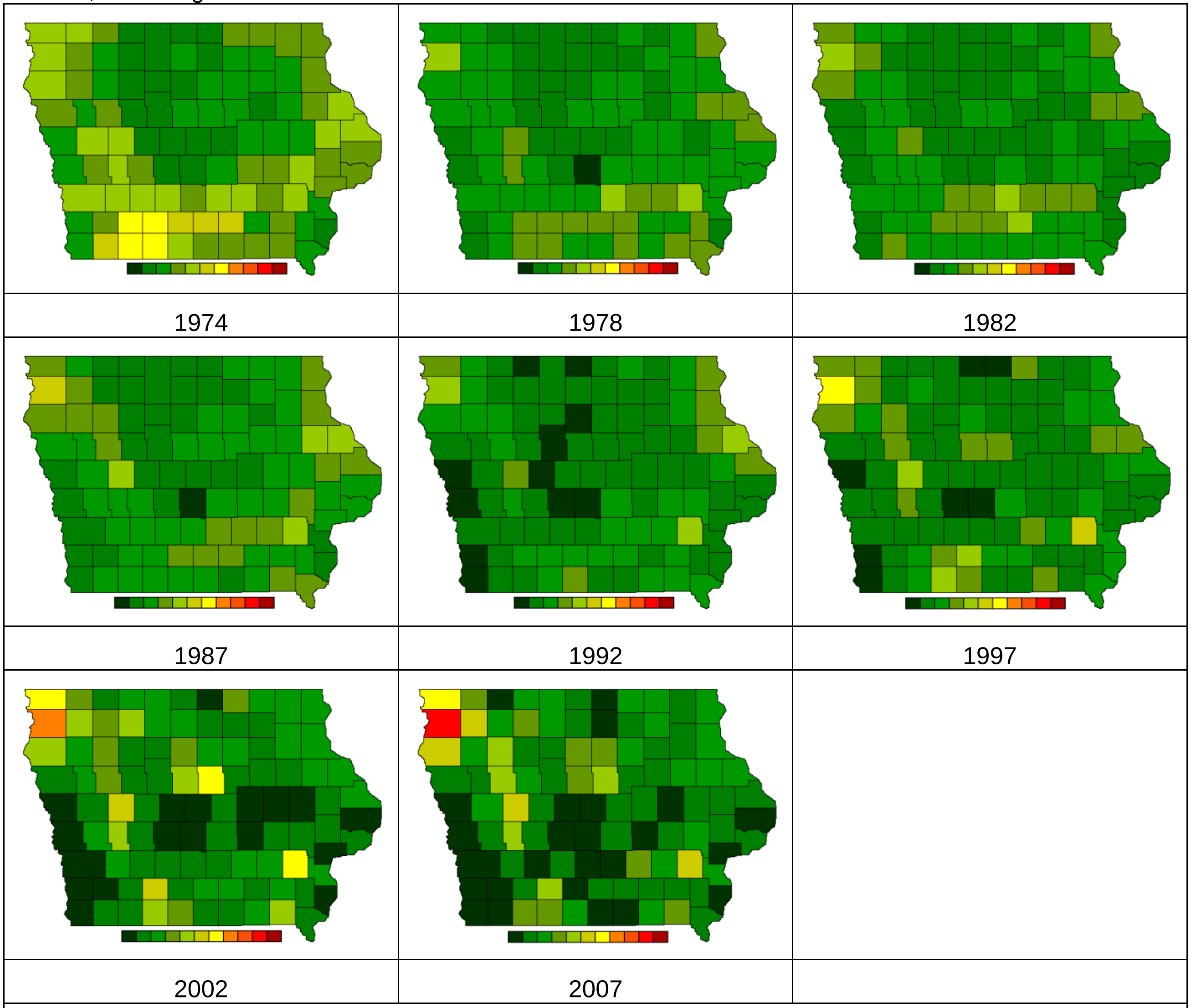


(a) (b) (c)

Figure 3. Estimated percent of manure (a) nitrogen, (b) phosphorus, and (c) potassium produced by beef, swine, dairy, and poultry as a function of year.

Our second question focused on the spatial distribution of nutrients at a county level and how this has changed with time. This analysis was performed to evaluate if within Iowa animal operations are congregating into specific regions as this could lead to the view of manure as a waste product in some areas while it would still be considered a resource at the state level. Specifically, this analysis will provide insight into what, if any regions may be in need of nutrient partitioning or extracting technologies that would make transport of the nutrients to manure poor regions more economically feasible. This analysis is repeated for each of the three nutrients of interest (nitrogen, phosphorus, and potassium) and for the census years of 1974, 1978, 1982, 1987, 1992, 1997, 2002, and 2007. Counties on the diagrams are color coded: counties that get the least (0-10%) of their required nutrient supply from manure are dark green; as a progressively greater percentage of nutrients could be supplied by the manure nutrients available within the country the shading changes to lighter greens, then yellow (60-70%), and eventually to a dark red (greater than 100% of required nutrient potentially available from manures).

In general, the same trends are seen for all nutrients. Counties in the northwest region are becoming progressively richer in manure nutrients in comparison to their crop nutrient demands. Specifically, for nitrogen I estimate that in the 1970s several counties (Adams, Taylor, Union, and Ringgold) could obtain more than 60% of their required nitrogen from manures. As nutrient demand continued to grow the percent that could be supplied by manures decreased; by 1992 only three counties (Sioux, Washington, and Dubuque) were estimated to be able to obtain more than 40% of their required nitrogen from manures. Since that time manure nitrogen has become more concentrated, such that Sioux county is now able to obtain more than 90% of its estimated nitrogen demand from manures. Several other counties (Lyon, Plymouth, O’Brien, Carroll, and Washington) are also obtaining a significant fraction of nitrogen from manures. However, there are also numerous counties (25) that now obtain less than 10% of their required nitrogen from manures. This illustrates that in Iowa concentration of animals and separation from crop production is becoming more prominent. Just as critical, the disappearance or reduction in the availability of animal manures is occurring in numerous other counties, indicating increases reliance on mineral fertilizers.



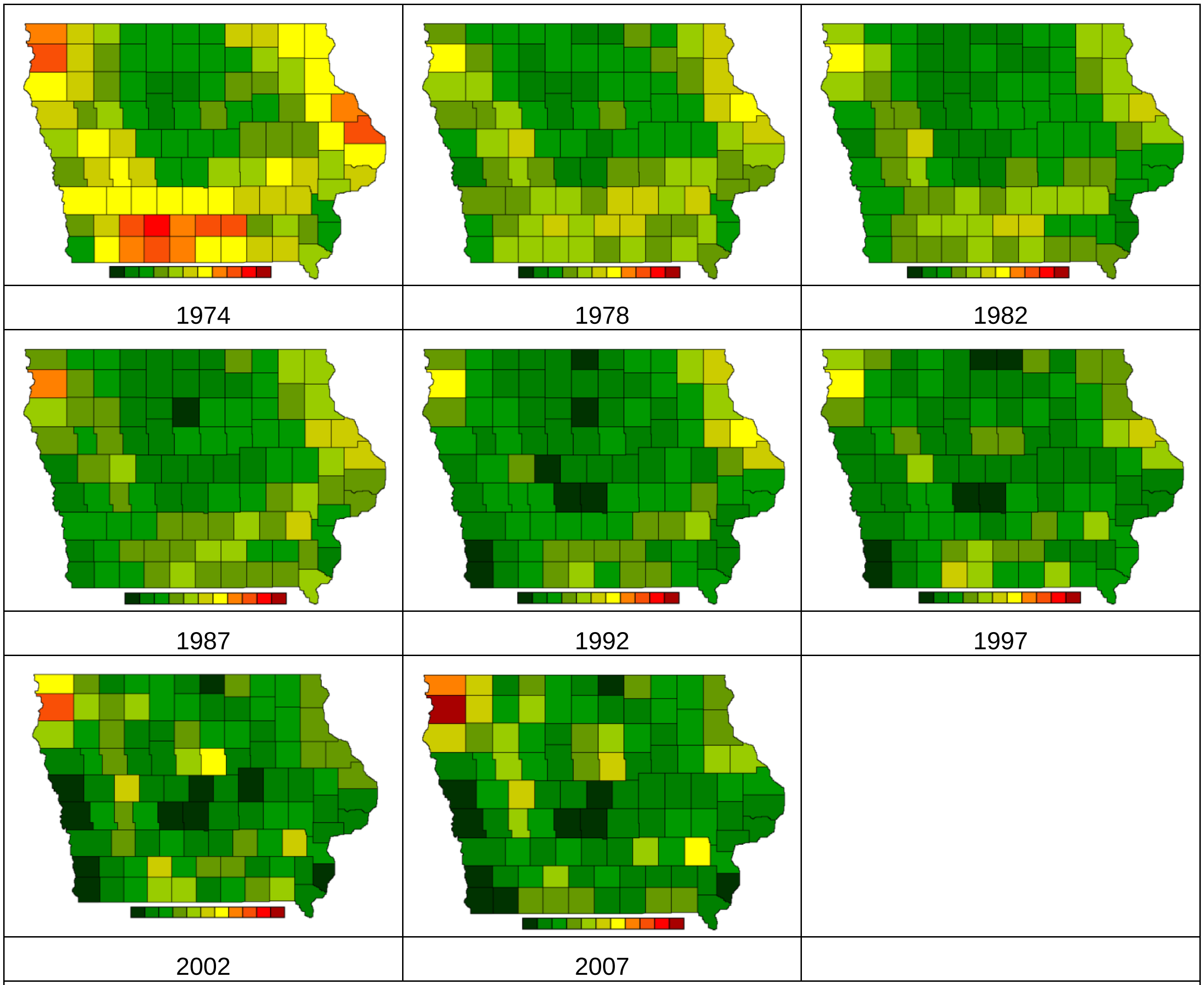
1974 1978 1982

1987 1992 1997

2002 2007

Figure 4. Ratio of manure nitrogen available for land application to crop nitrogen demand within a county. Darker green colors indicate that a lower percentage of nitrogen could be provided by manures. Colors get lighter green, yellow, and eventually red as a larger fraction of nitrogen can be obtained from the manures. Categories are 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, 90-100%, and greater than 100%.

In many ways similar trends were seen for phosphorus (figure 5) and potassium (figure 6). In the first year mapped (1974) the Des Moines lobe was clearly evident as these counties were able to obtain a significantly smaller fraction of their required phosphorus from manures than the rest of the state. At this time many counties (especially those along the Mississippi and Missouri rivers and in South Central Iowa) were phosphorus enriched with most of these counties able to obtain greater than 60% of the required phosphorus from manures. By 2007 only five counties (Lyon, Sioux, Carroll, Washington, and Hardin) could obtain more than 60% of their required phosphorus from manures. Similar to nitrogen, many counties are also obtaining only small quantities of their required phosphorus from manures. Specifically ten counties are now able to only obtain 10% or less of their phosphorus from manures.


1974 1978 1982

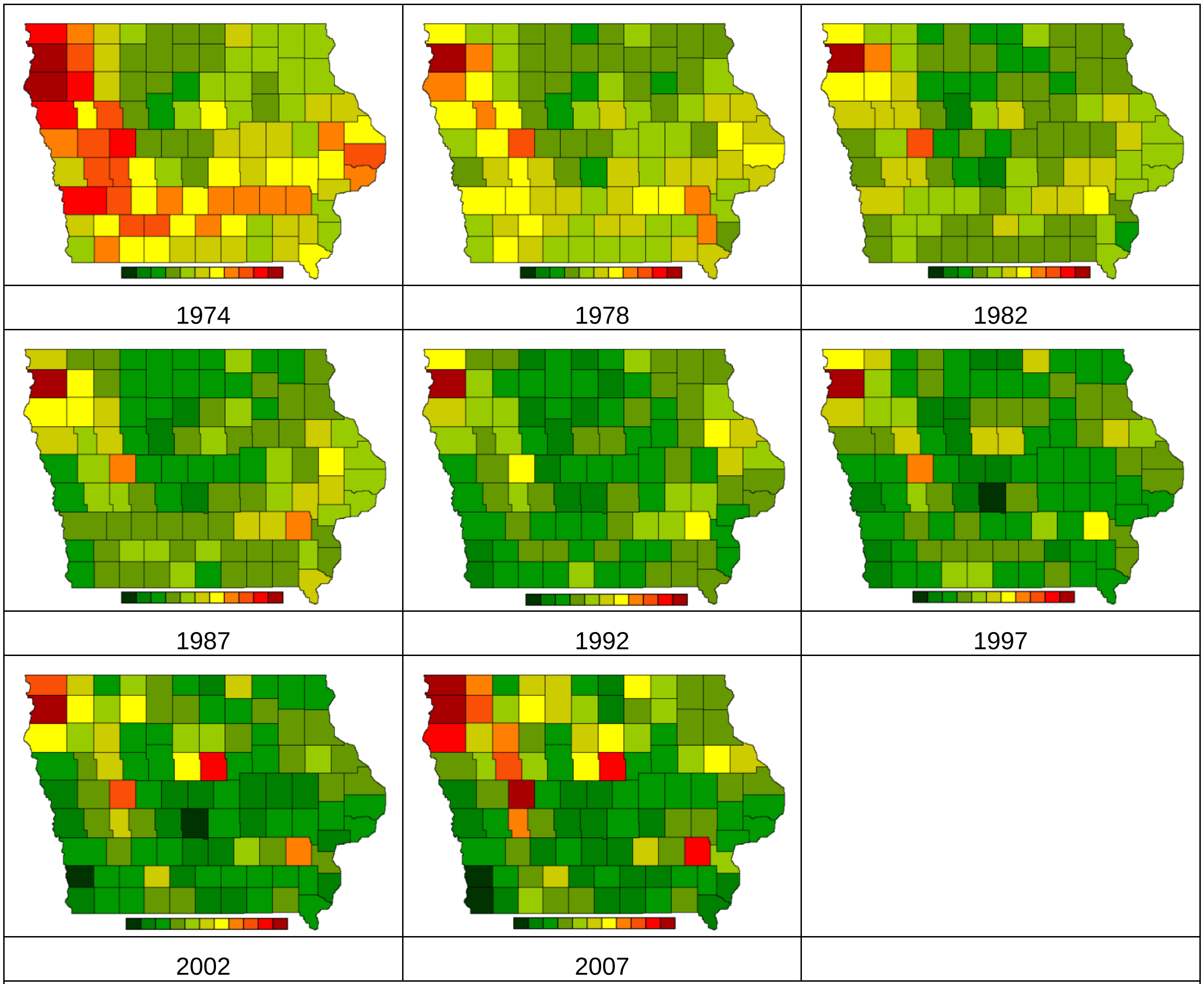
1987 1992 1997

2002 2007

Figure 5. Ratio of manure phosphorus available for land application to crop phosphorus demand within a county. Darker green colors indicate that a lower percentage of phosphorus could be provided by manures. Colors get lighter green, yellow, and eventually red as a larger fraction of nitrogen can be obtained from the manures. Categories are 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, 90-100%, and greater than 100%.

Conclusions:

These trends in manure nutrient availability in comparison to crop nutrient demand tend to indicate in most of Iowa nutrient assimilative capacity still far exceeds nutrient availability from manures in that county. However, there is strong evidence that animal production is concentrating and as a result becoming spatially separated from crop production areas. These trends indicate that opportunities for nutrient recovery and separation systems are starting to present themselves. As was shown, several areas are seeing increased availability of manure nutrients, and as such are nearing ratios where manure nutrient export from the county will be required to maintain nutrient balance. Also of note is that there are many areas in Iowa were these nutrients would be desirable as many counties are currently either mining soil reserves or becoming more reliant on mineral fertilizers to meet the nutrient needs of crops. This indicates that manure nutrient separation and nutrient recovery systems could provide a clear benefit as they provide opportunities to redistribute manure nutrients across the state, specifically from manure enriched counties to manure poor counties. Developing manure separation technologies that are economical and can be integrated into Iowa animal operations will be required to limit impact nutrient imbalances that separation in crop and livestock production present and to take full advantage of the nutrient resource manure provides.



1974 1978 1982

1987 1992 1997

2002 2007

Figure 6. Ratio of manure potassium available for land application to crop potassium demand within a county. Darker green colors indicate that a lower percentage of potassium could be provided by manures. Colors get lighter green, yellow, and eventually red as a larger fraction of nitrogen can be obtained from the manures. Categories are 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, 90-100%, and greater than 100%.

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