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Regional self-reliance of the Northeast food system

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Abstract

Farms producing similar products have become increasingly concentrated geographically over the past century in the United States (US). Due to the concentration of food production, a disruption in key production areas may reduce the availability of certain foods nationwide. For example, climate change poses such a threat, with projections of altered precipitation patterns, increased temperature and pest outbreaks, which may result in reduced crop yields and geographic shifts in crop adaptation. Analyses of the degree to which US regions can satisfy the food needs of their resident populations—a concept we refer to as *regional self-reliance* (RSR)—are therefore warranted. We focus on the Northeast region because of its high population density and declining agricultural landbase. Our objectives are to: (1) determine how agricultural land is used in the Northeast region; (2) determine the variety and amount of foods produced; and (3) analyze the relationship between food consumption and agricultural output. Annual (2001–2010) data on land area, yield and output of all crops and major livestock categories, as well as seafood landings, were catalogued. National annual (2001–2009) data on food availability were used as a proxy for estimates of food consumption, and these data were downscaled to a regional level and compared with regional production data in order to estimate RSR. In the Northeast region, approximately 65% of land in farms contributed directly to the food supply from 2001 to 2010, although this varied significantly across states. Just over one-half of all land in farms in the region was devoted to the production of livestock feed. The region produced >100 food crops annually from 2001 to 2009, and vegetables represented the majority of food crop production by weight. Chicken accounted for the largest weight of meat products produced. Compared to the Northeast region's share (~ 6%) of total land in farms in the nation, it accounted for disproportionately higher amounts of the national production of dairy (16%), eggs (13%), chicken (9%), lamb (7%) and vegetables (7%). However, the region accounted for ~22% of the national population and therefore produced a disproportionately low share of food on a per capita basis. RSR for plant-based foods was lowest for pulses (7%) and highest for vegetables (26%). There are four specific factors in the RSR in our analysis, each of which could result in substantial shifts (upward or downward) of the RSR in the future: land used for agriculture, crop (or animal) productivity, population and dietary preferences.

Key words: Northeast, regional food systems, land use, self-reliance, agriculture

Introduction

Crop and livestock production in the United States (US) has become more specialized at the farm level, and farms producing similar products have concentrated geographically over the past century[1]. The current production structure of livestock feeds, fruit, vegetables, food grains, nuts and oilseeds is the latest manifestation of those trends[2]. Although popular attention has focused on the potential energy costs and greenhouse gas emissions associated with long-distance transport of food, stimulating interest in *local food*[3,4], this represents a modest share of energy use within the agriculture and food sector[5,6]. A more serious concern may be the continued ability of the US agricultural system to maintain current production levels under climate change, especially given the reliance on irrigation in certain regions and for certain products. Climate change projections include altered precipitation patterns (amount and intensity), and temperature effects that will alter the range and severity of pest outbreaks in some areas. In some cases, this may result in reduced yields; in other cases, the outcome may be shifts in crop adaptation[7,8]. Although only 18% of US harvested cropland was irrigated in 2007[9], the reliance on irrigation in the production of fruits, vegetables and other specialty crops is often between 75 and 95% of total acreage[10].

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A disruption in key production areas may reduce the availability of these foods nationwide because of the geographic concentration of the production of some crop and livestock commodities (e.g. lettuce in California, swine in Iowa and North Carolina).

Given the concerns outlined above, investigations of the degree to which US regions can satisfy their own food needs—a concept that we refer to as *regional self-reliance* (RSR)—are warranted[11]. The capacity of a land base to supply the food demands of its population rests on how, and how much, agricultural land is used. Previous studies have evaluated agricultural production and food demand at different scales ranging from an urban center to national scale. Kremer and DeLiberty[12] used remote sensing, Geographic Information Systems (GIS) and parcel and zoning data to estimate the availability of bare or vegetated land in Philadelphia, Pennsylvania, with results indicating that land is widely available for residential food production in the city. In a follow-up study, Kremer and Schreuder[13] found that the landbase in and around Philadelphia could produce more than enough food to meet most dietary recommendations for the resident population. Colasanti and Hamm[14] used a similar approach applied to Detroit, Michigan, and found that vacant land areas could produce enough fruits and vegetables to meet a substantial proportion of current Detroit consumption amounts, yet much more land would be needed in order to produce enough fruits and vegetables for individuals to meet dietary recommendations. Peters et al.[15] focused on the state of New York, and used a complete-diet framework to estimate land-use requirements across diets characterized by differences in meat and fat content. They observed a nearly five-fold difference in the amount of land needed to accommodate dietary patterns. Peters et al.[16] used a spatial-optimization model to analyze the ability of New York State's agricultural land base to support the food needs of its population centers. Results demonstrated that, while New York City could scarcely meet any of its food needs from intra-state food production, all other population centers in the state could meet all, or nearly all, of their food needs. A similar approach was used by Hu et al.[17] to estimate the amount of food needed to satisfy federal dietary recommendations, and the distance that food would need to travel in order to reach certain populations in the Midwestern US. Buzby et al.[18] used national food supply data to estimate the difference between current and recommended consumption of various food groups, and applied that difference to production data to determine the changes in land use within each food group required to satisfy federal dietary recommendations. Additional methods have been developed using tabular[19–22] and model-based[23,24] approaches for application to a variety of spatial scales, but there remains to be a single agreed-upon method.

The high population density and declining agricultural land base of the Northeast US lends particular significance to an analysis of the degree to which the region can satisfy its own food needs. As noted above, earlier research sets precedents for analysis at various spatial scales, but none have included a comprehensive analysis of the ability of the entire Northeast region to satisfy its own food needs over a decadal time stamp. The present study aims to fill this gap by fulfilling several objectives: (1) determine how agricultural land is used in the Northeast region; (2) determine the variety and amount of foods produced; and (3) analyze the relationship between food consumption and agricultural output.

Methods

Spreadsheets were developed to catalog data on land area, yield and output of all crops and major livestock categories, as well as seafood landings, in each of the states in the Northeast region. Although there is no firm definition of the Northeast region, we have included the following states in order to be consistent with USDA National Institute of Food and Agriculture regions[25]: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia and the District of Columbia. National data on food availability (see below) were used as a proxy for estimates of food consumption[15,17]. These data were downscaled to a regional level and compared with regional production data, in order to estimate RSR. Subsequent sections demonstrate an approach to quantifying RSR in the Northeast.

Although our interest is estimating current production capacity, food consumption and the balance between these two factors, it is important to note that the contemporary agricultural land base in the Northeast region has contracted nearly 60% since 1929 (compared to a 7% decline nationwide), although the pace of change has been relatively flat since 1970[26]. The greatest proportional losses in the Northeast were in the New England states (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont), each of which experienced >70% decrease in land in farms and >60% decrease in harvested cropland over the past 90 years. Land that was once used for food production has reverted to woodland or has been developed for residential or commercial uses[27,28]. In many cases, abandoned agricultural land was unproductive, or marginal[29]. New York and Pennsylvania account for the greatest net loss of both land in farms and harvested cropland in the Northeast region since 1929[26], although these two states accounted for nearly 60% of the land in farms in the region from 2001 to 2010.

Estimating agricultural land use and crop production

The US Department of Agriculture (USDA) defines *land in farms* as any land managed as part of a farm[30]; we adopted this definition, and modified the framework used

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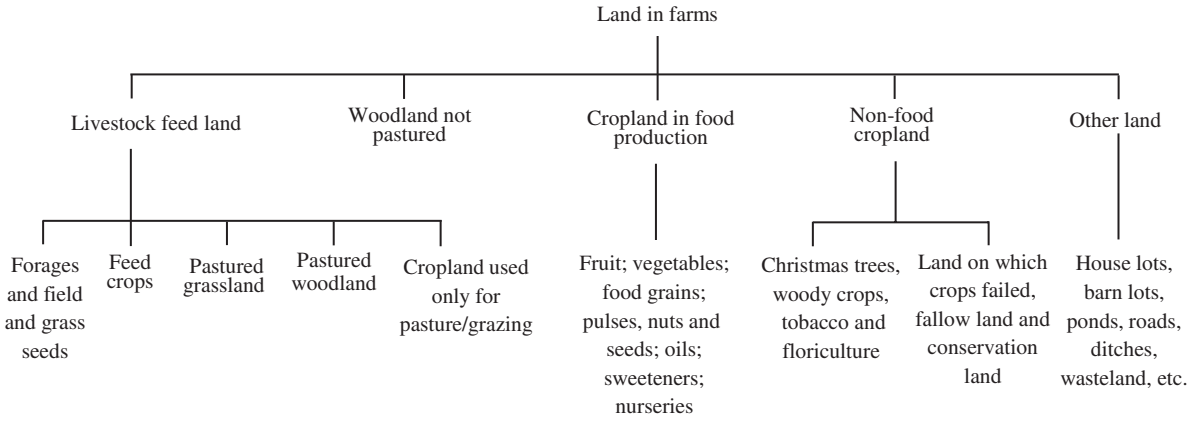

Figure 1. Land use classification.

in USDA Census of Agriculture[31] to categorize land uses (Fig. 1). As shown in Figure 1, land in farms includes: livestock feed land (forages and field and grass seeds, feed crops, pastured grassland, pastured woodland and cropland used only for pasture/grazing); woodland not pastured; cropland in food production (fruit; vegetables; food grains; pulses, nuts and seeds; oils; sweeteners; food crops grown in nurseries); non-food cropland (Christmas trees, woody crops, tobacco, floriculture, land on which crops failed, fallow land and conservation land); and other land (house lots, barn lots, ponds, roads, ditches and wasteland, etc.).

A review of data sources[32–53] was completed in order to quantify each of the land-use categories at the state level in the Northeast region annually from 2001 to 2010. In some cases, a land-use category may represent a single crop, such as broccoli used for processing or cucumbers destined for the fresh market. In other cases, a land-use category may represent a suite of crops that could not be disaggregated into individual crops due to lack of data availability, such as nursery stock. Data sources were reviewed in the following hierarchy of preference:

(1) USDA National Agricultural Statistics Service (NASS) Surveys[32];
(2) USDA NASS Agricultural Censuses[33–35];
(3) State Departments of Agriculture annual reports[36–41]; and
(4) State Departments of Agriculture specialty crop reports[42–45].

An annual dataset was constructed for more than 120 land-use categories. Data availability restrictions prevented the construction of a balanced panel dataset; data availability for each land-use category varies across the dataset, but data were included when possible.

Annual state yield and output data were less available across land-use categories in comparison to state land area data, necessitating the review of additional data sources, in descending preferential order:

(5) research trials at land grant universities[46–53];
(6) in cases where state-level land-use data were unavailable and agronomic conditions of the state are similar to regional conditions, regional yield data were used as a proxy for state-level yields; and
(7) remaining yield data gaps were filled through personal communication with experts in the field.

When data were available for only two of the three measures of interest (land area, yield and output), the missing value was estimated by solving:

$$O_{csi} = L_{csi} \times Y_{csi}, \quad (1)$$

where O is the output of a given crop (c) in a given state (s) in a given year (i), L is the land area and Y is the yield.

Out of the 91 crops for which land area data were available, yield and output data were available for 76 crops. Data on agricultural land use and output in the District of Columbia were not available and thus were excluded from the analysis. Regional output (r) of a given crop was estimated as:

$$O_{rc} = \sum O_{csi}, \quad (2)$$

where O is the output of a given crop (c). Land in multi-use crops (m) was attributed to livestock feed land or cropland in food production based on relative proportions provided by supply and utilization data[54,55]:

$$L_{mi} = \sum \left[\left(U_{cti} / \sum U_{cti} \right) \times O_{rci} \right], \quad (3)$$

where U is the given type of utilization (t) for a given crop in a given year.

Estimating production of meat, eggs, dairy and seafood

Regional meat production was estimated for five classes of animals: cattle, swine, lamb, chicken and turkey. Each class includes several subcategories for cattle (steers, heifers, milking cows, dry cows, bulls and calves) and swine (boars, sows, barrows and gilts). The regional output of beef, pork, lamb, turkey and chicken (f) was estimated as:

$$O_{fr} = \sum (N_{jsi} \times W_{jsi}), \quad (4)$$

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where N is the number of animals slaughtered within each sub-category (j) in a given state in a given year, and W is the live weight of a given sub-category of animal in a given state in a given year.

The numbers of beef cattle (steers, heifers, milking cows, dry cows, bulls and calves), swine (boars, sows, barrows and gilts) and lamb slaughtered annually in each state from 2001 to 2009 were obtained from USDA NASS annual slaughter reports[56]. State-level slaughter data for chickens and turkeys were not reported, and the number of broilers and other meat-type chickens sold live annually from 2001 to 2009 serves as a proxy[33,34]. The number of turkeys sold was obtained from USDA NASS 2002 and 2007 Censuses of Agriculture[33,34], and the proportion of turkeys sold for slaughter was obtained from USDA NASS 1997 Census of Agriculture[57] because subsequent Census iterations did not report the latter metric. Live weights of calves, swine, lamb, turkeys and chickens were obtained from USDA ERS[58]. Live weights reported by Zinn et al.[59] were adopted for steers and heifers, and we assumed weights of 561, 612 and 816 kg for dry cows, milking cows and bulls, respectively. Animals slaughtered in the Northeast region were assumed to be raised in the region. Some animals raised in the region were likely shipped outside of the region for slaughter.

Annual (2001–2009) state-level data on the number of layers, eggs produced per layer and total output of eggs were obtained from USDA NASS annual reports[58,60]. Annual (2001–2009) state-level data on the number of milking cows, milk output per cow and total output of milk were obtained from USDA ERS annual reports[61]. Regional output of eggs and milk (e) were estimated as:

$$O_{er} = \sum (G_{esi} \times Y_{esi}), \tag{5}$$

where G is the number of animals in a given state in a given year and Y is the output of a given product per animal (e) in a given state in a given year.

Annual data (2001–2009) on finfish and shellfish landings in the Northeast were captured for commercial operations[33,62–71]. Data were restricted to species caught in the Atlantic Ocean, Great Lakes and some brackish tidal basins by vessels owned and operated by US citizens. Annual output data were adjusted for non-food uses (livestock feed, industrial inputs, pet trade, pet feed, bait, recreation and conservation) and processing waste[72–74]. In some cases, data on the weights of certain species destined for food and pet feed, including inedible portions, (F) were not available, so these were estimated as:

$$F_p = [1 - (M_{in}/M_{iz})] \times O_{ip}, \tag{6}$$

where M is the market value of a given species (p) not destined for food and pet feed (n) or all uses (z), and O is the annual output of a given species. The total edible weight (V) of all species destined for food and pet feed was estimated as:

$$V_r = \sum \left[\left(F_{ip} + \sum J_{ip} \right) \times K_p \right], \tag{7}$$

where J is the weight of species for which data on the weight destined for food and pet, including inedible portions, were available; and K is the proportion of the edible amount of a given species. The total weight of all species destined for food (S) was estimated as:

$$S_r = \sum \left(V_r - \sum H_{ir} \right), \tag{8}$$

where H is the annual weight of all species destined for pet feed.

Estimating regional consumption

Food availability data were used as a proxy for consumption data[15,17]. Data were obtained from the Food Availability Data System[75], maintained by USDA ERS. USDA ERS estimates annual per capita food availability by subtracting annual exports from the annual sum of beginning stocks, domestic production and imports of individual commodities, and dividing the resultant by the national population. Annual (2001–2009) data were collected for dairy, eggs, turkey, chicken, beef, pork, lamb, fish and shellfish, in addition to >100 plant-based foods.

The Food Availability Data System reports the availability of some foods in *primary weight* (fruits, vegetables, pulses, eggs and dairy), others in *product weight* (food grains, meat products), and still others in *dry weight* (sweeteners). The primary weight of fruits, vegetables and pulses represents the weight of individual commodities directly after harvest; for eggs, the primary weight represents eggs including their shells; and for dairy, the primary weight represents the sum of all dairy products measured in fluid milk equivalents. The product weight of food grains and meats represents the weight of individual products after processing, such as milling (food grains) and dressing (meats). Sweeteners are reported in dry weight, which represents the weight of individual commodities less water content. All commodities reported in product and dry weight were converted to primary weight[58] in order to allow for comparison to output data.

Regional consumption (C) of a given commodity (y) was estimated as:

$$C_y = \sum (B_{yi} \times D_i), \tag{9}$$

where B is national per capita consumption of a given commodity per year, and D is the regional population per year[76].

Estimating regional self-reliance

Approximately 130 foods were identified from production and food availability data sources. Foods for which consumption data were not available were excluded from

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the RSR analysis ($n = 41$). Production data for 2010 were not included in the RSR analysis because consumption data were not yet available for that year. A total of 89 foods, including animal-based foods, fruits, vegetables, food grains, pulses, oils and sweeteners were considered for analysis (see Appendix 1). RSR represents the *net balance* of regional food production and food consumption, and is not a product of tracking food flows into, out of, or within the region. RSR (S) for a given commodity (y) was estimated as:

$$S_{yr} = (P_{yr}/C_{yr}) \times 100, \quad (10)$$

where P is the regional (r) production of a given commodity and C is the regional consumption of a given commodity.

Results

Land use

An annual mean of ~11 million hectares of land in the Northeast were used for agricultural production between 2001 and 2010 (Table 1). Agricultural land accounted for ~21% of the total land area in the region and ~6% of the land in farms in the nation[32,77]. Land in farms can be divided into land that contributes directly to the food supply (livestock feed land and cropland in food production) and land that does not (woodland not pastured, non-food cropland and other land). In the Northeast region, ~65% of land in farms contributed directly to the regional food supply from 2001 to 2010, although this varied significantly across states, from a high of 83% in Delaware to a low of 34% in New Hampshire.

Over one-half (56%) of all land in farms in the Northeast region from 2001 to 2010 was devoted to the production of livestock feed, which represented the primary agricultural land use for nine of the states in the region (Delaware, Connecticut, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, Vermont and West Virginia). Over 60% of livestock feed land was located in Pennsylvania and New York, and nearly 80% was located in Pennsylvania, New York and West Virginia.

Woodland not pastured represented the second largest agricultural land-use category in the region from 2001 to 2010, occupying 22% of all land in farms. Woodland not pastured represented the largest land-use category in New Hampshire, Massachusetts and Rhode Island.

Approximately 8% of all land in farms in the Northeast region from 2001 to 2010 was cropland in food production. Over 50% of this land was located in Pennsylvania and New York, and >70% was located in these two states plus Maryland. For each state in the region, cropland in food production as a proportion of total land in farms ranged from a high of 33% in Delaware to a low of <1% in Vermont and West Virginia.

Table 1. Northeast regional mean agricultural land area, 2001–2010.

Land area category	Regional total (10^3 ha)[1]	Proportion of total (%)
Total land in farms	10,982	100
Livestock feed land (grazed and harvested)	6140	56
Forages and field and grass seeds	2809	26
Feed crops	1181	11
Pastured grassland	1072	10
Pastured woodland	450	4.09
Cropland used only for pasture/grazing	629	5.73
Woodland not pastured	2445	22
Cropland in food production	835	7.60
Fruit	107	0.97
Commonly eaten fruit[2]	67	0.61
Berries	36	0.33
Melons	4	0.03
Vegetables	177	1.61
Dark green	4	0.03
Starchy	97	0.88
Red and orange	25	0.23
Other	51	0.46
Food grains	280	2.55
Pulses, nuts and seeds[3]	9	0.09
Oils[4]	258	2.35
Sweeteners[5]	37	0.33
Food crops grown in nurseries	<1	<0.01
Non-food cropland[6]	826	7.52
Other land[7]	737	6.71

[1] Hectares harvested unless otherwise specified.
[2] All fruit except berries and melons.
[3] Dry beans, dry peas, nuts and seeds.
[4] Corn, soybean, canola and sunflower seed.
[5] High-fructose corn syrup and glucose.
[6] Tobacco, Christmas trees, woody crops for paper manufacture, floriculture crops, land on which all crops failed, fallow land and conservation land.
[7] House lots, barn lots, ponds, roads, ditches, wasteland, etc.

Food grains accounted for the largest share (34%) of cropland in food production (i.e., grains used for human consumption rather than livestock feed); followed by oils (31%); vegetables (21%); fruit (13%); sweeteners such as high-fructose corn syrup and glucose (4%); pulses, nuts and seeds (1%); and food crops grown in nurseries (<0.1%). The majority (56%) of land on which vegetables were grown was devoted to starchy vegetables such as sweet corn, potatoes and green peas. Other vegetables, such as snap beans, cucumbers and pickles, cabbage and onions occupied approximately 32% of land dedicated to vegetables. Red and orange vegetables, such as pumpkins, tomatoes and squash, were grown on approximately 16% of regional land devoted to vegetables, and dark green vegetables, such as spinach and collards, occupied approximately 2% of all vegetable land in the region.

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Nearly two-thirds (63%) of land on which fruits were grown was devoted to commonly eaten fruits (i.e., any fruit other than berries and melons)[78] such as apples, grapes and peaches, most (83%) of which were grown in New York, Pennsylvania and New Jersey. Approximately 91% of berries were grown in Maine, New Jersey and Massachusetts. Blueberries and cranberries accounted for over 92% of total berry land area in the region.

Non-food cropland accounted for approximately 8% of all land in farms in the region from 2001 to 2010. Fallow land represented the largest share (54%) of the non-food cropland in the region, followed by conservation land (25%), land on which crops failed (11%), non-food crops grown in nurseries such as garden plants (6.33%), woodland crops such as Christmas trees (4.24%), and tobacco (0.57%).

Output and regional self-reliance

The Northeast region produced >100 food crops annually from 2001 to 2009. Vegetables represented the majority (41%) of food crop production by weight, followed by oils (19%), fruit (19%), food grains (16%), sweeteners (4%) and pulses (<1%) (Table 2).

Nearly 80% of dairy produced in the Northeast region was produced in New York and Pennsylvania (Table 3). Approximately 70% of chicken meat was produced in Maryland and Delaware, and ~62% of lamb was produced in Pennsylvania and New Jersey. Pennsylvania accounted for the largest share of eggs (57%), turkey (67%), beef (85%) and pork (94%) produced in the region, although it is important to note that these proportions are based on slaughter, and that some animals cross state lines to be slaughtered. For example, Pennsylvania accounted for approximately 32% of beef cattle on an inventory basis[33,34].

Compared to the Northeast region's share (~5%) of total land in farms in the nation[31,79], it accounted for disproportionately higher amounts of the national production of dairy (16%), eggs (13%), chicken (9%), lamb (7%) and vegetables (7%). However, the region accounted for ~22% of the national population[76] and therefore produced a disproportionately low share of food on a per capita basis.

RSR in the Northeast from 2001 to 2009 was higher for animal-based foods than plant-based foods. Among the animal-based foods, the region was most self-reliant for dairy (76%) and chicken eggs (71%). RSR for shellfish and fish was 45% and 23%, respectively. RSR for meat products was highest for turkey (30%) and chicken (29%), followed by lamb (17%), beef (16%) and pork (15%).

RSR for plant-based foods was low compared to animal-based foods, and ranged from 7% (pulses) to 26% (vegetables). The most recent iteration of the Dietary Guidelines for Americans[80] recommends increasing consumption of fruits and vegetables, particularly dark green as well as red and orange vegetables, yet, within the vegetable category, the region was most self-reliant for starchy vegetables (33%) and other vegetables (33%), followed by red and orange vegetables (13%) and dark green vegetables (11%). Within the fruit category, the

Table 2. Northeast regional mean production and consumption of plant-based foods, 2001–2009.

Self-reliance category	Mean regional production (10^6 kg)	Mean regional consumption (10^6 kg)	Mean RSR (%)[1]
Fruit	1389	7622	18
Commonly eaten fruit[2]	1124	6590	17
Berries	167	278	60
Melons	98	754	13
Vegetables	2953	11,387	26
Dark green vegetables	39	364	11
Starchy vegetables	1458	4472	33
Red and orange vegetables	452	3554	13
Other vegetables	1003	2996	33
Food grains	1150	14,627	7.86
Pulses[3]	15	212	7.23
Oils[4]	1396	14,398	9.69
Sweeteners[5]	290	3752	7.73
Total	11,535	71,005	16

[1] Percent of regional consumption met by regional production, (production/consumption)*100.
[2] All fruit except berries and melons.
[3] Dry beans and peas.
[4] Corn, soybean and canola.
[5] High-fructose corn syrup, glucose, honey, cane and beet sugar, maple syrup, molasses, refiners' syrup, surgarcane syrup,and sorgo.

Table 3. Northeast regional mean self-reliance of animal-based products, 2001–2009.

Self-reliance category	Mean regional production (10^6 kg live weight)	Mean regional consumption (10^6 kg live weight)	Mean RSR (%)[1]
Dairy[2]	13,043	17,079	76
Eggs[3]	676	946	71
Shellfish	166	372	45
Turkey	187	622	30
Chicken	1107	3827	29
Fish	229	988	23
Lamb	12	69	17
Beef	717	4426	16
Pork	388	2552	15
Total	1836	3431	36

[1] Percent of regional consumption met by regional production, (production/consumption)*100.
[2] Fluid milk equivalent.
[3] Chicken eggs.

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region was most self-reliant for berries (60%), followed by commonly eaten fruit (17%) and melons (13%).

Discussion

Land use

The use of agricultural land in the Northeast, and how it has changed over time, reflects changes in consumer preference, the increased availability of certain products out of season (including through imports), and structural and market forces that have decreased the competitiveness of agriculture in the region. Our baseline analysis, presented here, provides a contemporary snapshot of the current land use and production capacity of agriculture in the Northeast region of the US.

In absolute terms, there is substantial diversity in the Northeast food system. Our data from 2001 to 2009 indicate that more than 100 crops were produced in the region. In addition to animal products from six major livestock species, there were also more than 250 species of fish and shellfish brought to shore in the region. Our results also show, however, the degree to which land use for crop production in the region is skewed to a small number of crops, which reflects national trends toward commodity crops. For example, nearly 40% of the land area used for cultivated crops (excluding land used for pasture and forage crops) was used to produce corn (grain and silage), compared to ~28% nationally. Just nine crops (corn, soybeans, wheat, alfalfa, oats, barley, potatoes, apples and Christmas trees) accounted for nearly 90% of the cropland area in the region.

Buzby et al.[18] and Peters et al.[15] previously demonstrated that per capita land requirements are higher for grains and livestock feed crops than for other crops. For example, the per capita land area requirement of grains at the national level for the US was estimated to be approximately five times higher than for fruits and vegetables[18]; if we include the feed crops (mostly grains but also grain-based silage crops) and food grains designations, our results show that the situation in the Northeast is identical (the ratio for the region is 5.14). Because of the predominance of perennial forages and pasture in the Northeast region, we estimate that livestock feed (which includes grains, silage and hay crops and pasture) accounts for ~ *17 times* more land than fruits and vegetables (Table 1).

There are several significant challenges to increasing the landbase for agriculture in the Northeast, which has been suggested to meet policy or economic development goals in the region[11]. A significant issue in expanding the agricultural landbase is that it would require the conversion of marginal land to cropland uses. This makes any assumptions of maintaining or increasing crop output at the regional level less compelling, because it would necessitate a larger shift in land use for each unit of output gained. An exception to this would be sites containing soils meeting prime farmland designation that are currently not being used for agriculture (prime farmland soils that reverted to forest, for example).

As noted above, the per capita requirements for specialty crops such as fruits, vegetables and nuts are much smaller than for grains and livestock feed crops. The greater capital and labor requirements for the production of specialty crops, combined with the need for a narrower range of soil characteristics (and also irrigation capacity), make it likely that increased regional production of specialty crops would entail *conversion* from one crop category to another. Specifically, this would necessitate a shift from agronomic to specialty crops rather than a conversion of marginal land to cropland generically; this would represent a marginal shift in agricultural land use. For example, the data we have used indicate that increasing the regional land area devoted to fruit and vegetable production (currently about 284,000 ha) by 50% via conversion would represent only 14% of land now used for the three predominant agronomic crops (corn, soybeans and wheat, totaling ~2 million ha).

Regional self-reliance

The concept of RSR might seem to imply that (1) the foods produced in the region are consumed in the region; and (2) the foods are available at the same time of year that consumers demand them. However, we do not base our analysis on *either* of these assumptions—our analysis is a net balance between production and consumption, conducted on an annual timestep (thus it does not consider seasonality). There are four specific factors in the RSR in our analysis, each of which could result in substantial shifts (upward or downward) of the RSR in the future: land used for agriculture (discussed above), crop (or animal) productivity, population and dietary preferences. The magnitude of the impact from each individual factor is determined by a unique set of drivers.

A projected population increase of two million (3.4%) people in the region by 2030[81] would cause a proportional shift in regional food demand, assuming that per capita consumption and dietary choice remained constant. It seems more likely, however, that the impact of this shift will be different across food products. Over the past three decades, food consumption has increased for some products (fats and oils, nuts and poultry) and decreased for others (dairy, red meat)[82]. This trend would obviously be interrupted if dietary preferences shift toward federal dietary guidance, which calls for increased consumption of fruit, some vegetables and low-fat dairy[80].

As population increases, maintaining RSR might be possible for some food products through productivity increases alone. For example, dairy output per cow has increased dramatically over the past century even in the face of steep reductions in cow inventory and on a shrinking associated landbase[83]. Likewise, some agronomic crops, most notably wheat but also soy and corn, have also exhibited long-term positive yield trends[84,85].

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However because many specialty crops are not grown under a yield maximization framework, and do not have a significant research infrastructure for yield improvement, increased aggregate output is more likely to be strongly affected by expanded acreage rather than by yield increases. Increased output would also necessitate the development of supply chain infrastructure in the region, which in the Northeast has experienced a long-term decline[86].

It is clear that the directional effects (upward or downward) of climate change on agricultural production are likely to vary by crop and region[7,8,87]. Although our analysis does not directly address climate scenarios, the low RSR for some food categories could feasibly be used to develop policies that encourage increased production of those categories in the Northeast, given the potential impacts of climate change both inside and outside of the region. In this light, two factors may interact to contribute to increased production of some products in some regions. First, the potential impacts of climate change on major production centers (Western and Southwestern US, for example) are particularly dire[88,89], which would dramatically impact water availability in those areas. Second, and related, this would necessitate increasing output in other regions of the US.

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Appendix 1. Data included in analysis, by land use category.

Category	Land area	Production	Food consumption
Livestock feed			
Forages and field and grass seeds			
Alfalfa seed	✓	✓	
Ryegrass seed	✓	✓	
Small grain hay	✓	✓	
Wild hay	✓	✓	
Alfalfa haylage or greenchop	✓	✓	
Other haylage, silage and greenchop	✓	✓	
Corn silage and greenchop	✓	✓	
Corn forage	✓	✓	
Sorghum silage	✓	✓	
Grassland pastured	✓		
Woodland pastured	✓		
Feed crops			
Barley	✓	✓	
Corn	✓	✓	
Dry shelled corn	✓	✓	
High moisture shelled corn	✓	✓	
High moisture ground ear corn	✓	✓	
Canola	✓	✓	
Oats	✓	✓	
Sorghum	✓	✓	
Soybeans	✓	✓	
Rye	✓	✓	
Wheat	✓	✓	
Sunflower seed, oil varieties	✓	✓	
Alfalfa	✓	✓	
Animal-based products			
Dairy		✓	✓
Eggs		✓	✓
Shellfish		✓	✓
Chicken		✓	✓
Turkey		✓	✓
Fish		✓	✓
Lamb		✓	✓
Beef		✓	✓
Pork		✓	✓
Woodland not pastured	✓		
Cropland in food production			
Fruit			
Commonly eaten fruit			
Apples	✓	✓	✓
Apricots	✓	✓	✓
Avocadoes			✓
Bananas			✓
Cherries, Sweet	✓	✓	✓
Cherries, Tart	✓	✓	✓
Coconut			✓
Dates			✓
Figs			✓
Grapes	✓	✓	✓
Grapefruit			✓
Kiwifruit	✓		✓
Lemons			✓
Limes			✓
Mangoes			✓
Nectarines	✓		

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Appendix 1. (*Cont.*)

Category	Land area	Production	Food consumption
Olives			✓
Oranges			✓
Papaya			✓
Peaches	✓	✓	✓
Pears	✓	✓	✓
Persimmons	✓		
Pineapple			✓
Plums and prunes	✓		✓
Tangerines			✓
Other non-citrus fruit	✓		
Other fruits and nuts	✓		
Berries			
Blackberries	✓	✓	✓
Blueberries	✓	✓	✓
Boysenberries			
Cranberries	✓	✓	✓
Currants	✓		
Loganberries			
Raspberries	✓	✓	✓
Strawberries	✓	✓	✓
Other berries	✓		
Melons			
Cantaloup	✓	✓	✓
Honeydew	✓	✓	✓
Watermelons	✓	✓	✓
Vegetables			
Dark green			
Broccoli	✓	✓	✓
Collards	✓	✓	✓
Romaine lettuce	✓	✓	
Kale	✓	✓	✓
Spinach	✓	✓	✓
Turnip greens	✓	✓	✓
Watercress	✓		
Starchy			
Potatoes	✓	✓	✓
Sweet corn	✓	✓	✓
Green peas	✓	✓	✓
Sugar and snow peas	✓	✓	
Green southern peas	✓	✓	
Red and orange			
Squash	✓	✓	✓
Sweet potatoes	✓	✓	✓
Tomatoes	✓	✓	✓
Carrots	✓	✓	✓
Bell peppers	✓	✓	✓
Pumpkins	✓	✓	✓
Other			
Artichokes			✓
Asparagus	✓	✓	✓
Beans, snap	✓	✓	✓
Beets	✓	✓	
Brussels sprouts	✓	✓	✓
Cabbage	✓	✓	✓
Cauliflower	✓	✓	✓
Celery	✓	✓	✓

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Appendix 1. (*Cont.*)

Category	Land area	Production	Food consumption
Chicory	✓		
Cucumbers and pickles	✓	✓	✓
Daikon			
Eggplant	✓	✓	✓
Escarole/endive	✓	✓	✓
Garlic	✓	✓	✓
Ginseng	✓		
Herbs	✓		
Horseradish	✓		
Head lettuce	✓	✓	✓
Leaf lettuce	✓	✓	✓
Mushrooms	✓	✓	✓
Mustard greens	✓	✓	✓
Okra	✓	✓	✓
Onions	✓	✓	✓
Parsley	✓	✓	
Other peppers	✓	✓	✓
Radishes	✓	✓	✓
Rhubarb	✓		
Turnips	✓	✓	
Vegetables, mixed	✓		
Other vegetables	✓		
Food grains			
Barley, grain	✓	✓	✓
Corn, grain	✓	✓	✓
Oats, grain	✓	✓	✓
Sorghum, grain	✓	✓	
Rye, grain	✓	✓	✓
Wheat	✓	✓	✓
Whole wheat flour	✓	✓	✓
White flour	✓	✓	✓
Durum flour	✓	✓	✓
Popcorn	✓	✓	
Proso millet			
Pulses, nuts and seeds			
Dry beans	✓	✓	
Dry peas	✓	✓	
Almonds			✓
Chestnuts	✓		
Hazelnuts	✓		✓
Macadamia nuts			✓
Peanuts			✓
Pecans, all	✓		✓
Pistachio nuts			✓
Walnuts, English	✓		✓
Sunflower seed, non-oil varieties	✓	✓	
Other nuts			
Oils			
Soybeans	✓	✓	✓
Sunflower seed, oil varieties	✓	✓	
Canola	✓	✓	✓
Sweeteners			
High-fructose corn syrup	✓	✓	✓
Glucose	✓	✓	✓
Maple syrup			
Honey		✓	✓
Cane and beet sugar			✓

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Appendix 1. (*Cont.*)

Category	Land area	Production	Food consumption
Food crops grown in nursuries			
Vegetables			
Vegetable seeds	✓		
Kale	✓		
Other green leafy vegetables	✓		
Tomatoes	✓		
Peppers	✓		
Collards	✓		
Turnips	✓		
Kale	✓		
Herbs	✓		
Cucumbers and pickles	✓		
Lettuce	✓		
Other vegetables	✓		
Other food crops	✓		
Mushrooms, *Agaricus*	✓		
Fruit and nuts			
Strawberries			
Other fruits and nuts			
Grapevines			
Citrus and subtropical fruits			
Non-food cropland			
Tobacco	✓		
Woodland crops			
Christmas trees	✓		
Woody crops for paper manufacture	✓		
Fallow land			
Idle cropland	✓		
Cropland in cultivated summer fallow	✓		
Land on which crops failed	✓		
Conservation land	✓		
Non-food crops grown in nurseries			
Aquatic plants	✓		
Bulbs, corms, rhizomes and tubers	✓		
Cuttings, seedlings, liners and plugs	✓		
Bedding/garden plants	✓		
Cut flowers and florist greens	✓		
Foliage plants	✓		
Potted flowering plants	✓		
Other floriculture and bedding crops	✓		
Flower seeds	✓		
Nursery stock	✓		
Other nursery crops	✓		
Tobacco	✓		
Other land (house lots, barn lots, ponds, roads, ditches, wasteland, etc.)	✓		

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