CHAPTER 2

The Changing Landscape of Global Agriculture

Jason M. Beddow, Philip G. Pardey, Jawoo Koo, and Stanley Wood

1. INTRODUCTION

Location matters when it comes to assessing agricultural productivity levels and trends. Most find familiarity with the notion that the amount and composition of agricultural output of a particular country or region of the world tends to change over time, but many are less familiar with the spatial dynamics of agriculture. The spatial structure and location of agricultural production both between and within countries, which we dub the landscape of agriculture, also varies over time. Agriculture is an inherently spatial process, with yields (and hence output) being greatly influenced by local factors such as weather and climate, soils, and pest pressures. Consequently, agricultural production and productivity are especially sensitive to spatial and inter-temporal variations in natural factors of production. As we do in this chapter, giving more explicit attention to the spatial dimensions of agriculture and how they change over time deepens our under-

---

Jason Beddow is a PhD candidate in the Department of Applied Economics at the University of Minnesota. Philip Pardey is a professor in the Department of Applied Economics at the University of Minnesota and director of the International Science and Technology Practice and Policy (InSTePP) center. Jawoo Koo is a research fellow and Stanley Wood is a senior research fellow at the International Food Policy Research Institute, Washington, D.C.

The authors are grateful for the assistance of Ulrike Wood-Sichra and Kate Sebastian in processing FAO data, and Michelle Hallaway and Connie Chan-Kang for assisting with entering and cleaning the U.S. data. Zhe "Joe" Guo provided GIS assistance with the global corn, wheat, rice, and soybeans spatial disaggregation. The work for this project was partly supported by the University of Minnesota, the U.S. Agency for International Development, and the Bill and Melinda Gates Foundation.

standing of the production and productivity performance and potential of this sector. The following section begins by presenting a broad assessment of changes in the global footprint of agriculture over the past three centuries. Agriculture is continually on the move, and this spatial volatility has profound implications for how productivity metrics can and should be interpreted.

Consideration of explicitly spatial patterns is useful, but additional insights can be gained by conducting analyses across meaningful spatial aggregations. Such spatial aggregations summarize certain attributes of space that affect agricultural production and productivity. For example, assessing production in terms of geopolitical aggregates is helpful since national or subnational borders help delineate the boundaries of economic, political, and social factors that affect the production choices made by farmers and other decisionmakers. However, geopolitical boundaries provide a poor proxy for agroecology. Thus, a more complete view of agricultural production can be developed by placing production in both geopolitical and agroecological space, as we do in Sections 3 and 4, respectively. Since movements in the footprint of agriculture necessarily imply underlying changes in the natural and socioeconomic factors that drive productivity, thoughtful interpretation of differences in a productivity metric across time or space requires consideration of the extent to which such changes might or might not be captured by that metric. Therefore, these assessments provide grounding and context for the discussions of productivity in the remainder of this volume.

Agricultural statistics are almost always reported on a geopolitical basis, but analysts are increasingly placing agricultural production in agroecological space. Recent examples include the work of Wood, You, and Zhang (2004) and You and Wood (2005) to develop geo-referenced global crop geographies for the world's principal (food) crops. Ramankutty and Foley (1999) and Ramankutty et al. (2008) have developed long-run geo-referenced maps of the location of crop production worldwide. It is to these sources of data—supplemented with global, commodity-specific production data from FAO—that we turn to assess the spatial dynamics of agriculture from both a geopolitical and an agroecological perspective.

2. SPATIAL DYNAMICS OF GLOBAL CROPPED AREA

While natural inputs play an important, if not defining, role in agricultural production, agriculture is the antithesis of natural. The output and productivity responses to these natural factors are affected by a myriad of human interventions. Choices about what, where, and when to grow or graze are obvious influences. Modifying the physical or environmental landscape—from leveling or terracing fields to adding fertilizer, supplemental irrigation water, or herbicides and pesticides, all the way to hydroponic production in glasshouse controlled environments—is commonplace. Modifying the genetics of crops and animals is also common.[1] For most of the 10,000-year history of agriculture, the purposeful selection and cultivation of crops and animals was without scientific direction. The rediscovery of Mendel's laws of heredity in 1900 gave added impetus to genetic modification in agriculture. The commercialization of hybrid corn in the United States beginning in the 1930s and the release of genetically modified (including transgenic) crops beginning in the 1990s are a continuation of the long history of human-induced genetic modification that is the essence of agriculture. It is the continuously evolving interaction between genes and the environment that underscores the value of a spatially sensitive perspective on agriculture production processes. The history of this evolution begins with the origins of the crops themselves.

Where crops, or their precursor plants, originated and where they are now principally grown are two sides of the same coin. Identifying the centers of origin of cultivated crops, and even whether such centers exist at all, is subject to considerable debate. Perhaps the most well-known line of reasoning started with the work of Vavilov (1926), who proposed that crops had geographical "centers of origin" and identified eight centers of origin based on measures of diversity. As summarized by Harlan (1971), it was later recognized that the centers of origin may differ from centers of diversity, and further, that the process of domestication can be geographically dispersed. A big part of the longer history of agricultural innovation has to do with the human-induced spatial movement of plants and animals. Candolle (1884, p. 2) noted that when it is feasible to do so, people "soon adopt certain plants, discovered elsewhere, of which the advantage is evident, and are thereby diverted from the cultivation of the poorer species of their own country." Further, Candolle observed that the ancient propagation of a number of useful plants in the Mediterranean (by Egyptians and Phoenicians) enabled later migrants to carry West Asian genetic material into Europe at least 4,000 years ago, and that there is evidence of well-established Chinese cultivation of rice, sweet potatoes, wheat, and millets

[1]The domestication of plants and animals distinguishes agriculture from earlier forms of food production, which involved hunter-gatherer activities whereby humans did not typically manage or in other ways knowingly modify (e.g., genetically) the food sources they sought.

as early as 2,700 BC.[2] It is clear that the pre-history of agriculture was driven by human-mediated dispersal and propagation of crop genetic material and therefore that the landscape of agriculture is, and has long been, subject to near continuous change.

Most agricultural production today uses genetic material that had its source hundreds or even thousands of miles away, but this is a comparatively recent phenomenon (Table 2.1). After thousands of years of slow development, slow improvement, and gradual movement of plants and animals, all driven by human action, the rate of change accelerated in the past 500 years. An important event in this history was the "Colombian Exchange" that was initiated when Columbus first made contact with native Americans in the "New World" (Crosby 1987, Diamond 1999). Most of the commercial agriculture in the United States today is based on crop and livestock species introduced from Eurasia (e.g., wheat, barley, rice, soybeans, grapes, apples, citrus, cattle, sheep, hogs, and chickens), though with significant involvement of American species (e.g., corn, peppers, potatoes, tobacco, tomatoes, and turkeys) that are also distributed throughout the rest of the world. The global diffusion of agriculturally significant plants and animals, and their accompanying pests and diseases, has been a pivotal element in the history of agricultural innovation.

The more recent, but still lengthy, spatial history of cropping patterns developed by Ramankutty and Foley (1999) used 1992 satellite-derived land-cover estimates along with historical (geopolitical) crop inventory data and a simple land-cover change model to estimate global cropping patterns back to 1700. Here, we make use of Ramankutty and Foley's long-run cropping data along with a similar global cropland dataset for 2000 (Ramankutty et al. 2008) to draw conclusions about changes in the geography of agricultural production over the last three centuries. These datasets are distributed by the Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin and for the sake of brevity will hereafter be referred to as the "SAGE" series (see the appendix).

We used a variety of techniques to represent the changing spatial patterns evident in the SAGE data. Figure 2.1, Panels a and b, give a mapped representation of the SAGE data for 1700 and 2000 respectively. Darker shades indicate that greater percentages of each 55.7-by-55.7 kilometer pixel (projected to the

[2] In fact, Fuller et al. (2009) recently reported evidence of the domestication of rice in the Lower Yangtze region of Zhejiang that dates to between 6,900 and 6,600 years ago.

Table 2.1. Regions of origin and current production of major feed, food, and fiber crops

Crop	Center of Origin	Top Five Producing Countries in 2005-07		
		Country	Production (mmt)	Global Share (percent)
Wheat	Central Asia	China	103.9	17.0
		India	71.0	11.6
		United States of America	53.4	8.7
		Russian Federation	47.4	7.8
		France	35.2	5.8
		Top Five Total	*310.8*	*50.9*
Corn	South Mexico and Central America	United States of America	294.0	40.1
		China	145.7	19.9
		Brazil	43.1	5.9
		Mexico	21.2	2.9
		Argentina	18.9	2.6
		Top Five Total	*523.0*	*71.3*
Rice	India	China	184.4	28.7
		India	139.3	21.7
		Indonesia	55.2	8.6
		Bangladesh	42.3	6.6
		Viet Nam	35.7	5.6
		Top Five Total	*456.9*	*71.1*
Barley	Abyssinia (Ethiopia)	Russian Federation	16.5	12.0
		Germany	11.5	8.3
		Canada	11.0	8.0
		France	10.1	7.3
		Turkey	8.8	6.4
		Top Five Total	*58.0*	*42.0*
Soybeans	China	United States of America	80.6	37.0
		Brazil	53.9	24.8
		Argentina	41.4	19.0
		China	15.8	7.3
		India	8.9	4.1
		Top Five Total	*200.6*	*92.2*
Cassava	South America	Nigeria	44.3	20.2
		Brazil	26.6	12.1
		Thailand	22.0	10.0
		Indonesia	19.6	8.9
		Congo, Democratic Republic of	15.0	6.8
		Top Five Total	*127.5*	*58.1*
Coffee	Abyssinia (Ethiopia)	Brazil	2.3	30.5
		Viet Nam	0.9	11.8
		Colombia	0.7	9.3
		Indonesia	0.7	8.7
		Mexico	0.3	4.1
		Top Five Total	*4.8*	*64.3*

Table 2.1. Continued

Crop	Center of Origin	Top Five Producing Countries in 2005-07: Country	Production (mmt)	Global Share (percent)
Bananas	Indo-Malaya	India	18.1	23.5
		China	7.0	9.1
		Brazil	6.9	8.9
		Philippines	6.7	8.7
		Ecuador	6.1	8.0
		Top Five Total	*44.8*	*58.3*
Tomatoes	South America	China	32.6	25.8
		United States of America	11.3	8.9
		Turkey	9.9	7.9
		India	8.9	7.0
		Egypt	7.6	6.0
		Top Five Total	*70.3*	*55.6*
Potatoes	South America	China	71.1	22.3
		Russian Federation	37.5	11.8
		India	24.6	7.7
		Ukraine	19.3	6.1
		United States of America	18.9	5.9
		Top Five Total	*171.5*	*53.8*
Apples	Central Asia	China	25.9	40.8
		United States of America	4.4	6.9
		Iran, Islamic Republic of	2.7	4.2
		Turkey	2.3	3.6
		Italy	2.1	3.4
		Top Five Total	*37.3*	*58.9*
Oranges	India	Brazil	18.1	28.4
		United States of America	8.0	12.6
		Mexico	4.1	6.5
		India	3.5	5.6
		China	2.8	4.4
		Top Five Total	*36.5*	*57.5*
Grapes	Central Asia	Italy	8.5	12.7
		France	6.7	10.0
		United States of America	6.3	9.5
		Spain	6.2	9.2
		China	6.1	9.1
		Top Five Total	*33.7*	*50.4*
Cotton	South Mexico and Central America	China	20.1	28.2
		United States of America	12.2	17.1
		India	10.2	14.3
		Pakistan	6.4	8.9
		Uzbekistan	3.5	5.0
		Top Five Total	*52.3*	*73.6*

Sources: Centers of origin are from Schery's (1972) adaptation of Vavilov (1951). See the appendix for sources of production shares.

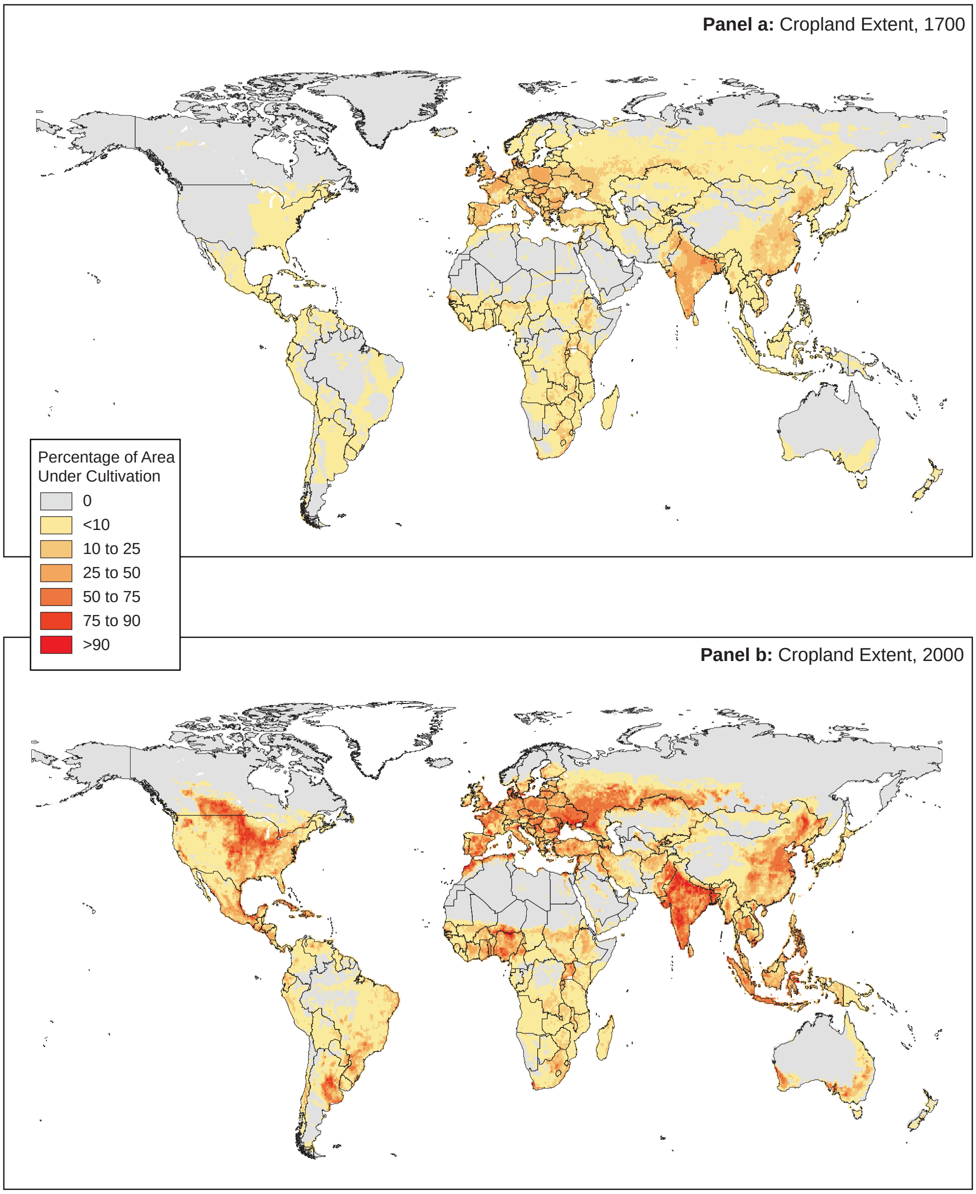


Figure 2.1. Panels a and b. The changing global landscape of crop production, 1700 to 2000

Source: Derived from SAGE data (see the appendix).

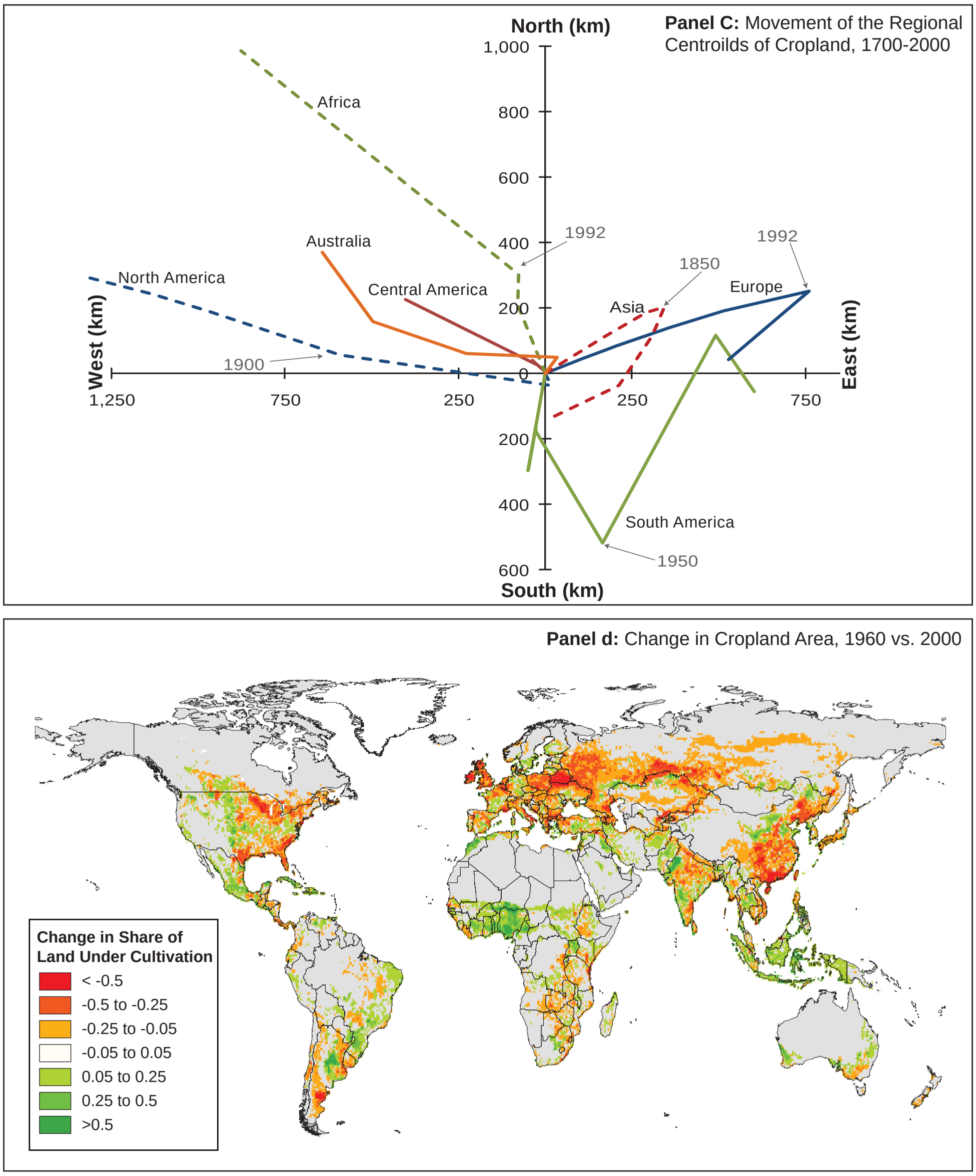


Figure 2.1. Panels c and d. The changing global landscape of crop production, 1700 to 2000

Source: Derived from SAGE data (see the appendix).

equator) are deemed to be cropped. Beginning in 1700, agricultural cropland occupied just 9% of the world's total land area, with most of that cropland located in Asia (accounting for 48.5% of the world's cropped area at that time), Europe (28.5%), and Africa (19.6%). Notably, the sparsely settled New Worlds of Australia, New Zealand, and the Americas collectively accounted for just 3.2% of the land worldwide under permanent crops in 1700. By 2000, the New World share had grown to 27.1% of the total cropped area.

The net effect of the movement of land in and out of cropped agriculture means that agriculture is geographically mobile, particularly when one takes an especially long-run perspective. Figure 2.1, Panel c, provides an indication of the distance and direction of the spatial relocation of agriculture globally by plotting the movement in the "centroids" or centers of gravity of production by region for the period beginning in 1700 (when each region's centroid is centered on a zero latitude-longitude grid coordinate) through to 2000. Each centroid is an estimate of the geographic center (center of mass) of the cropped area in the corresponding region. The location of the centroid itself is not particularly enlightening, and it could easily be the case that a centroid is in a location that does not produce any crops at all, or is otherwise not representative of the general agricultural situation in a country. However, movements in the centroid are revealing as an indication of the influences of changing patterns of settlement, infrastructure, and technologies on the location of agriculture.

According to these data, North America and Africa have seen the largest movements in their production centroids, both shifting about 1,300 kilometers over the 300-year period. As was the case with the other continents, most of this movement occurred after 1900. However, the year 2000 centroids for other regions more or less represent a continuation of the trend from 1950 to 1992; the only anomaly seems to be in Africa, where almost all of the measured movement in its centroid occurred between 1992 and 2000.[3] The Asian centroid moved the least, changing by only 15 kilometers to the east and 137 kilometers to the south.

---

[3]It seems more likely that the year 1992 and 2000 datasets were not fully conformable than that a massive structural shift in African production occurred during this period. However, the northward movement of agriculture in sub-Saharan Africa is consistent with the finding of Liebenberg, Pardey, and Kahn (2010) that the farmed area in South African agriculture peaked at 91.8 million hectares in 1960, then declined steadily to 82.2 million hectares by 1996, where it has since been more or less stable.

Except in Africa and Asia, the general trend favored movement in longitude rather than latitude. The pronounced northward movement in Africa was almost matched by an equivalent move westward, and, while the Asian centroid showed much more absolute movement along the east-west axis, the net movement over the period was almost due south. Averaging across all of the regions, the net longitudinal movement was 4.6 times as large as the net latitudinal movement. This pattern is related to an argument by Diamond (1999, p. 185), who stated that "localities distributed east and west of each other at the same latitude share exactly the same day length and its seasonal variations. To a lesser degree, they also tend to share similar diseases, regimes of temperature and rainfall, and habitats or biomes (types of vegetation)." Thus, a variety that is successful at a given location is more likely to be successful at other locations with similar latitude, and therefore a spread along the east-west axis is easier than a spread along the north-south axis.[4] This argument provides insights into the forces underlying the direction of agricultural movements, although the implications for modern movements in *overall* production are less clear. For example, opposite latitudinal movements in different crops may be netted out of an assessment of overall production. Second, Diamond took a very long-run view, looking back to pre-history. Insofar as crop management and varietal improvement technologies are reducing the yield-depressing effects of constraints to agricultural production at the more extreme latitudes, one might expect more recent data to exhibit relatively more movement toward the poles.

Over the past three centuries, agricultural cropland in Asia and Europe did move along an east-west axis, but there was considerable movement along a north-south axis as well. In addition, the direction of Eurasian development changed course. European cropland moved in a northeasterly direction until the early 1990s, then took a U-turn, heading southwesterly during the 1990s, no doubt the consequence of an implosion in Soviet agriculture during this period (see Swinnen and Van Herck in Chapter 10 of this volume). Asia moved simi-

[4]Diamond couched his discussion in the context of social developments stretching back into prehistory. Our assessment of the spatial mobility of cropped agriculture begins in 1700. Developments after 1700 dominate the economic landscape. For example, Maddison (2003) reports that global population was just 603 million in 1700 compared with 6.1 billion in 2001, while global GDP grew from an estimated 371 billion in 1700 to 37 trillion in 2000 (in constant 1990 international dollars). Moreover, most of the increase in the area under crops occurred after 1700, with global cropped area expanding by an estimated 253% since then (from 422 million hectares in 1700 to 1.49 billion hectares in 2000 [Ramankutty and Foley 1999 and Ramankutty et al. 2008]).

larly, following a northeasterly trajectory until the 1850s, and then also took a southwesterly track. As of 2000, the Asian centroid was in north-central Bhutan near the border within China, suggesting that the relative rates and spatial patterns of cropland development in China and India dominate the movement in the region's centroid. However, expanding cropland in Indochina and Indonesia during the latter half of the nineteenth century and throughout the twentieth century would tend to tug Asia's centroid southward.

As one might expect given the way these landscapes were settled (particularly with regard to agriculture), both the North American and Australian centroids moved strongly in a westerly direction. This westward movement came with an evident northerly drift that became more pronounced for North America beginning in 1900 and in 1950 for Australia. Notably, a more northerly direction of development for North American agriculture means cooler climates and shorter growing seasons while for Australia it means movement toward more tropical growing conditions. The more northerly path taken by North American agriculture during the twentieth century coincides with the massive ramping up of institutions and investments pertaining to agricultural research and development (see Alston et al. 2010), suggesting that technological factors began playing a more prominent role in the location of crop production.[5] The same forces may have also been operative in Australia, with increasing attention given to tropical technologies by Australian agricultural research institutions during the twentieth century, overlaid with (and part of) a broader government-sponsored program of infrastructure and economic development that put greater emphasis on the more northerly parts of the country (Davidson 1966 and 1981).

Cropland in Central America[6] shifted northwesterly, as developments in Mexico increasingly dominated that landscape. In stark contrast, South American cropland moved strongly in a southerly direction from 1700 to the 1950s, then dramatically changed course, heading northeast for much of the latter half of the twentieth century as Brazilian agriculture occupied

[5]Settlement patterns and the importation of cold-tolerant varieties help to explain the northerly movement of North American agriculture during the nineteenth century. Twentieth century expansion was much less dependent on opening of new lands and importation of germplasm, and much more dependent on the homegrown development and uptake of new corn varieties, notably the rapid uptake of short-duration hybrid varieties beginning in the 1930s that allowed for more intense production, and that spurred a movement into more northerly areas.

[6]Central America is typically defined as the area of Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. We also include Mexico because of its climatic and agricultural-historical similarities with the Central American countries.

an increasing share of the region's cropland (an estimated 25.3% in 1950 and 46.7% in 2000). As in Australia, the South American reversal of direction may stem largely from technological and economic policy developments in Brazil. The country rapidly ramped up its agricultural research capacity during the latter half of the twentieth century (Beintema, Avila, and Pardey 2001), and increasingly targeted that effort to more northerly climes. Spillover technologies from other countries—most notably day-length insensitive soybean varieties developed in the United States (Pardey et al. 2006)—enabled large tracts of land to be opened up for agriculture in the Cerrados region of Brazil. These technological factors were reinforced by a series of national development strategies that also targeted more northerly regions of the country.

Panel d of Figure 2.1 uses the SAGE series to show the change in cropped area over the four decades spanning 1960 to 2000. It indicates the localized movement of acreage in and out of agriculture since 1960, or, more specifically, the change in the area share dedicated to crop production for each of the 259,200 mapped pixels (i.e., a value of -50% indicates that half the acreage in that pixel shifted out of cropping agriculture since 1960). The darker the red shading, the greater the percent decline in cropped area per pixel; the darker the green shading, the greater the percent increase in cropped area per pixel. The collapse of the former Soviet Union is evident in terms of substantial declines in cropped area throughout Eastern Europe. The SAGE data also indicate declines in cropped area in parts of Western Europe, northeastern, southern, and southeastern United States, and significant parts of China.[7] There was a substantial increase in cropped areas throughout the Indochina Peninsula, Indonesia, West Africa, Mexico, and Brazil. The overall picture is one of contracting area under crops in temperate regions and increasing cropped area in tropical parts of the world during the last four decades of the twentieth century.

While the centroid of production provides a sense of the "average" location of production for a region, it is also useful to characterize the spatial dispersion of production. One can summarize spatial dispersion in a variety of ways,

[7]Wood, Sebastian, and Scherr (2000, p. 28) document the reduction in cultivated land in China during the first half of the 1990s, largely attributing this to expanded industrial and urban uses of land. Zhang et al. (2007) imply that this trend continued into at least the early part of the twenty-first century. For example, the authors estimate that 260,000 hectares of Chinese cultivated land was converted to non-agricultural uses between 1991 and 2001.

most commonly by assessing whether observations seem to be correlated with other nearby observations by calculating test statistics such as Moran's I (Moran 1950) and Geary's C (Geary 1954) metric.[8] In the present case, these statistics were calculated for each region in each year and the null hypothesis of spatial homogeneity was rejected for any reasonable degree of certainty, confirming the common-sense expectation that agriculture was not distributed uniformly across any of the continents.[9]

For our purposes, it is perhaps more useful to consider metrics of dispersion that are not explicitly spatial. Economists often analyze income distributions using a methodology first described by Lorenz (1905), who graphed cumulative income distribution against population percentiles. If income were equally distributed among the population, the Lorenz curve would be a 45-degree line through the origin, and the degree to which the curve departs from that line is usually summarized by the Gini coefficient (Gini 1912). Here, we make use of the pixilated landscape (30 arc-minute or 5 arc-minute pixels) inherent in the SAGE series and use Gini's procedure to assess the degree to which crop production is concentrated within each region.[10]

In this spatial context, the calculated Gini coefficients will equal zero if each of a region's pixels contains the same share of the region's agricultural area; the value of the coefficients will increase as agriculture becomes more concentrated in fewer pixels, and a coefficient of unity indicates that all production is in a single pixel.[11] In general, Gini coefficients differ more across regions than within regions over time. In every period, crop production was most spatially concentrated in North America and Australia and was least concentrated in Asia and Central America (Table 2.2). The relatively high coefficients for North America and Australia reflect a relatively low ratio of arable to total land, while the low Central American coefficients reflect the opposite, along with a tendency for

---

[8]Indeed, it is generally assumed that spatial autocorrelation is present unless there is evidence to the contrary. For example, the "first law of geography" states "Everything is related to everything else, but near things are more related than distant things" (Tobler 1970, p. 236).

[9]To reduce the scope of the problem, the spatial weights required for the calculations were defined using rook contiguity rather than an inverse distance metric. In general, these yield similar results but can differ, especially if production tends to exhibit more global autocorrelation than local autocorrelation. This does not affect the present conclusion.

[10]A 5 arc-minute grid yields pixels (cells) that are of about 86 square kilometers at the equator.

[11]Technically, the Gini coefficient calculated over discrete units (e.g., grid cells) cannot equal one; however, under perfect inequality the Gini coefficient approaches unity as the number of units approaches infinity.

Table 2.2. Spatial dispersion of production by year and region

	Gini Coefficient			3rd Quartile		
Region	**1800**	**1900**	**2000**	**1800**	**1900**	**2000**
North America	0.94	0.88	0.87	4.54	8.71	9.56
Central America	0.68	0.68	0.68	24.77	24.77	25.05
South America	0.77	0.75	0.73	18.17	18.73	13.33
Europe	0.80	0.78	0.76	16.07	16.72	11.47
Africa	0.78	0.78	0.79	16.11	15.99	13.21
Asia	0.75	0.74	0.70	18.41	19.72	20.63
Australia	0.93	0.93	0.90	5.37	5.52	4.96

Sources: See the appendix.
Note: The third quartile shows the percentage of each region's total area accounting for one-quarter of cropland.

relatively non-intensive production. Over time, the Gini coefficients for Africa and Central America were stable, while those for the other regions reflected a decreasing spatial concentration of production, as the agricultural footprint of these areas expanded.

Table 2.2 also displays production quartiles which, as implied by the relatively stable Gini coefficients, are also fairly stable over time. The third quartile shows the percentage of the region's total land area that contains 75% of the crop area. By this measure, the largest changes occurred in North America, which concentrated three-quarters of its cropped area in only 4.5% of its land area in 1800. By 2000, 9.6% of the region's land area constituted the same portion of overall cropped area. However, the increased (but still rather concentrated) spatial dispersion of cropped area in North America is a special case, as the interior of the continent, which is generally favorable for agricultural production, was not heavily settled until after 1800. By contrast, Central American and Asian production remained relatively spatially dispersed over the entire period, while South American, European, and African agriculture all became more concentrated after 1900.

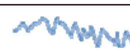
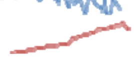
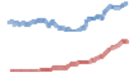
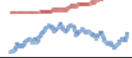
3. SPATIAL DYNAMICS OF GLOBAL CROP PRODUCTION

The previous section explored the long-run, spatially explicit view of agricultural change provided by Ramankutty and Foley (1999) and Ramankutty et al. (2008). We now turn to alternative empirical views of global production for more recent decades by first exploring the commodity- and country-specific data assembled by FAO. These data enable a crop-level assessment of the changing landscape of production within and among countries. Throughout the section, simple economic concepts are employed to provide additional insights that could not otherwise be gleaned from a geopolitical assessment, namely, by considering the interactions between geography, economic development (as measured by income per person), and crop values.

3.1. Global Changes in What Is Produced

Since 1961, a large area has been devoted to the production of cereal crops worldwide, increasing from about 648 million harvested hectares in 1961 to about 700 million hectares in 2007 (roughly 5.6% of the world's ice-free land area, and 55.8% of global harvested hectares).[12] In 2007, oil crops (such as soybeans and rapeseed) had the second-largest physical footprint, with harvested area for these crops totaling around 250 million hectares—more than double the 113 million hectares of oil crops that were harvested in 1961. Over half (52%) of the increased area in oil crops reflects a nearly fourfold increase in the area devoted to soybeans. Table 2.3 shows the trends in area devoted to each of the major crop categories used by FAO. Notably, while area devoted to production of oil crops increased steadily over the period, the area under cereals production increased to a maximum of about 720 million hectares by 1985, then generally decreased until an increasing trend again took hold during the new millennium.

Table 2.3. Global harvested area by crop category

	Area (million ha) and Trend		
Category	**1961**	**Trend**	**2007**
Fiber	38.7		35.8
Fruits	24.5		47.1
Oil crops	113.4		250.5
Pulses	64.0		73.3
Root crops	47.6		54.6
Vegetables	23.7		52.4
Cereals	648.0		699.8

Sources: See the appendix.

[12]This value was calculated based on Ramankutty et al. (2008), who reported that 15 million km^2 of cropland accounted for about 12% of the total ice-free land area in 2000 (which implies that there are roughly 125 million km^2 of ice-free land area).

Further, the total area devoted to pulses, fiber crops, and root crops was little changed, while the areas under fruit and vegetable crops both increased fairly rapidly (with the latter increasing at an increasing rate).

While the land area under cereal production increased from 1961 to 2007, total harvested area over all crops increased even more, so the share of land devoted to cereal production shrank from 67.5% in 1961 to 57.7% in 2007. This was a widespread development, such that the harvested area dedicated to cereals decreased relative to other crop categories in every region of the world except Eastern Europe. The largest changes were in Latin America and North America, which reduced the share of their cropland devoted to cereals by 17.6 and 14.0 percentage points, respectively (Table 2.4). Offsetting this reduction, the same two regions devoted relatively more of their land to oil crops, and in both regions nearly all of the increase in land devoted to oil crops is accounted for by increased soybean production.

3.2. Changes in Where Crops Are Produced

Changes in the global crop mix have been accompanied by changes in the distribution of production among and within countries and regions. Over the past four and a half decades, global cereal output became increasingly concentrated in Asia. This region increased its share of global cereal production from 37.6% in 1961 to 47.2% by 2007, most of which resulted from relatively fast growth of wheat and corn production in China.[13] Over the same period, North American output of cereals grew at about the global average rate, while output in the Former Soviet Union and Europe increased at a slower-than-average rate (2.0%, 0.6%, and 1.4% per year, respectively). Similar patterns were seen for

[13]Here the aggregate production of cereals, fiber crops, fruits, vegetables, roots, and pulses is a simple sum of the quantity of production (by weight) of each crop in a particular crop category. This measure of the aggregate quantity of production is affected by changes in the composition of the aggregate, with subtle but substantive implications for assessing changes in crop productivity (and, notably, aggregate cereal yields). For example, average wheat yields in Minnesota in 2007 were 3.0 tons per hectare while corn yielded 9.8 tons per hectare on average. Forming a “total cereals” perspective by simply summing 10 hectares of wheat output (by weight) and 10 hectares of corn output (by weight) would imply a cereal yield of 6.4 tons per hectare. If all the wheat acreage were switched to corn, estimated cereal yields would increase to 9.8 tons per hectare, absent any change in the average yield of corn (or wheat). These compositional effects will confound efforts to interpret changes in measures of aggregate crop productivity when the aggregate quantities of crop output are formed by simply summing the components of the aggregate (as done by FAO and many other analysts). Alston et al. (2010) explore the empirical implications of alternative aggregation methods when analyzing productivity developments in twentieth century U.S. agriculture.

Table 2.4. Share of cropland devoted to various crop types, by region

Region	Year	Fiber	Fruits	Vegetables	Roots	Pulses	Oil Crops	Cereals
				(percentage)				
North America	1961	5.6	1.0	1.4	0.7	0.7	18.0	72.5
	2007	3.2	0.9	1.1	0.5	2.6	33.3	58.5
Latin America and Caribbean	1961	7.2	3.6	2.2	5.2	9.2	13.7	58.9
	2007	1.7	5.2	2.1	3.7	6.4	39.5	41.4
Europe	1961	1.0	7.7	4.0	8.3	6.6	3.9	68.4
	2007	0.6	7.6	3.3	2.6	1.7	18.0	66.2
Former Soviet Union	1961	2.8	1.2	1.3	6.0	2.9	6.4	79.4
	2007	2.5	1.9	2.0	5.0	1.8	13.9	72.9
Africa	1961	4.5	4.3	2.0	8.3	7.1	16.8	57.1
	2007	2.6	4.5	2.9	12.0	10.5	13.7	53.9
Asia	1961	4.3	1.6	3.0	4.1	9.3	12.8	65.0
	2007	3.9	4.0	6.9	3.3	6.9	18.2	56.8
Oceania	1961	0.2	2.2	1.0	2.0	0.4	4.4	89.8
	2007	0.6	1.8	0.7	1.2	6.0	7.8	81.9
World	1961	4.0	2.6	2.5	5.0	6.7	11.8	67.5
	2007	3.0	3.9	4.3	4.5	6.0	20.6	57.7

Sources: See the appendix.

other types of crops, with Asia increasing its share of fiber, fruit, and vegetable production, again reflecting large increases in Chinese production of these types of commodities (Table 2.5).

In addition to considering geopolitical boundaries, it is also useful to delineate the agricultural landscape according to economic factors. To get a sense of how economic development is related to agricultural production, we grouped countries into two categories, "lower income" and "upper income," according to their income per person.[14] Between 1961 and 2007, the lower-income countries increased their share of production of all types of crops except oil crops. These

[14]The World Bank (2009) classifies countries according to their 2008 per capita gross national income expressed in U.S. dollars. The income groups are high income, greater than $11,905; upper-middle income, $3,856-$11,905; lower-middle income, $976-$3,855; and low income, less than $976. To simplify the presentation, we group the low and lower-middle income countries into one category called "lower income" and the upper-middle and high income countries into a second aggregate called "upper income." It may be helpful to keep in mind that the upper-income group includes Brazil and Russia while China and India are included in the lower-income group.

Table 2.5. Share of world crop production, by commodity type, 1961 versus 2007

Region	Year	Fiber	Fruits	Vegetables	Roots	Pulses	Oil Crops	Cereals
				(percentage)				
North America	1961	20.7	10.0	9.1	3.5	2.8	19.4	20.6
	2007	15.5	5.1	4.5	3.1	10.3	13.3	19.8
Latin America and Caribbean	1961	12.1	16.7	4.1	7.1	8.6	7.9	5.4
	2007	6.2	20.5	4.5	7.8	11.2	17.6	7.4
Europe	1961	3.6	30.7	21.6	30.3	9.6	9.8	16.5
	2007	1.7	12.6	7.6	8.5	5.5	8.3	11.7
Former Soviet Union	1961	13.8	2.9	8.3	18.5	9.0	10.4	13.5
	2007	6.5	2.2	4.4	9.8	3.8	4.3	6.7
Africa	1961	7.9	13.9	6.1	10.5	8.7	15.4	5.3
	2007	6.0	12.6	6.2	28.4	18.9	5.6	6.3
Asia	1961	42.0	24.5	50.3	29.7	61.0	36.3	37.6
	2007	63.2	45.9	72.3	41.8	48.3	50.1	47.2
Oceania	1961	0.0	1.3	0.5	0.4	0.1	0.7	1.1
	2007	0.9	1.1	0.4	0.5	2.1	0.8	1.0
Lower Income	1961	48.9	34.1	47.3	37.6	67.6	48.7	37.6
	2007	66.1	55.1	72.3	69.4	65.5	43.8	51.0
Upper Income	1961	51.1	65.8	52.7	62.3	32.3	51.3	62.4
	2007	33.9	44.9	27.7	30.6	34.5	56.2	49.0

Sources: See the appendix.

countries markedly increased their share of fruits, vegetables, cereals, fiber, and root crops. By 2007, lower-income countries produced 55.1% of the world's fruits (by weight), up from 34.1% in 1961. Indeed, the global growth in the quantity of fruit production was driven by a 361% increase in fruit production by lower-income countries (most of which occurred in the richer countries of this group). The lower-income countries also increased their share of vegetable output from 47.3% of production by weight in 1961 to 72.3% in 2007. By contrast, the upper-income countries increased only their share of oil crop production, from 51.3% to 56.2%, largely reflecting changes in Brazil.

The spatial concordance between (changes in) crop area and crop output are not always close. For example, in 2007 nearly 44% of the world's corn output came from North America while that region accounted for only 23.0% of the area devoted to corn. More strikingly, China increased its global share of wheat production from 6.4% in 1961 to 18.1% in 2007, while its share of land devoted to wheat shrank slightly. Such differences in output and area shares reflect differences in average yields (land productivity) across regions. They also reinforce the findings previously mentioned of the substantial spatial relocation in cropped area worldwide, pointing to even greater movement in the location of production for specific crops both among and within countries. This movement has many important economic implications, not least in relation to understanding the fundamental forces driving observed changes in (aggregate) crop production and productivity estimates.[15]

Between 1961 and 2007, the world's fruit and vegetable production area became more concentrated in Asia and, to a lesser extent, Africa (Table 2.6). Asia now accounts for 45.5% of the land devoted to fruit production and 71.5% of the

Table 2.6. Share of world crop area, by commodity type, 1961 versus 2007

Region	Year	Fiber	Fruits	Vegetables	Roots	Pulses	Oil Crops	Cereals
				(percentage)				
North America	1961	16.4	4.8	6.5	1.7	1.3	17.9	12.6
	2007	11.9	2.6	2.7	1.2	4.7	17.8	11.2
Latin America and Caribbean	1961	11.8	9.2	5.8	7.0	9.1	7.6	5.8
	2007	5.8	13.4	4.9	8.1	10.5	19.1	7.1
Europe	1961	2.8	33.7	18.1	18.7	11.1	3.7	11.3
	2007	1.4	14.3	5.6	4.3	2.1	6.4	8.4
Former Soviet Union	1961	10.8	7.0	8.3	18.7	6.7	8.4	18.2
	2007	7.8	4.7	4.4	10.4	2.7	6.2	11.7
Africa	1961	11.6	17.7	8.4	17.4	11.1	14.8	8.8
	2007	14.0	18.7	10.6	42.8	27.7	10.6	15.0
Asia	1961	46.6	26.8	52.4	36.2	60.6	47.1	42.0
	2007	58.7	45.5	71.5	32.8	50.5	39.2	43.9
Oceania	1961	0.0	0.8	0.4	0.4	0.1	0.4	1.3
	2007	0.4	0.9	0.3	0.5	1.9	0.7	2.7
Lower Income	1961	56.9	37.2	55.1	52.4	70.7	59.7	46.6
	2007	71.6	60.4	78.2	76.1	77.4	48.8	56.0
Upper Income	1961	43.1	62.8	44.8	47.5	29.3	40.3	53.4
	2007	28.4	39.6	21.7	23.8	22.5	51.2	44.0

Sources: See the appendix.

[15] A more in-depth assessment of productivity developments worldwide and in specific countries is provided in the following chapters.

land devoted to vegetable production, versus 26.8% and 52.4% in 1961, respectively. This change resulted mostly from increases in Asian fruit production area rather than from decreases elsewhere. Europe's fruit area decreased by 18.5% overall over the period, the net result of a 30.5% decrease in Western Europe and a 62.3% increase in Eastern Europe.

Over the same period, Asia increased its vegetable production area by a remarkable 202.4%. Increased vegetable area in China (18.3 million additional hectares) contributed to this change, although Asia without China still more than doubled its land devoted to vegetable production. A similar percentage increase in vegetable land area was seen in Africa (179.2%), although the continent only managed to keep pace with worldwide increases, maintaining a global share of production of slightly more than 6% during both periods.

3.3. Global Crop Production: An Economic View

In the preceding analyses, the crop categories used to describe changes in the cropped areas and amounts produced were based on quantities (by weight) of crop production aggregated into standard crop categories conceived on the basis of the biology of each crop (e.g., cereals, fruits, root crops, and so on). In this section we re-aggregate the crop quantities into crop categories conceived on the basis of the per unit value of each crop.

To conduct our analysis of the shifting landscape of crops grouped on economic criteria, all 157 crops (and crop products) in the FAO database (FAOSTAT) were classified into three groups, low, medium, and high unit-valued crops according to their average international price during 1999-2001 as reported by Wood-Sichra (2005).[16] Crop values ranged from about $20 per metric ton for sugarcane to nearly $4,500 per metric ton for vanilla. Acreage in low unit-valued crops is dominated by the cereals (wheat, corn, rice, and barley) and soybeans, which account for about 70% of the area in low-value crops. The most important high unit-valued crops (by area) were cotton, coffee, sesame seeds, cocoa, tobacco, and tea while the acreage in medium unit-valued crops was dominated by commodities such as dry beans, various peas, pulses, groundnuts, and olives.

[16]Prices reported by Wood-Sichra are the 1999-2001 average international prices used by FAO to form their production indices (see http://faostat.fao.org/site/612/default.aspx). Crops with an average price greater than $700 per metric ton were classified as high-value crops, while those with prices under $250 per metric ton were classified as low-value crops. Most livestock products would fall in the high-valued class, but here we limit our analysis to a consideration of plant products (not least because area under production is a more straightforward concept for crops versus livestock production).

Between 1961 and 2007, the global share of total cropped area devoted to low- and high-value crop production increased by about the same percentage, 24.2% and 28.5%, respectively. Over the same period, the area devoted to medium-value commodities increased by 68.8% (Table 2.7). Thus, there was a slight shift toward production of medium-value crops, and that shift was evident in both lower- and upper-income countries. However, the nature of the change was different for different types of countries: the importance of medium-value crops increased in the upper-income countries in part because of reductions in high-value crop area, while lower-income countries increased the area of all three classes of crops. This analysis reveals that the decline in harvested area in the Former Soviet Union and Europe resulted from decreases in area under low-value crops (by 38.9 and 20.7 million hectares, respectively) combined with small increases in the area under medium-

Table 2.7. Area by crop value class and region, 1961 and 2007

Region	Year	Value Class		
		Low	Medium	High
			(million ha)	
North America	1961	97.4	3.3	7.2
	2007	115.6	10.4	5.2
Latin America and Caribbean	1961	51.3	7.9	13.2
	2007	115.1	12.1	10.6
Europe	1961	91.2	16.5	2.1
	2007	70.5	19.1	2.2
Former Soviet Union	1961	142.7	4.3	2.6
	2007	103.8	5.0	3.1
Asia	1961	333.6	58.7	24.4
	2007	421.1	95.1	39.6
Africa	1961	76.5	16.0	11.3
	2007	149.1	36.8	17.1
Oceania	1961	9.7	0.2	0.1
	2007	21.5	2.0	0.4
World Total	1961	802.9	106.9	60.9
	2007	996.4	180.4	78.2
Lower Income	1961	380.3	70.0	35.2
	2007	548.5	126.2	56.6
Upper Income	1961	422.6	36.9	25.7
	2007	448.0	54.2	21.6

Sources: See the appendix.

and high-value commodities. Nevertheless, low-value crop area increased overall because of substantial increases in every other region.

4. AN AGROCLIMATIC PERSPECTIVE ON CROP LANDSCAPES

The spatial lens through which we have examined patterns of agricultural production is explicitly geopolitical. Both the national and subnational production data that underpin our analysis are collected and reported according to administrative (geopolitical) boundaries that, while not arbitrary, are demarked with little or no consideration of the agroecological variation that directly affects crop location choices and the production and productivity potentials of these crops. Thus, considering crop production totals aggregated over geopolitical space masks significant spatial heterogeneity within these aggregates that can have important policy and practical consequences.

To illustrate this issue, consider two countries: country A has spatially uniform growing conditions for its 200,000 hectares of rain-fed corn that each yield around 1.5 tons per hectare, while country B contains large extents of more arid areas where 160,000 hectares of production yield a meager 700 kg per hectare under rain-fed production and other more-favored areas where around 40,000 hectares yield 4.7 tons per hectare under irrigation. Both countries report identical national corn production statistics: 200,000 hectares of corn averaging around 1.5 tons per hectare (Table 2.8, Panel a). While the reported corn yields for both countries are identical, this masks the spatial heterogeneity inherent in these geopolitical aggregates, thereby compromising efforts to understand the factors that affect productive performance and variations in productivity over time and among countries.

For example, consider two adjacent countries that equally share 400,000 hectares of corn across a well-watered plain cut by national boundaries that yield some 2 tons per hectare. Additionally one has a further 200,000 hectares under dryland conditions yielding 800 kg per hectare, while the second has some 50,000 hectares of land under irrigation yielding 5 tons per hectare. When presented as national aggregates, their respective average yields of 1.4 tons per hectare and 2.6 tons per hectare suggest quite different production contexts (with perhaps little scope for technology spillover between these two countries) (Panel b of Table 2.8). Yet the common agroecological domain they share is the largest single productive resource, and so the productivity potentials of the two countries have much more in common than

Table 2.8. Spatial aggregation bias: geopolitical versus agroecological units

Geopolitical Aggregation	Agroecological Aggregation	Implications
Panel a		
Country A: 200,000 ha, 1.5 ton ha^{-1}	Country A: Warm, wet lowlands – 200,000 ha, 1.5 ton ha^{-1}	Geopolitical aggregations infer similar production contexts. Agroecological aggregations reveal large differences.
Country B: 200,000 ha, 1.5 ton ha^{-1}	Country B: Hot, semi-arid, poor soils – 160,000 ha, 700 kg ha^{-1} Hot, irrigated, good soils – 40,000 ha, 4.7 ton ha^{-1}	
Panel b		
Country A: 400,000 ha, 1.4 ton ha^{-1}	Country A: Warm, wet plains—200,000 ha, 2 ton ha^{-1} Hot, semi-arid—200,000 ha, 800 kg ha^{-1}	Geopolitical aggregations infer dissimilar production contexts. Agroecological aggregations reveal extensive commonalities.
Country B: 250,000 ha, 2.6 ton ha^{-1}	Country B: Warm, wet plains—200,000 ha, 2 ton ha^{-1} Warm, irrigated, good soils—50,000 ha, 5 ton ha^{-1}	

Source: Developed by the authors.

would be inferred from a consideration of yield relativities absent the agroecological information.

Panels a through d of Figure 2.2 show the year 2000 estimates of the global crop geographies for corn, wheat, rice, and soybeans, respectively. In these plots, the larger the share of cropped area per pixel in the indicated crop, the darker the shade. Panel e of Figure 2.2 shows 16 agroecological zones based on moisture and temperature. To reveal some of the within-country variation in the production landscape of agriculture, we overlaid the agroclimatic representation on the respective 2000 global crop geographies for corn, wheat, rice, and soybeans to generate production area and quantity estimates for these four crops stratified by agroclimatic regions within countries. For each crop this generated a spatial regrouping of the area and quantity data for a total of 785 agroclimatic-by-country classifications. To simplify the presentation of these data, the countries were re-ag-

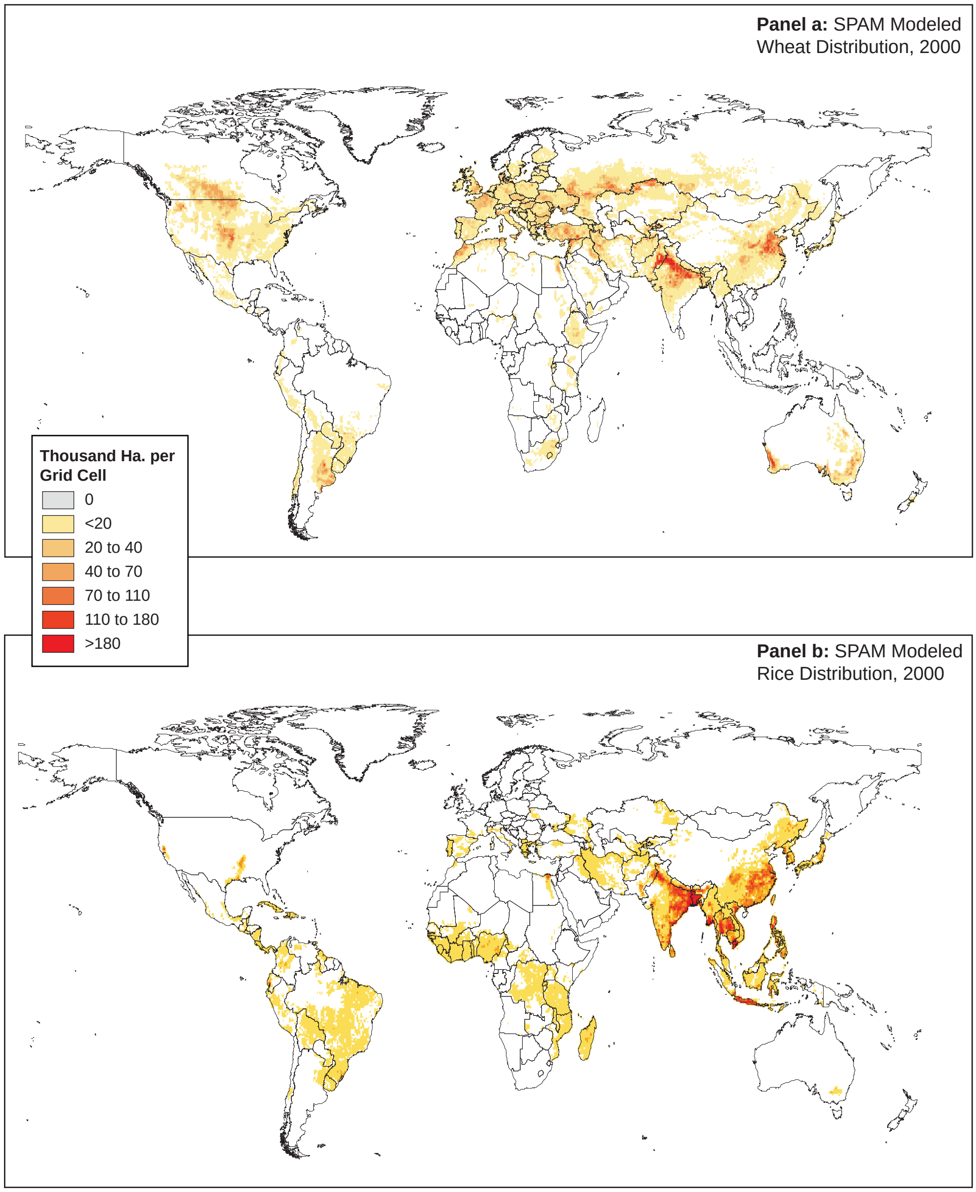


Figure 2.2. Panels a and b. Global agroclimatic zones and year 2000 crop geographies

Sources: Crop allocation data are documented by You and Wood (2005). Global agroecological zones were modified from Sebastian (2006).

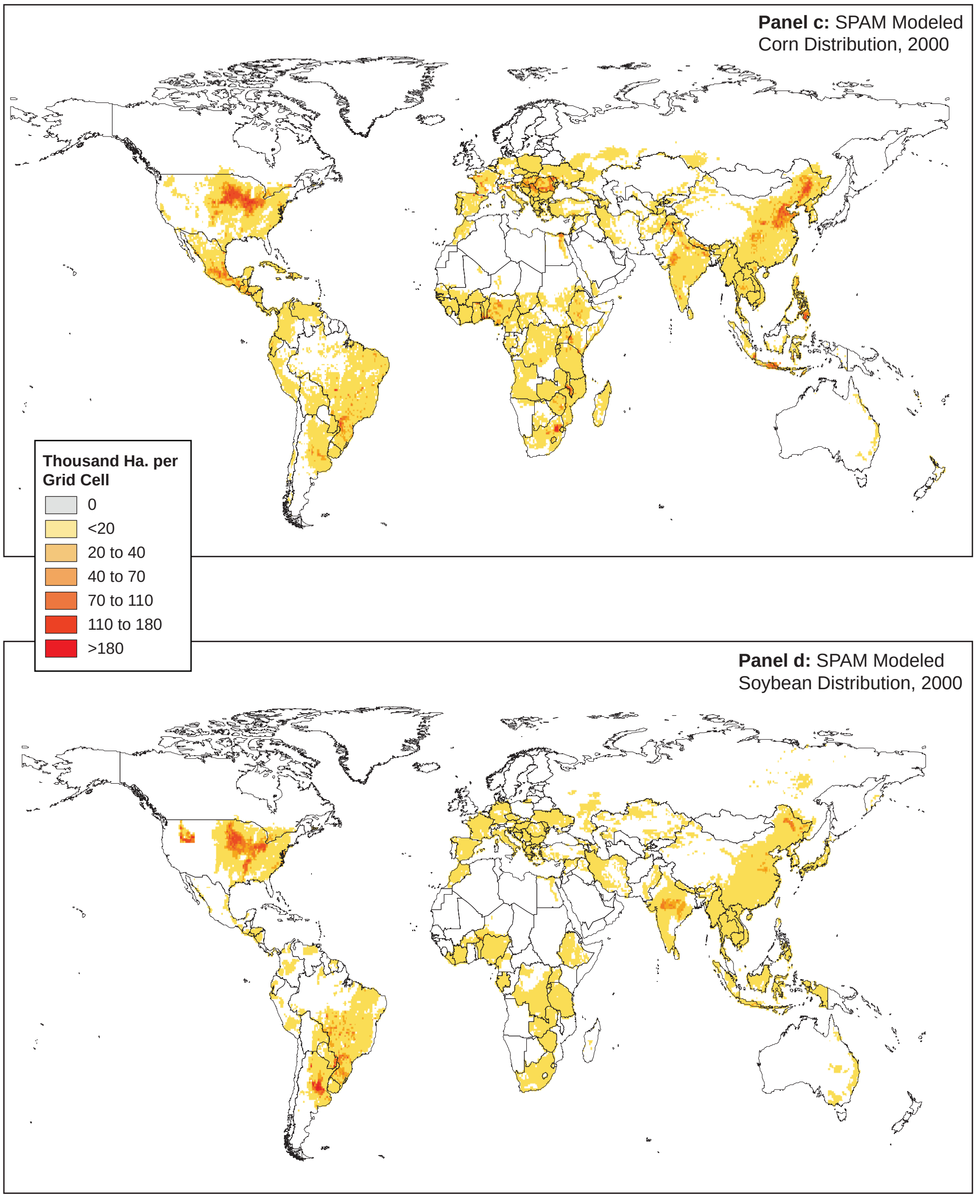


Figure 2.2. Panels c and d. Global agroclimatic zones and year 2000 crop geographies

Sources: Crop allocation data are documented by You and Wood (2005). Global agroecological zones were modified from Sebastian (2006).

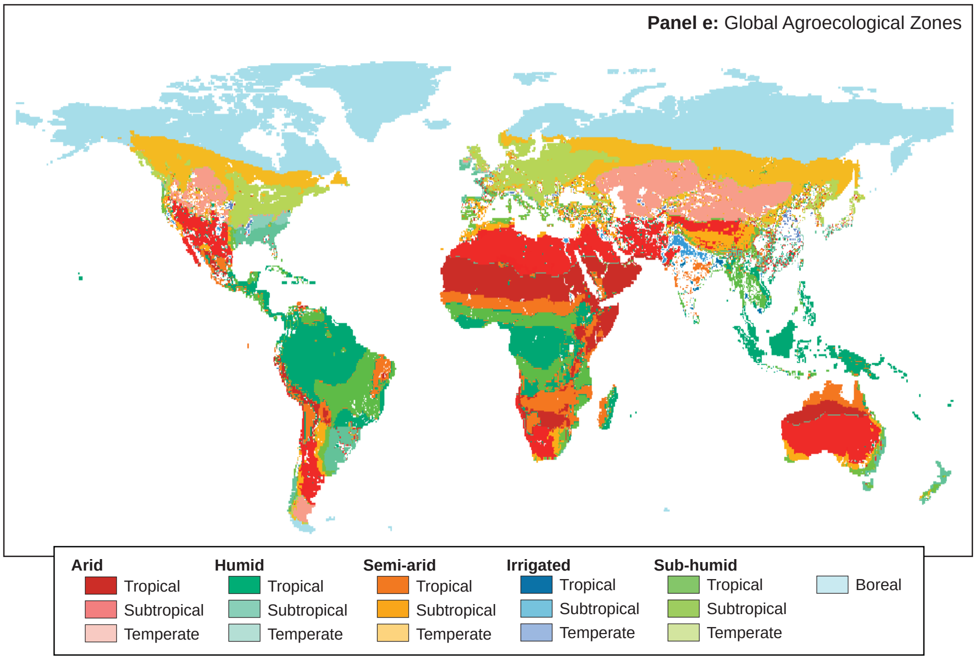


Figure 2.2. Panel e. Global agroclimatic zones and year 2000 crop geographies

Sources: Crop allocation data are documented by You and Wood (2005). Global agroecological zones were modified from Sebastian (2006).

gregated into two geopolitical groups, lower income and upper income (as defined in Section 3), and the pixilated crop geographies within countries were collapsed into three agroclimatic groups: temperate, subtropical, and tropical.

Figure 2.3 summarizes the results of this analysis, with Panel a showing the global area and production shares for each crop for the year 2000, stratified into three agroclimatic regions. Panels b and c preserve the structure of Panel a but include only lower- and upper-income country area and production shares, respectively. The percentages in brackets under the area and output labels at the bottom of these two panels indicate the respective lower- and upper-income country crop shares overall. The preponderance of global rice production in 2000—be it assessed in terms of area harvested or quantities produced—occurred in tropical or subtropical areas, whereas global wheat production and soybean production were split more evenly between temperate and tropical areas. Two-thirds (66%) of the world's corn production came from temperate areas, which accounted for just 43% of the global

Figure 2.3. Corn, soybean, rice, and wheat production and area by agroclimatic zone

Sources: Developed by the authors using data from FAO and Sebastian (2006).

area under corn. This implies that corn yields in temperate zones are much higher on average than corn yields in tropical and subtropical areas, which accounted for 57% of the global area in corn but produced only 34% of the world's corn output. The temperate area and output shares for global soybean production were more evenly split, at 51% and 56% respectively, implying a comparatively small variation in average soybean yields in tropical versus temperate areas.[17]

A comparison of the data represented in Panels b and c is revealing. As one might expect, less than 40% of the lower-income country areas planted to all four crops were located in temperate zones, and only 8% of the rice area is classified as temperate (Panel b). In contrast, most of the corn, soybean, and wheat cropped area in the upper-income countries was in temperate zones, although there was a significant share (65%) of rice acreage located in tropical and subtropical landscapes (Panel c). Even with this rather coarse representation of agroclimatic patterns of production, it is evident that the agroclimatic landscape of agriculture is substantially more heterogeneous in lower-income countries than it is in higher-income countries.

Comparison of the area shares with output shares reveals that all four commodities have higher yields in temperate areas than in tropical areas in both upper- and lower-income countries. This indicates that at least some of the productivity disparity between upper- and lower-income countries is driven by agroecology. As a result, inter-regional comparisons of partial productivity metrics are often implicitly qualified by assumptions about the comparability of agroecologies across regions. Further, the ever-changing spatial footprint of agricultural production requires that inter-temporal comparisons—even within the same country or region—be subject to similar caveats.

5. CONCLUSION

Subtle but substantial forces shape the spatial landscape of global agriculture. The comparative stability of total harvested area for many crops (and, notably, the cereals) worldwide over the latter half of the twentieth century belies the significant spatial relocation in crop production. Our analysis shows that global agriculture is spatially mobile, both over the long run stretching back several

[17]Global soybean production is highly concentrated in just a few countries. In 2007, Brazil, Argentina, China, and the United States collectively accounted for 88% of world soybean production, and 80% of area.

centuries (and into prehistory) and during more recent decades. Further, both the location of cropped areas and the quantity of crop production vary among countries as well as across (agroecological) areas within countries.

The sizeable shifts in the spatial structure of agriculture revealed by our analysis adds substantial complexity to understanding the fundamental forces that affect changes in past (and potential future) agricultural productivity. This is particularly so when the location of crop production shifts over time and among agroecologies both within and among countries. A distinguishing attribute of agriculture is that its production processes are greatly affected by a host of natural inputs, such as sunlight, temperature, and rainfall (including daily, weekly, monthly, and yearly averages as well as variations in the intensity and incidence of these factors among and within these periods of time), day length, and wind speed. Typically these inputs go unmeasured, at least by economists trying to quantify agricultural production and productivity trends. Putting agriculture in a spatial-cum-agroecological setting, as well as tracking movements in that setting, provides for a more meaningful assessment of productivity trends, which are typically assessed at much coarser spatial scales, such as the state, country, or regional aggregates reported throughout the remainder of this book.

APPENDIX: ADDITIONAL DETAILS ON DATA SOURCES AND ANALYSIS

Many of the results presented in this chapter required extensive manipulation of the referenced datasets. The following subsections provide additional details on how the data were processed.

Calculation of Production and Area Shares

The base area and production data are from FAO. Country designations used in both periods pertain to 2008 geopolitical boundaries. Country-specific values were estimated using a decomposition procedure for states that were previously part of a statistical or national aggregation. Subnational data were obtained for Kazakhstan, Ukraine, and Russia from the U.S. Department of Agriculture, Foreign Agricultural Service (2008). Otherwise, data were estimated using the decomposition procedure for a number of countries, including those that made up the Socialist Federal Republic of Yugoslavia, the People's Democratic Republic of Ethiopia, Czechoslovakia, Serbia and Montenegro, the Belgium-Luxembourg statistical unit, and the Former Soviet Union (FSU). This decomposition allows for direct comparison of current and historical values.

Countries were aggregated into regions using a modified version of country aggregations developed by Wood-Sichra (2005). In order to render an analysis that is consistent with the remainder of the volume, the values presented in Section 2 include FSU separately. Thus, FSU production and area are netted out of both Europe and Asia.

Calculations Using Global Land-Use Data

The base data are described by Ramankutty et al. (2008) and Ramankutty and Foley (1999) and were downloaded from the SAGE Web site (www.sage.wisc.edu) in May of 2009. The pixilated land-use data in the 2000 series from Ramankutty et al. are based on an underlying set of cropland and pasture inventory data consisting of observations for 15,990 administrative (i.e., national and subnational) units worldwide, compared with information from just 348 administrative units that were used by Ramankutty and Foley to estimate crop cover for the 1700-1992 period. In addition, the pixilated data in the 2000 series are reported on a 5 arc-minute grid, which we aggregated to a 30 arc-minute grid for consistency and to facilitate processing with the pre-2000 series. These data are intended to represent "permanent croplands" (excluding shifting cultivation), which corresponds to FAO's notion of "arable lands and permanent crops." Although the SAGE authors make no claims about the conformability of their two series, we implicitly assume that the year 2000 values are a continuation of the 1700-1992 series. Given the inherent limitations of the underlying administrative data and the long period of backcasting involved to generate the 1700-1992 series, any results derived from these pixilated data should be used with caution, but we nonetheless deem them informative of likely broad-brush, long-run changes in the global landscape of agriculture.

To calculate centroids, a modified version of the HarvestChoice raster-to-country mappings from the International Rice Research Institute (2008) was used to assign the SAGE data to countries. The countries were assigned to regions using a modified version of region definitions developed by Wood-Sichra (2005). Grid cell sizes were approximated using the Haversine formula as given by Sinnott (1984) after Snyder (1987), and the center of gravity ("centroid") of each region was then calculated by weighting the product of the estimated area and the estimated portion under cropping for each cell.

REFERENCES

Alston, J.M., J.S. James, M.A. Andersen and P.G. Pardey. 2010. *Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending.* New York: Springer.

Beintema, N.M., A.F.D. Avila, and P.G. Pardey. 2001. "Agricultural R&D in Brazil: Policy, Investments, and Institutional Profile." Washington, DC and Brasilia: IFPRI, Embrapa, and FONTAGRO.

Candolle, A. de. 1884. *Origin of Cultivated Plants, The International Scientific Series,* Vol. 49. London: Kegan Paul, Trench and Co.

Crosby, A.W. 1987. *The Columbian Voyages, the Columbian Exchange and their Histories.* Washington, DC: American Historical Association.

Davidson, B. 1966. *The Northern Myth.* Melbourne: Melbourne University Press.

———. 1981. *European Farming in Australia: An Economic History of Australian Farming.* Amsterdam: Elsevier.

Diamond, J.M. 1999. *Guns, Germs, and Steel : The Fates of Human Societies.* New York: Norton.

FAOSTAT Database. Food and Agriculture Organization. http://faostat.fao.org/ (accessed June 2009).

Fuller, D.Q., L. Qin, Y. Zheng, Z. Zhao, X. Chen, L. Hosoya and G.-P. Sun. 2009. "The Domestication Process and Domestication Rate in Rice: Spikelte Bases from the Lower Yangtze." *Science* 323:1607-1610.

Geary, R.C. 1954. "The Contiguity Ratio and Statistical Mapping." *Incorporated Statistician* 5 (3): 115–145.

Gini, C. 1912. *Variabilità e mutabilità Fac.* Giurisprudenza: University Cagliari.

Harlan, J.R. 1971. "Agricultural Origins: Centers and Noncenters." *Science* 174(4008): 468–474.

International Rice Research Institute. 2008. Miscellaneous (HarvestChoice) Grid Databases. http://gislnxserver.irri.org/hc/grids.html (accessed May, 2009).

Liebenberg, F., P.G. Pardey and M. Kahn. 2010. "South African Agricultural Research and Development: A Century of Change." Department of Applied Economics Staff Paper, University of Minnesota, forthcoming.

Lorenz, M.O. 1905. "Methods of Measuring the Concentration of Wealth." *Publications of the American Statistical Association* 9(70): 209–219.

Maddison, A. 2003. *The World Economy: Historical Statistics.* Paris: Organization for Economic Cooperation and Development.

Moran, P.A.P. 1950. "Notes on Continuous Stochastic Phenomena." *Biometrika* 37(1/2): 17–23.

Pardey, P.G., J.M. Alston, C. Chan-Kang, E. Magalhães, and S. Vosti. 2006. "International and Institutional R&D Spillovers: Attribution of Benefits Among Sources for Brazil's New Crop Varieties." *American Journal of Agricultural Economics* 88(1): 104–123.

Ramankutty, N., A.T. Evan, C. Monfreda, and J.A. Foley. 2008. "Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000." *Global Biogeochemical Cycles* 22(January). http://www.agu.org (accessed May 5, 2009).

Ramankutty, N., and J.A. Foley. 1999. Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles* 13(4): 997–1027.

Schery, R.W. 1972. *Plants for Man.* Englewood Cliffs, NJ: Prentice Hall.

Sebastian, K. 2006. *Classification of Countries by Agricultural-Ecological Zone Class.* Washington, D.C.: International Food Policy Research Institute.

Sinnott, R.W. 1984. "Virtues of the Haversine." *Sky and Telescope* 68(2): 159–159.

Snyder, J.P. 1987. "Map Projections—A Working Manual." U.S. Geological Survey Professional Paper 1395. Washington, DC.

Tobler, W.R. 1970. "A Computer Movie Simulating Urban Growth in the Detroit Region." *Economic Geography* 46(June): 234–240.

U.S. Department of Agriculture, Foreign Agricultural Service. 2008. Unpublished data. Washington, DC.

Vavilov, N.I. 1926. "Studies on the Origin of Cultivated Plants." *Bulletin of Applied Botany, Genetics and Plant Breeding* 16(2): 1–248.

———. 1951. *The Origin, Variation, Immuity and Breeding of Cultivated Plants*. New York: Ronald Press.

Wood, S., K. Sebastian, and S.J. Scherr. 2000. "Pilot Analysis of Global Ecosytems—Agroecosystems." Washington, DC: International Food Policy Research Institute and World Resources Institute.

Wood, S., L.Z. You, and X. Zhang. 2004. "Spatial Patterns of Crop Yields in Latin America and the Caribbean." *Cuadernos de Economía* 41(December): 361–381.

Wood-Sichra, U. 2005. Market and Population Data Base, User and System Manual Version 4.0. International Food Policy Research Institute, Washington, DC.

You, L.Z., and S. Wood. 2005. "Assessing the Spatial Distribution of Crop Areas using a Cross-Entropy Method." *International Journal of Applied Earth Observation and Geoinformation* 7(4):310–323.

Zhang, K., Z. Yu, X. Li, W. Zhou and D. Zhang. 2007. "Land Use Change and Land Degradation in China from 1991 to 2001." *Land Degradation and Development* 18(2): 209–219.