Development of GTAP version 9
Land Use and Land Cover database
for years 2004, 2007 and 2011

by

Uris Lantz C. Baldos

GTAP Research Memorandum No. 23

August 2017

I. Background and Motivation

Understanding the challenges of achieving environmental sustainability goals given future demand for food, fiber and fuel requires economic models and databases that incorporate spatially explicit information on land use and land cover (LULC). The GTAP LULC database and its variants have been extensively used in a wide variety of applications aimed at examining the land-environment-energy nexus (Golub et al., 2012; Hertel et al., 2010; Liu, Hertel, Taheripour, Zhu, & Ringler, 2014; Stevenson, Villoria, Byerlee, Kelley, & Maredia, 2013; F. Taheripour, Hertel, Tyner, Beckman, & Birur, 2010; Farzad Taheripour & Tyner, 2012). It has been more than a decade since the first release of the GTAP LULC database in 2005 which combined geospatial data on land use and land cover into the version 6 GTAP database – benchmarked to year 2001 (GTAP LULCv.6). The methodology for creating and using this database is well documented (Lee, Hertel, Rose, & Avetsiyan, 2009; C. Monfreda, Ramankutty, & Hertel, 2009; Sohngen, Tennity, Hnytka, & Meeusen, 2008). Looking back the development of the first GTAP LULC was no simple task as it required the expertise of several researchers to identify and process relevant geospatial information. And because of this, succeeding updates of the GTAP LULC database (namely v.7 for 2004 and v.8 for 2004, 2007) relied on readily available but aggregated GTAP LULCv.6 albeit using national-level (i.e. FAOSTAT) or unpublished spatial-data[1] in order to update the 2001 land use and land cover information to the required benchmark year.

This memorandum documents the development of the GTAP LULC v.9 database. In keeping with the multi-year release of GTAP v.9, the GTAP LULC v.9 data is developed for each benchmark year (i.e. 2004, 2007 and 2011). But unlike previous releases, GTAP LULCv.9 is created directly from the latest, high-resolution (i.e. 5-minute) spatial land cover and land use maps. Since these maps can be readily downloaded online, it is possible to replicate GTAP LULCv.9 if users know how to handle spatial data and if they follow the methods outlined in this document. Furthermore, by developing the capacity to handle spatial data within the Center, new spatial LULC information can be easily incorporated in future releases of the GTAP LULC.

[1] Land cover data for v.7 and v.8 used the beta version of "Global Cropland and Pasture Data: 1700-2007" by Ramankutty (2011). However, the updates on this database has been discontinued by the author and has it been pulled out from the web.

II. Data and Methods for GTAP LULC v.9

Figure 1 and 2 summarize the data and methods used in creating and updating the land cover and land use information in the GTAP LULCv.9 database, respectively. At the core of the v.9 database are fine-resolution (5-minute) geospatial maps on administrative areas, growing conditions, land cover and land use. Each workflow starts with the creation of Global Agro-Ecological Zone (GAEZ) map which contains both administrative and agro-ecological zone information. Administrative boundaries are taken from the Global Administrative Areas map v2.8 (2016) which contains information on the boundaries of 256 countries. These are mapped to the 226 GTAP countries and GTAP regions for v.9 (see Appendix I). Following GTAP LULCv.6, each 5-minute grid-cell of the Earth's land area is classified according to agro-ecological zones (AEZs) (see Appendix II and Appendix III). AEZ categories are created using information on length of growing period (LGP) and thermal climate from the latest information from FAO/IIASA GAEZ v.3 (2012). The LPG shows the number of days in a year when the prevailing temperature and available moisture permit crop growth (i.e. days wherein average daily temperature is above 5^{o}C and actual evapotranspiration is above the threshold level of 0.5). On the other hand, the thermal climates broadly classify each grid-cell according to tropics, subtropics, temperate, boreal and arctic climates (IIASA/FAO, 2012). The original thermal climates (8 types) are reclassified to 3 zones (Tropical, Temperate and Boreal).

With the GAEZ map on hand, Figure 1 further shows how information from different land cover maps are combined into the GTAP LULC database. Fractional cropland and pasture cover maps for year 2000/01 developed by Ramankutty et al (2008) (downloadable from http://www.earthstat.org/) is combined with the fractional urban cover information created from urban cover maps by Schneider et al (2009, 2010). Fractional cropland, pasture and urban land information are then added together in each grid cells. To ensure that total fractional land cover do not exceed 100%, fractional land cover data are normalized for grid cells which exceed the said threshold. For each grid cell, the residual fractional land cover (taken from the difference between 100% and the combined fractional cropland, pasture and urban cover) are reassigned to

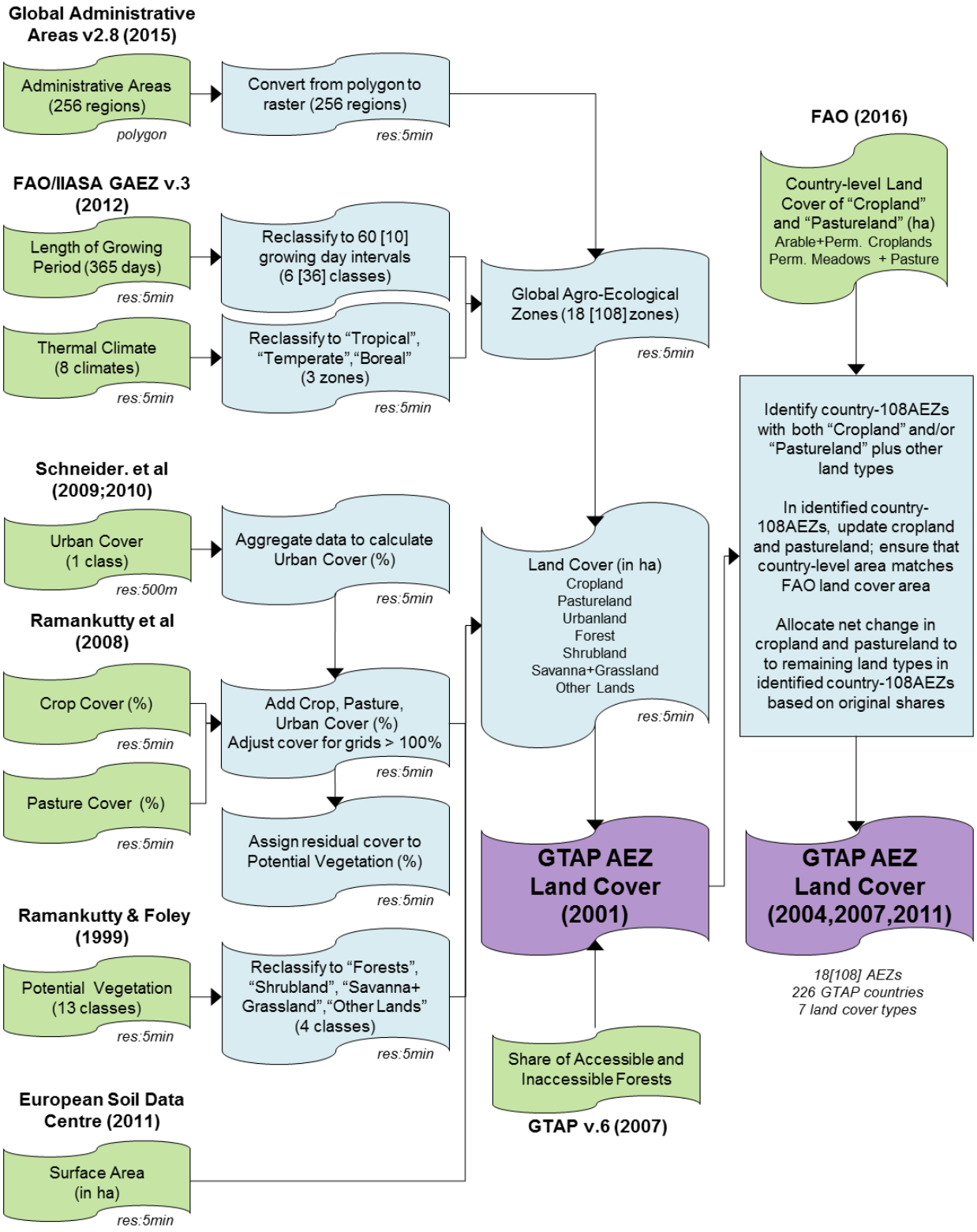


Figure 1. Workflow for creating the land cover data for year 2000/01

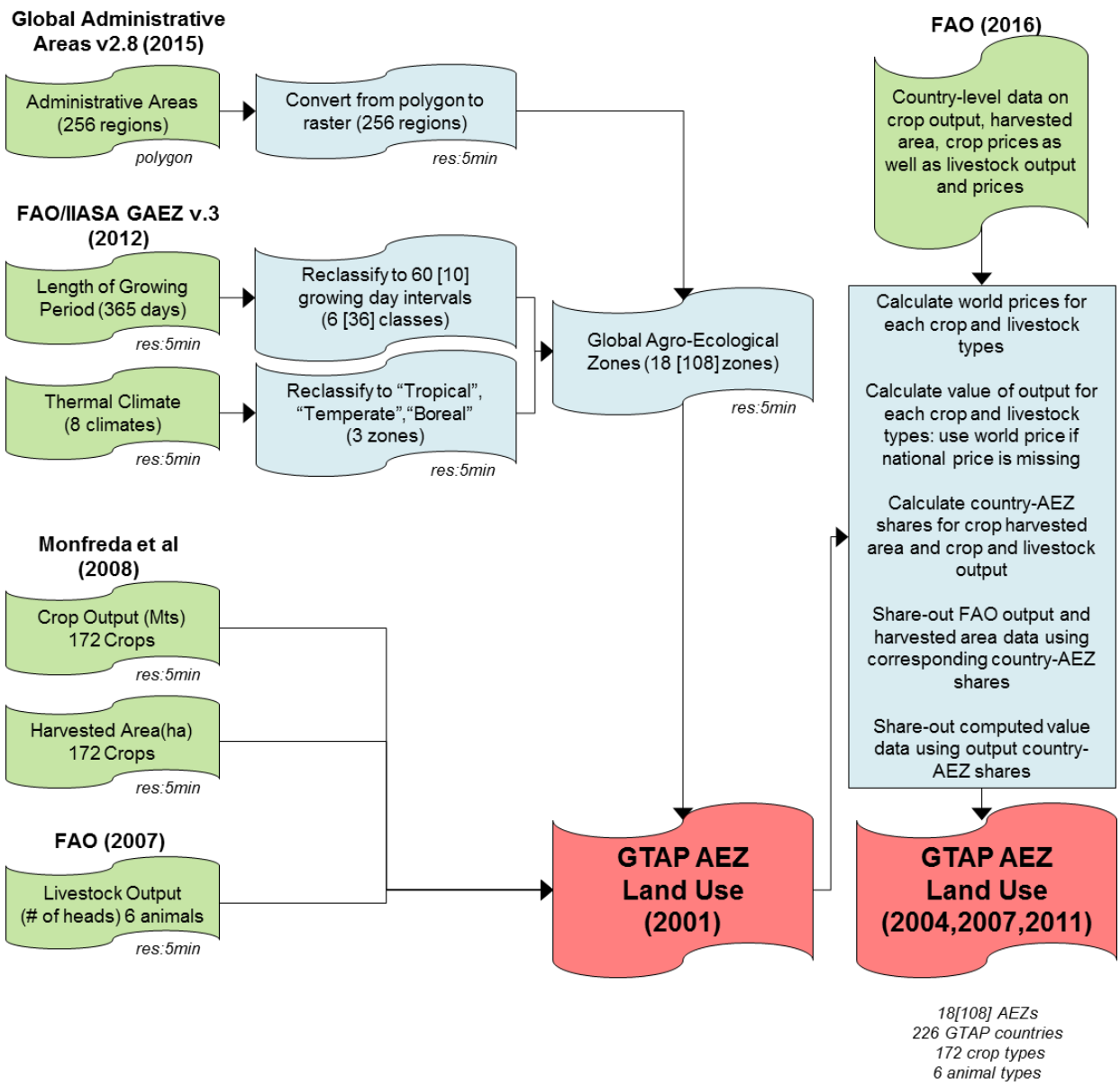


Figure 2. Workflow for creating the land use data for year 2000/01

vegetation classes using the potential vegetation map developed by Ramankutty and Foley (1999). The authors assigned each grid cell of the world to one of 13 potential vegetation classes. These classes are further reclassified into 4 land types (namely Forests, Shrubland, Savanna + Grasslands and Other Lands). The complete fractional land cover maps are converted to hectares using 5-minute surface area map from the European Soil Data Center (2012). To separate accessible[2] and inaccessible forest cover, the region-18AEZ shares computed by Sohngen et al (2008) for GTAP LULC v.6 are used. The resulting land cover database from the data and methods mentioned above is for base year 2001, 140 regions, 7 land cover types and for 18 and 108 AEZs.

To the best of our knowledge, there are no available maps which have more recent land cover (as well as land use) information. So in order to update the new 2001 base year land cover database for each benchmark years (i.e. 2004, 2007, 2011) national level data from FAOSTAT (2016) is used. Starting with the 108 AEZ land cover data, cropland and pasturelands are first updated using national-level land cover for these land types for each benchmark year. Thus, cropland and pastureland area between FAO and GTAP LULC at the national-level are the same. Note that land cover is updated only in region-108AEZ wherein both cropland, pasture and other land types are present (if this condition is not met, land cover in a region-108AEZ is fixed to the 2001 base year values). For each region-108AEZ that is updated, the net change in cropland and pasture are allocated to other land types using their original shares in the base year 2001. Finally, updated land cover for 108AEZs are then aggregated to 18 AEZs.

Figure 2 shows the workflow of the land use data for GTAP LULC v.9. Starting with the GAEZ map, the gridded production and harvested area for 172[3] crops from Monfreda et al. (2008) are used. Unlike previous versions which use representative crops to share-out livestock land rents, v.9 uses gridded livestock (6 types) output from FAO (2007). National level prices from FAOSTAT (2016) are used to calculate the value of crop and livestock production. Once output, harvest area and value of output data are constructed for base year 2001, region-108AEZ shares for these variables are created. These shares are then used to share-out national level output, harvest area and value of output data information from FAOSTAT (2016) for the benchmark years (Appendix IV). Finally, the data is aggregated to 18 AEZs.

[2] Accessible forest area includes forests with land rents such as managed forest and unmanaged forest which are easily accessible.

[3] The original Monfreda et al database is for 175 crops but at the time of creating the database production and harvested area for minor commodities (popcorn, coir, gums) were not available.

III. Results and Evaluation of GTAP LULC v.9

a. Land cover

Figures 3, 4 and 5 illustrate global land cover area (in M ha) for cropland, pasture and forest (orange, blue and green figures) by region-AEZ for the years 2004, 2007 and 2011 (upper, middle and lower panel), respectively. Regions where cropland area are sizable (i.e. dark colored polygons) include U.S. (AEZ8 and AEZ10), Russia (AEZ8 to AEZ10), India (AEZ3), Indonesia (AEZ6), China (AEZ9 and AEZ12) and Australia (AEZ8). Pastureland cover hot spots are located in Australia (AEZ7), Saudi Arabia (AEZ7), Brazil (AEZ5) and U.S. (AEZ8). Forest cover are relatively large in Russia (AEZ14 and AEZ15), Brazil (AEZ6), U.S. (AEZ10 and AEZ12), Democratic Republic of the Congo (AEZ6), China (AEZ 12) and Indonesia (AEZ6).

Table 1 summarizes total land cover of cropland, pasture and forest – summed for all countries – for each AEZ given the benchmark years 2004, 2007 and 2011. Globally, cropland are generally located in AEZ8, AEZ9 and AEZ10 (with annual average area at around 290, 238, 236 M ha, respectively). Note that prevailing thermal climates in AEZ8 to AEZ10 are classified as "Tropical cool to Temperate cool" with growing days ranging from 60 to 230 days. Pasturelands are mostly concentrated in AEZ7, AEZ8 and AEZ1 (on average, around 852, 664, 267 M ha, respectively) while most of the world's forests are in AEZ6, AEZ10 and AEZ15 (around 289, 216 and 215 Mha). Looking at the absolute changes between 2004 and 2007, global cropland and pasture area declined while forest cover increased slightly. AEZs where large gains in cropland area are observed include AEZ2 to AEZ4 while AEZ8 to AEZ10 experienced cropland cover reduction over this period. AEZ7 to AEZ9 show reduction in pastureland area while forest cover expanded in AEZ9 to AEZ11. Significant gains in cropland cover and strong reductions in pasture cover are observed for the period 2007 to 2011. Cropland expanded rapidly in AEZ4 to AEZ6 while almost all AEZs show reduction in pasture cover over this period. Change in forest cover are generally mixed with area increasing slightly in AEZ10 and AEZ11 and declining in AEZ6 and AEZ4. Land cover for cropland, pasture and forest for selected GTAP regions are listed in Table 2. Between 2004 and 2007, cropland cover in these regions are generally declining particularly in the U.S., Australia and Canada. Australia experienced reduction in pasture cover while in the U.S., pasture cover increased. Almost all regions in

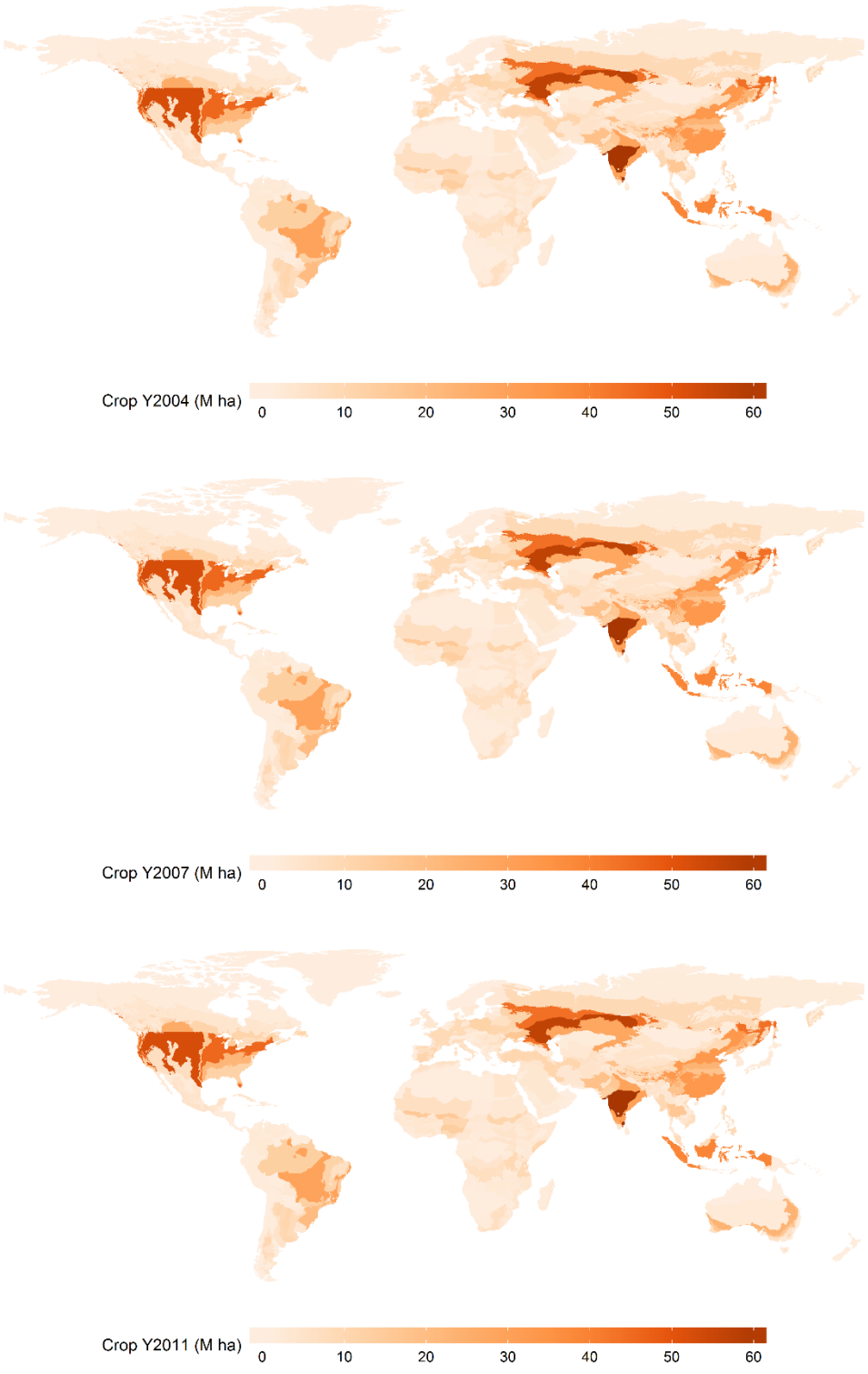


Figure 3. Global distribution of cropland by region and AEZ: 2004 2007 2011

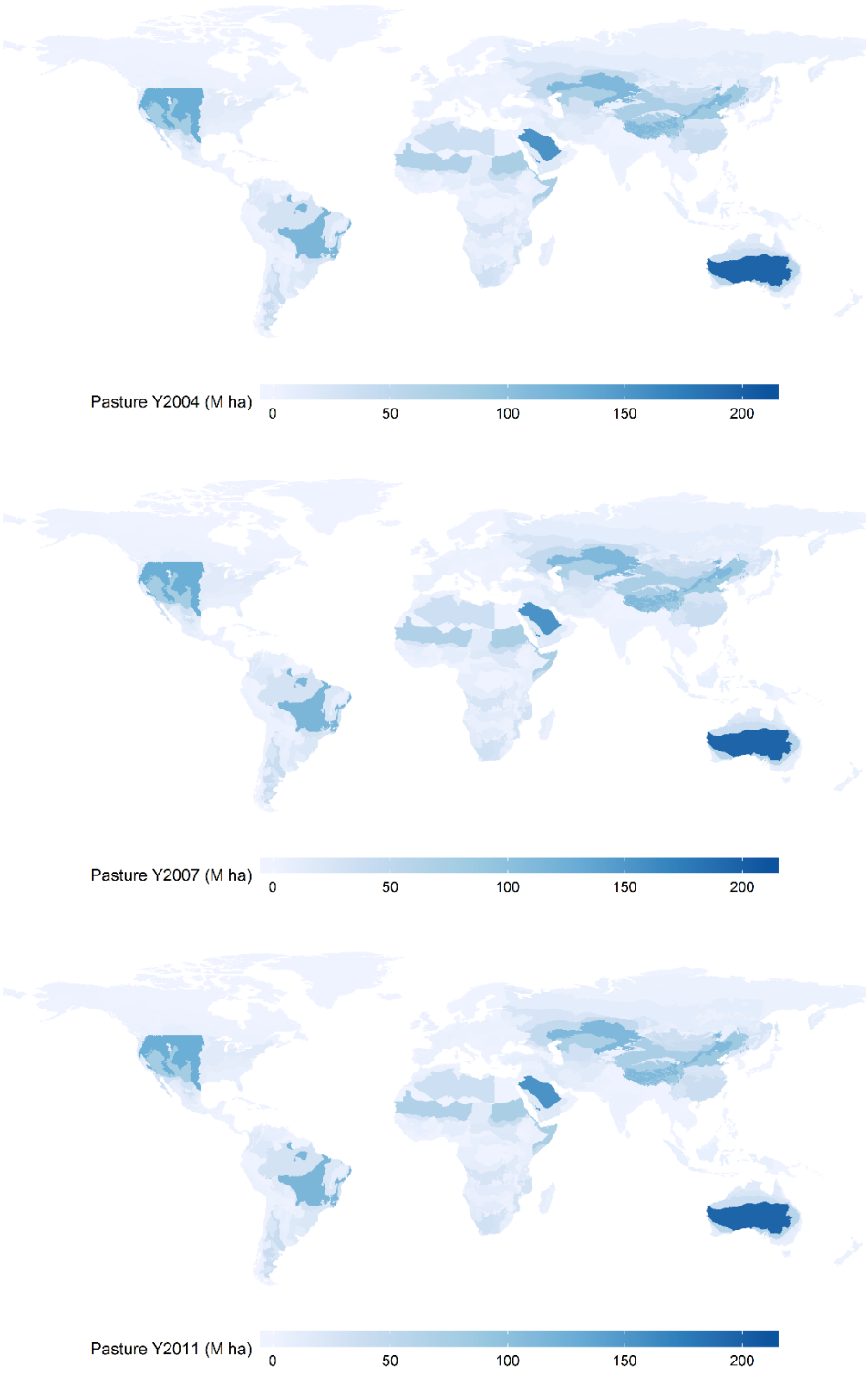
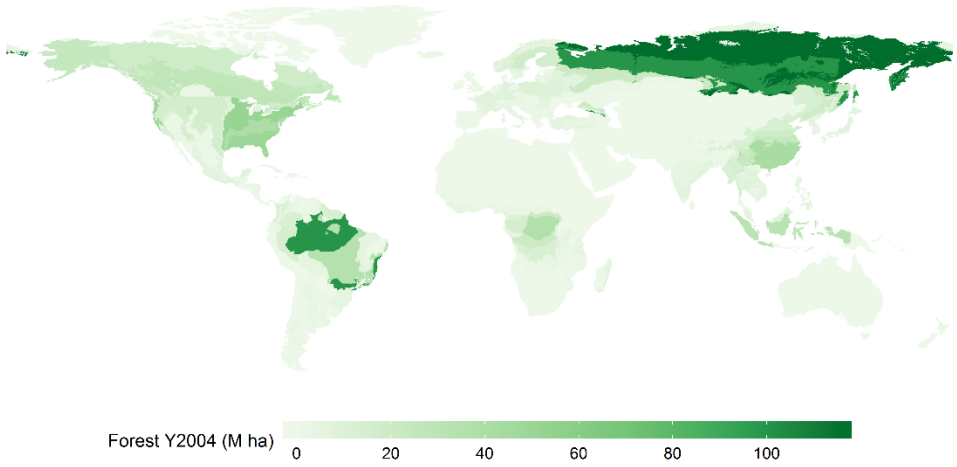
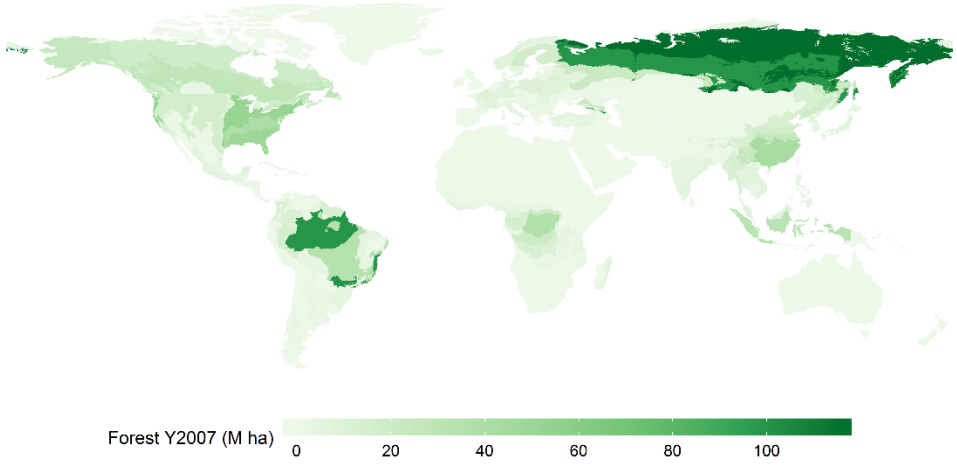


Figure 4. Global distribution of pastureland by region and AEZ: 2004 2007 2011





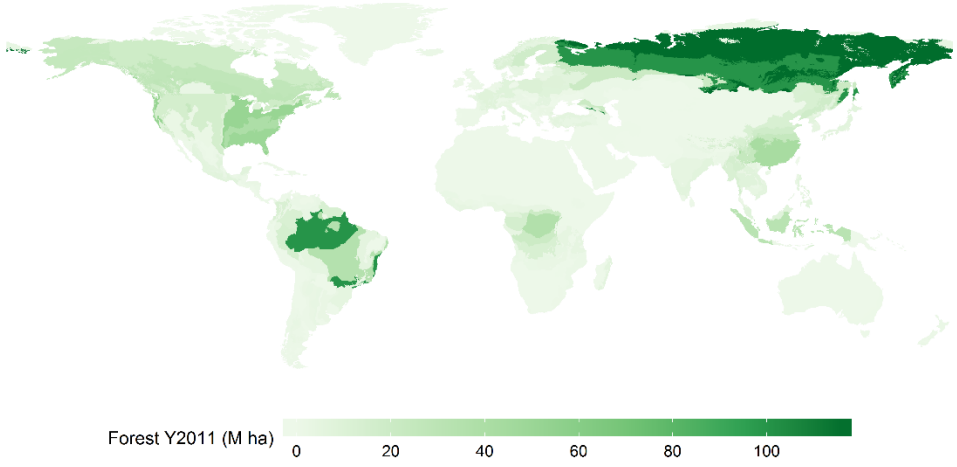


Figure 5. Global distribution of forests by region and AEZ: 2004 2007 2011

Table 1. Total area and relative changes in land cover categories by AEZ: 2004, 2007, 2011

Area (in M ha)	2004			2007			2011			Difference: 2007 - 2004			Difference: 2011 - 2007		
	Crop	Pasture	Forest	Crop	Pasture	Forest	Crop	Pasture	Forest	Crop	Pasture	Forest	Crop	Pasture	Forest
AEZ1	14.2	266.4	0	14.6	268.3	0	15.1	266.3	0	0.5	1.8	0	0.4	-2	0
AEZ2	55.8	158.6	1.3	57.6	159.1	1.3	59.3	157.9	1.3	1.8	0.5	0	1.7	-1.3	0
AEZ3	108.9	182.6	19.9	110.5	182.2	19.9	113.5	181.4	19.8	1.6	-0.4	0	3	-0.8	-0.1
AEZ4	137	202.4	83.6	139.9	202.5	82.8	145.2	202.4	81.4	2.8	0	-0.8	5.4	0	-1.5
AEZ5	101.9	209.4	142.6	103.4	209.4	141.8	107.2	209.4	140.8	1.5	0	-0.7	3.7	-0.1	-1.1
AEZ6	87.1	89.7	289.6	87.6	89.9	289.3	93.2	89.7	287.4	0.5	0.2	-0.3	5.6	-0.1	-1.8
AEZ7	58.7	861.3	3.1	58.6	851.9	3	57.4	844	3	-0.1	-9.5	-0.1	-1.2	-7.8	0
AEZ8	295	668.3	25.9	290.1	660.8	26.1	285.3	662.2	27.1	-4.9	-7.5	0.1	-4.8	1.4	1
AEZ9	240	227.1	106	237.4	225.6	107.1	236.6	224.9	108	-2.6	-1.5	1.1	-0.8	-0.7	0.8
AEZ10	238.7	147.2	213.5	236.3	146.9	215.3	233.9	145.4	218.2	-2.4	-0.3	1.8	-2.4	-1.5	2.8
AEZ11	94.2	83.6	104.5	93.8	83.9	105.5	92.7	83.5	107	-0.4	0.3	1	-1	-0.4	1.5
AEZ12	91.4	129.9	114.4	91.7	130.3	114.7	93.9	129.7	114.6	0.3	0.4	0.2	2.2	-0.6	-0.1
AEZ13	1.1	50.3	5.4	1	50.5	5.3	1.1	50.4	5.3	0	0.2	0	0	-0.1	0
AEZ14	4	64.6	177.2	4	64.9	177.2	3.9	64.9	177.1	-0.1	0.3	0	-0.1	-0.1	0
AEZ15	16.3	23	214.5	16.1	23	214.5	15.8	23	214.6	-0.2	0	0	-0.3	0	0.1
AEZ16	0.4	1.5	3.1	0.3	1.5	3.1	0.3	1.5	3.1	0	0	0	0	0	0
AEZ17	0	0	0.4	0	0	0.4	0	0	0.4	0	0	0	0	0	0
AEZ18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1544.6	3365.9	1505	1543	3350.6	1507.4	1554.3	3336.5	1509	-1.6	-15.3	2.3	11.3	-14.2	1.6

Table 2. Total area and relative changes in land cover categories for selected countries: 2004, 2007, 2011

Area (in M ha)	2004			2007			2011			Difference: 2007 - 2004			Difference: 2011 - 2007		
	Crop	Pasture	Forest	Crop	Pasture	Forest	Crop	Pasture	Forest	Crop	Pasture	Forest	Crop	Pasture	Forest
Australia	48.1	392	1.2	44.5	380.9	1.2	48.1	361.6	1.2	-3.6	-11.1	0	3.5	-19.3	0
Brazil	75.6	196.5	145.9	75.6	196	146	79.4	196	145.1	0	-0.5	0.1	3.7	0	-0.8
Canada	52.1	15.4	96.2	50	15.3	97	47.9	14.7	97.9	-2.1	-0.1	0.7	-2.1	-0.6	0.9
China	124.4	392.8	112.6	122.6	392.8	113.5	122.5	392.8	113.5	-1.9	0	0.9	0	0	0
France	19.5	10.1	15.4	19.4	9.9	15.6	19.3	9.6	15.9	-0.1	-0.2	0.2	-0.1	-0.3	0.3
India	169.9	10.5	16.2	169.2	10.4	16.3	169.4	10.3	16.3	-0.7	-0.1	0.1	0.2	-0.1	0
Indonesia	42.4	11	34.5	42	11	34.6	45.5	11	33.6	-0.4	0	0.1	3.5	0	-0.9
Russia	124	92	249.8	123.4	92.1	249.9	121.7	93	250	-0.6	0.1	0.1	-1.7	0.9	0.1
USA	169.8	241.8	212.3	164.5	248.4	213.1	154.3	250.4	217.2	-5.3	6.6	0.8	-10.2	2	4
South Africa	13.7	83.9	1.2	13	83.9	1.3	12.4	83.9	1.3	-0.7	0	0	-0.5	0	0

Table 2 show slight gains in forest cover over the period 2004 to 2007. Cropland further expanded in several countries especially in Australia, Brazil and Indonesia during 2007 to 2011. However, over the same period cropland cover in the U.S. declined sharply. The reduction in pasture cover observed in Australia during 2004-2007 seem to persist in 2007-2011. Changes in forest cover are generally mixed during this period, with area reductions in Brazil and Indonesia and expansion in U.S., Canada and France.

b. Land Use

Global distribution of coarse grains, paddy rice and wheat production (left, middle and right panels) for benchmark years 2004, 2007 and 2011 (top, middle and bottom panels) are illustrated in Figure 6. Most of the world's coarse grains (left panel) are produced in the U.S. (AEZ8 to AEZ10), China (AEZ9 and AEZ10), Brazil (AEZ5 and AEZ12), Russia (AEZ8 and AEZ9) and India (AEZ3). Hotspots for global paddy rice production (middle panel) are generally concentrated in East, South and South East Asia specifically in China (AEZ11 and AEZ12), India (AEZ3 and AEZ4), Thailand (AEZ4), Vietnam (AEZ5), and Myanmar (AEZ4). Relative to the crops mentioned above, global production of wheat is more widely dispersed. Key regions wherein wheat production is high include the U.S. (AEZ8), India (AEZ8 and AEZ9), Russia (AEZ8 and AEZ9), Canada (AEZ8), France (AEZ10), Kazakhstan (AEZ8) and China (AEZ9 to AEZ11). Figure 7 shows the global distribution of harvested areas for coarse grains, paddy rice and wheat (left, middle and right panels) for benchmark years 2004, 2007 and 2011 (top, middle and bottom panels). In general, the hotspots of harvested area are in the same region-AEZs where production hotspots are also observed.

Global production and harvested area of selected GTAP crops for each benchmark year are listed in Table 3. Relative changes for periods 2004-2007 and 2007-2011 are also summarized in the table. In general, world output for most selected crops grew during the period 2004-2007. Output of sugar cane & beet rose sharply followed by fruits & vegetables, oilseeds, paddy rice and coarse grains (around 269, 116, 56, 49 and 46 MMt, respectively). At the same time, harvest area for coarse grains and fruits & vegetables also expanded strongly. Both production and harvested areas grew faster during the period 2007-2011 compared to 2004-2007. Crop production rose for fruits & vegetables, sugar cane & beet, and oilseeds (at 289, 220 and 126 MMt, respectively). With significant growth in production, it is not surprising that harvested

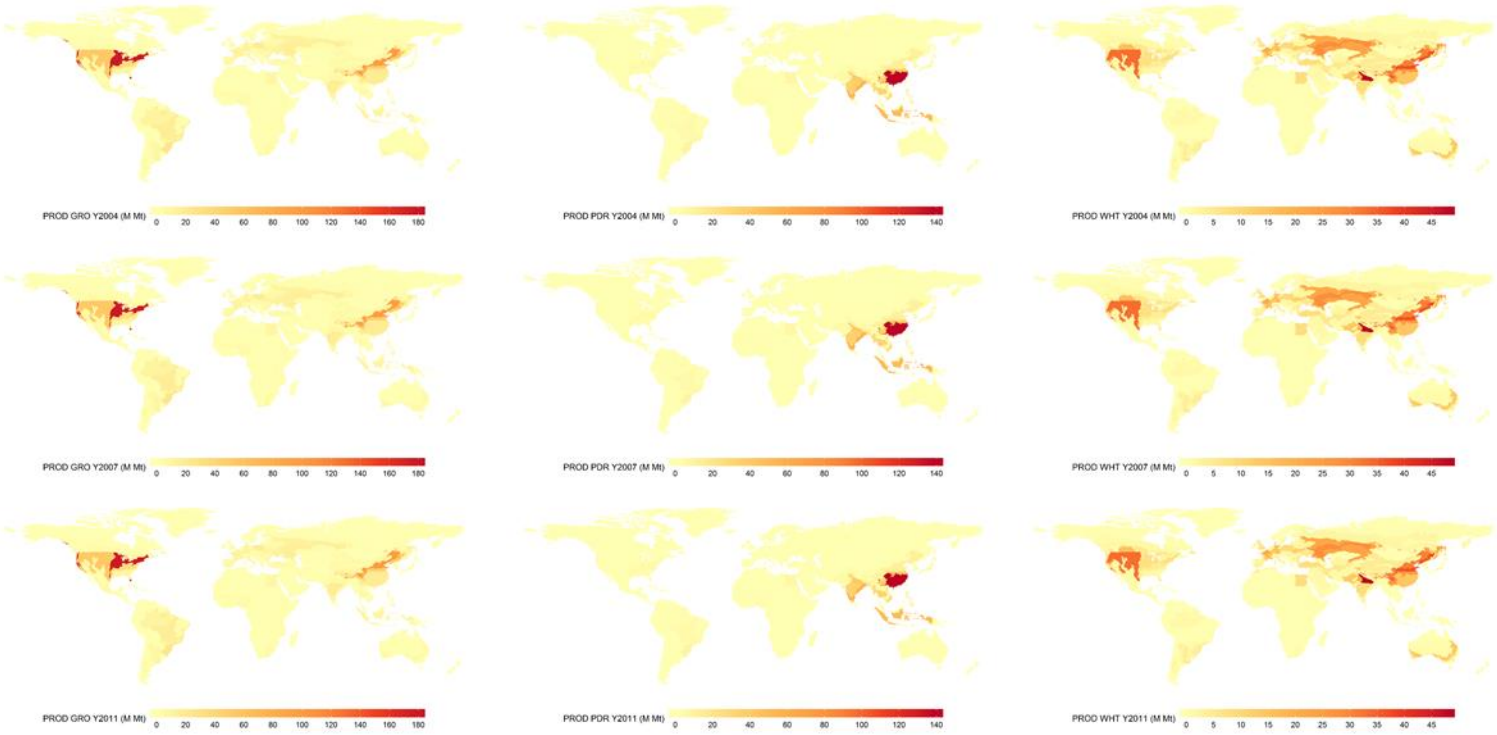


Figure 6. Production of coarse grains, paddy rice and wheat by region and AEZ: 2004 2007 2011

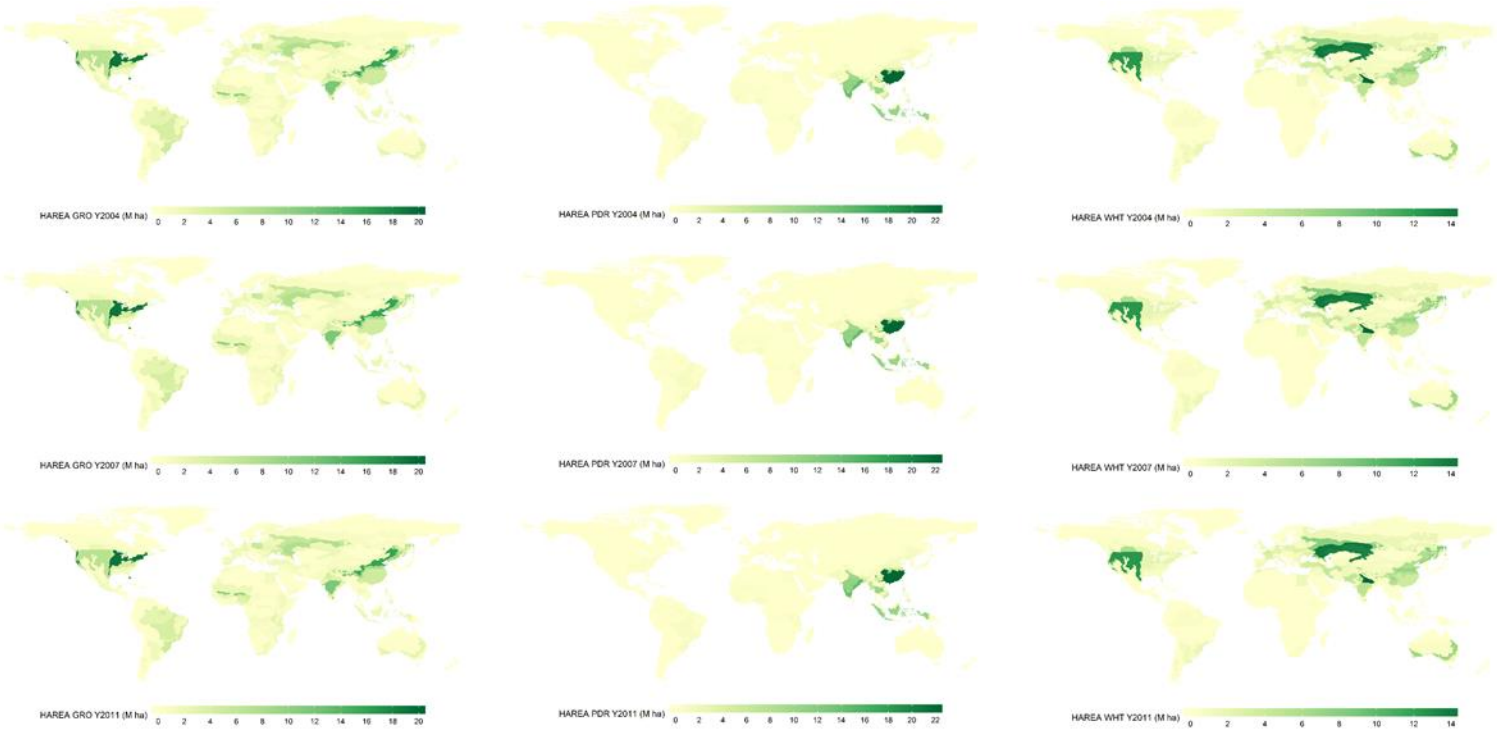


Figure 7. Harvested area of coarse grains, paddy rice and wheat by region and AEZ: 2004 2007 2011

Table 3. Global production and harvested area and relative changes for selected crops: 2004, 2007, 2011

GTAP Crop Categories	Production (MMts)			Difference: 2007 -2004	Difference: 2011 -2007
	2004	2007	2011		
Paddy Rice	609	658	723	49	65
Wheat	629	610	693	-19	83
Coarse Grains	1030	1076	1153	46	77
Fruits and Veg.	2189	2305	2594	116	289
Oilseeds	560	616	742	56	126
Sugar Cane & Beet	1574	1843	2062	269	220
Plant Fibres	77	80	85	3	6
Other Crops	2983	3009	2943	25	-66
GTAP Crop Categories	Harvested Area (Mha.)			Difference: 2007 -2004	Difference: 2011 -2007
	2004	2007	2011		
Paddy Rice	151	155	163	5	7
Wheat	216	216	220	0	4
Coarse Grains	304	315	311	11	-4
Fruits and Veg.	232	243	259	11	16
Oilseeds	208	212	241	4	29
Sugar Cane & Beet	25	28	31	2	3
Plant Fibres	38	36	38	-2	1
Other Crops	200	199	212	-1	13

Table 4. Production and relative changes for selected countries and crops: 2004, 2007, 2011

	Production (1000 Mts)			Difference: 2007 -2004	Difference: 2011 -2007
	2004	2007	2011		
Paddy Rice					
Australia	553	163	723	-390	560
Brazil	13277	11061	13477	-2216	2416
Canada	0	0	0	0	0
China	180523	187397	202667	6874	15270
France	115	88	128	-27	40
India	124697	144570	157900	19873	13330
Indonesia	54088	57157	65757	3069	8600
Russia	471	705	1056	234	351
USA	10540	8999	8389	-1541	-610
South Africa	3	3	3	0	0
Wheat					
Australia	21905	13569	27410	-8336	13841
Brazil	5819	4114	5690	-1705	1576
Canada	24796	20054	25261	-4742	5207
China	91952	109298	117414	17346	8116
France	39693	32764	35994	-6929	3230
India	72156	75807	86874	3651	11067
Indonesia	0	0	0	0	0
Russia	45413	49368	56240	3955	6872
USA	58697	55820	54419	-2877	-1401
South Africa	1687	1905	2005	218	100
Coarse Grains					
Australia	12105	10695	11854	-1410	1159
Brazil	44868	54267	58419	9399	4152
Canada	25983	28055	22036	2072	-6019
China	140689	161117	200549	20428	39432
France	30709	26477	27832	-4232	1355
India	32992	40109	43086	7117	2977
Indonesia	11225	13288	17643	2063	4355
Russia	30348	30135	34499	-213	4364
USA	319789	350306	324048	30517	-26258
South Africa	10334	7599	10911	-2735	3312

Table 5. Harvested area and relative changes for selected countries and crops: 2004, 2007, 2011

	Harvested Area (1000 ha.)			Difference: 2007 -2004	Difference: 2011 -2007
	2004	2007	2011		
Paddy Rice					
Australia	66	20	76	-46	56
Brazil	3733	2891	2753	-842	-138
Canada	0	0	0	0	0
China	28616	29179	30311	563	1132
France	20	17	22	-3	5
India	41907	43910	44010	2003	100
Indonesia	11923	12148	13204	225	1056
Russia	125	157	207	32	50
USA	1346	1112	1059	-234	-53
South Africa	1	1	1	0	0
Wheat					
Australia	13399	12578	13502	-821	924
Brazil	2807	1853	2139	-954	286
Canada	9389	8636	8544	-753	-92
China	21626	23721	24272	2095	551
France	5237	5239	5825	2	586
India	26595	27995	29069	1400	1074
Indonesia	0	0	0	0	0
Russia	22920	23501	24836	581	1335
USA	20222	20639	18496	417	-2143
South Africa	830	632	605	-198	-27
Coarse Grains					
Australia	6811	7240	5491	429	-1749
Brazil	13886	14800	14325	914	-475
Canada	6773	7590	4877	817	-2713
China	29371	33158	36700	3787	3542
France	4097	3800	3812	-297	12
India	29304	28929	27547	-375	-1382
Indonesia	3357	3630	3865	273	235
Russia	17449	16652	15585	-797	-1067
USA	35211	40168	37177	4957	-2991
South Africa	3490	2771	2605	-719	-166

areas particularly for oilseeds and fruits & vegetables also expanded. Tables 4 and 5 summarize production and harvested areas of paddy rice, wheat and coarse grains for selected GTAP countries, respectively. Top producers of paddy rice include China, India and Indonesia while China, India and the U.S. lead wheat production. The U.S. and China grow most of the world's of coarse grains. Looking at the periods 2004-2007 and 2007-2011, changes in crop production and harvested areas generally follow the same direction but there are exceptions. In particular, during 2007-2011 coarse grains in Australia, Brazil, India, Russia and South Africa experienced contraction in harvested areas despite growth in production.

c. Land Rents[4]

With the geospatial land use and land cover at hand, the land rents in the original GTAP v.9 data for agricultural, livestock and forestry sectors are then shared out for each region-AEZ. Figure 8 shows the value of land endowments (EVOA) by region-AEZ for each benchmark year. Value of land endowments are highest in China (AEZ9 to AEZ12), Saudi Arabia (AEZ7), India (AEZ3, AEZ4 and AEZ9), Russia (AEZ8 and AEZ9) the U.S. (AEZ 10) and Canada (AEZ10). Summing EVOA across all regions, Table 6 shows the value of land endowments by AEZ. More than half of the land rents are concentrated in AEZ7 to AEZ10 and in AEZ12. Looking at changes across benchmark years, the growth in land rents remains strong for both period although the increase is relatively smaller in 2007-2011 compared to 2004-2007. Most of the rise in land rents are concentrated in AEZ7 to AEZ10.

Figure 9 shows the producer expenditure on land endowments (EVFA) by the coarse grain, paddy rice and wheat sectors (left, middle and right panels) for each region-AEZ in 2004, 2007 and 2011 (top, middle and bottom panels). Note that the distribution of EVFA is based on the distribution of crop production so it is not surprising Figure 9 mirrors the distribution in Figure 6. Expenditures on land endowments by the agricultural, livestock and forestry sector are summarized in Table 7. Among the agricultural sectors, expenditures on land inputs is highest for fruits and vegetables followed by other crops. More than half of the purchases of land by the livestock sector is generated by the raw milk sector. Key sectors which increased their spending in land inputs – in 2007-2011 relative to 2004-2007 – include paddy rice, sugar cane and sugar beet and cattle, sheep, goats, horses sectors.

[4] Land rent figures and tables in this section are based on GTAP database v9.0a (April 2016). The same methods are used to create the land rent data for v9.1 (May 2016) and v9.2 (Jan 2017)

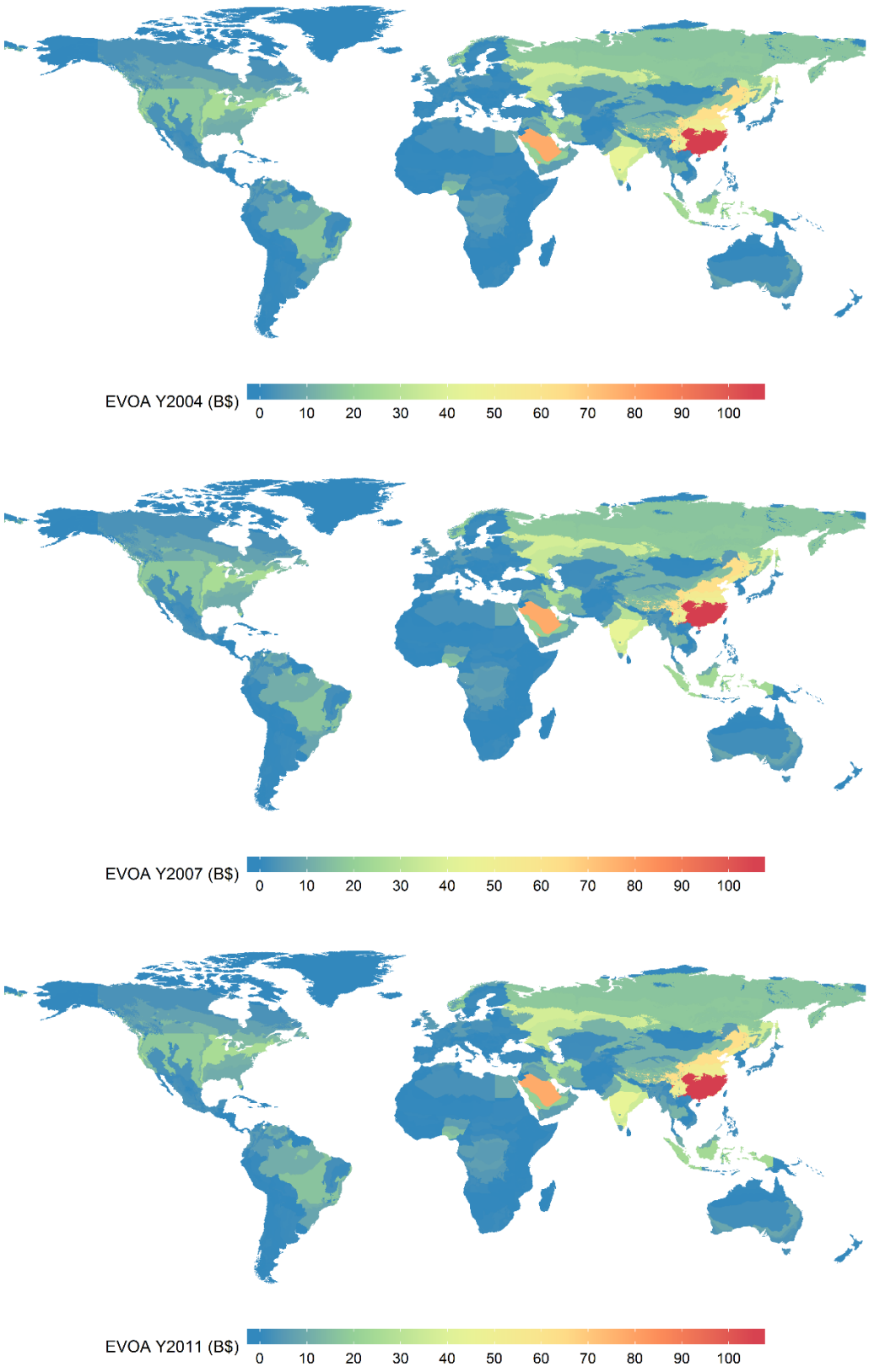


Figure 8. Value of land endowments at agent's prices (EVOA) by region and AEZ: 2004 2007 2011

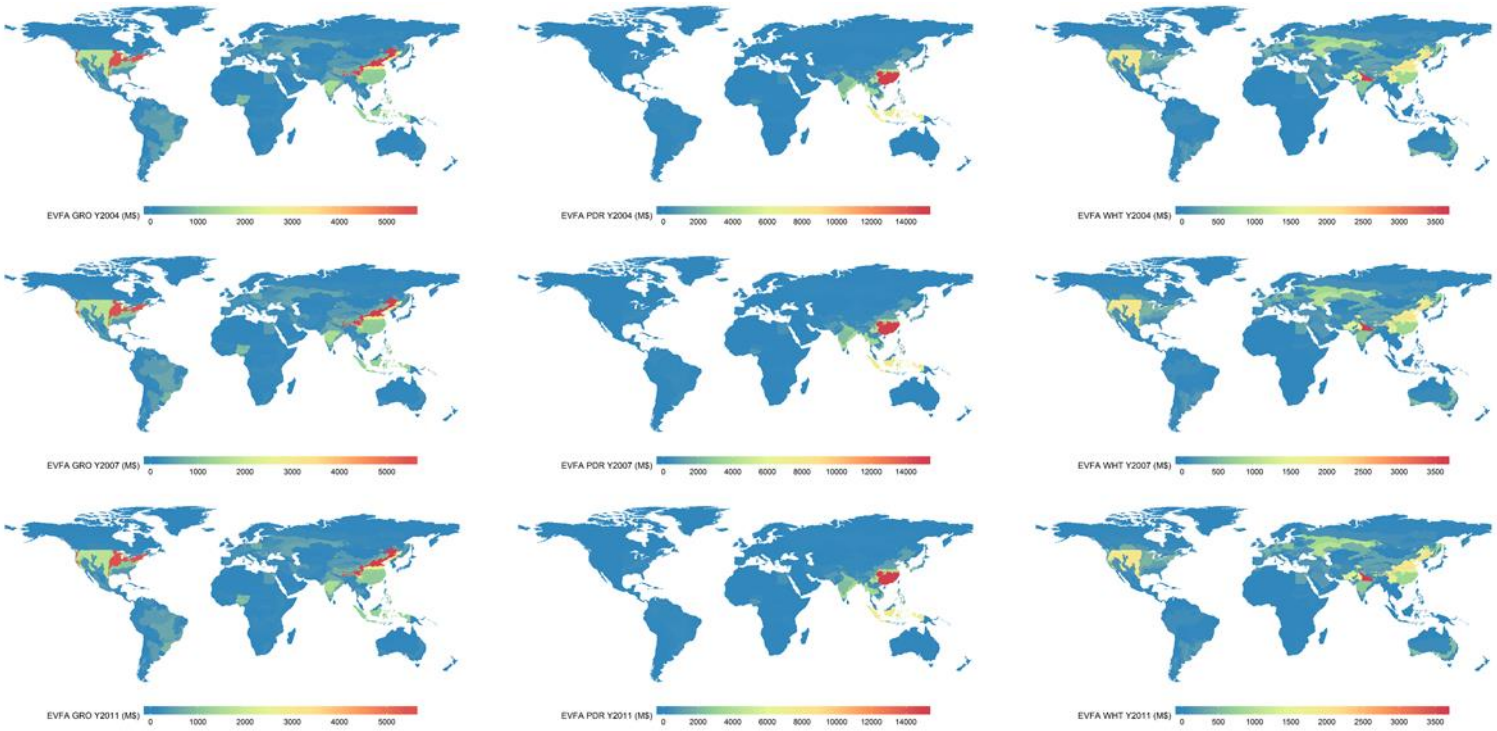


Figure 9. Value of producer expenditure on land inputs at agent's prices of coarse grains, paddy rice and wheat by region and AEZ: 2004 2007 2011

Table 6. Value of land endowments at agent's prices in M USD: 2004, 2007, 2011

EVOA (in M USD)	2004	2007	2011	Difference: 2007 -2004	Difference: 2011 -2007
AEZ1	17866	34187	53141	16321	18954
AEZ2	6998	13004	21211	6006	8207
AEZ3	22463	37622	59422	15159	21800
AEZ4	34752	57777	97169	23025	39392
AEZ5	30324	52164	86629	21840	34465
AEZ6	30953	54519	81267	23566	26748
AEZ7	60183	120237	197439	60054	77202
AEZ8	52980	95289	153437	42309	58148
AEZ9	75490	130278	204000	54788	73722
AEZ10	78417	126429	179158	48012	52729
AEZ11	41994	63865	97448	21871	33583
AEZ12	56195	86547	140601	30352	54054
AEZ13	1189	2186	4239	997	2053
AEZ14	13061	25098	34463	12037	9365
AEZ15	23907	40517	54517	16610	14000
AEZ16	3771	7140	12319	3369	5179
AEZ17	77	164	311	87	147
AEZ18	0	0	0	0	0

Table 7. Value of producer expenditure on land endowments at agent's prices in M USD: 2004, 2007, 2011

EVFA	2004	2007	2011	Difference: 2007 -2004	Difference: 2011 -2007
Paddy Rice	28880	40948	72860	12068	31912
Wheat	13587	21149	32927	7562	11778
Coarse Grains	19162	31803	51722	12641	19919
Fruits and Veg.	107573	158593	232280	51020	73687
Oilseeds	21798	33366	56358	11568	22992
Sugar Cane and Beet	7173	11227	19538	4054	8311
Plant Fibres	6494	9651	15844	3157	6193
Other Crops	41799	53598	78035	11799	24437
Cattle, sheep, goats, horses	19361	27342	46917	7981	19575
Raw milk	25829	38812	56368	12983	17556
Wool, silk-worm cocoons	1564	2853	5036	1289	2183
Forestry	55186	80018	108065	24832	28047

a. Comparing land cover, land use and land rents in v.8 and v.9

To see key differences in land cover, land use and land rents, v.9 is compared with v.8 for benchmark years 2004 and 2007 data[5]. Difference in cropland, pasture and forest cover by AEZ are highlighted in Figure 9 (top, middle and bottom panels). Light-colored markers represent v.8 data while dark colored markers represent v.9 data. Looking at cropland cover for years 2004 and 2007 (left and right panels), strong deviations between v.8 and v.9 are observed in AEZ6 to AEZ9. Cropland cover in AEZ6 and AEZ7 are smaller under v.9 relative to v.8 while cropland area is higher for AEZ8 and AEZ9. Pasture cover in AEZ8 is significantly larger in v.9 than in v.8 while forest cover is generally similar between the two versions. Of course, differences between land cover in v.8 and v.9 are expected. In addition to using new maps, note that in v.9 cropland and pasture cover is exactly calibrated to national-level crop and pasture land cover from FAOSTAT (2016). There are also differences in the patterns of crop production and harvested area in v.9 and in v.8. Figures 10 and 11 shows the production and harvested area of coarse grains, paddy rice and wheat (top, middle and bottom panels) for years 2004 and 2007 (left and right panels) by AEZ. Starting with coarse grains, differences in production and harvested areas between v.8 and v.9 are observed in AEZ8 and AEZ9. For paddy rice, deviations between v.8 and v.9 are notable in AEZ3, AEZ5, AEZ6, AEZ9 and AEZ10 while for wheat the differences are clustered in AEZ7 to AEZ9.

Figures 12 and 13 shows the differences in the computed land rents for v.8 and v.9. Figure 12 shows the value of land endowments (EVOA) in B USD and as % of global value (top and bottom panels) for years 2004 and 2007 (left and right panels) by AEZ. Looking at the values (top panel), EVOA in each AEZ are different between v.8 and v.9 due to differences GTAP base data. But even if we control for the GTAP base data versions – by looking at the % shares (bottom panel) – there are still deviations between v.8 and v.9 particularly in AEZ1 and AEZ6 to AEZ11. Value of producer expenditure on land inputs at agent's prices (EVFA) by the agriculture, livestock and forestry sectors in each AEZ are illustrated in Figure 13. Here, the expenditure of land inputs in the agriculture and livestock sectors are quite different from v.8 and v.9 which is expected due to the use of new high resolution maps to share-out GTAP land rents. For livestock, relying on gridded livestock production instead of representative feed crops to

[5] A comparison between the 2011 GTAP LULC data documented in this memorandum and the 2011 GTAP LULC by Levano et al. (2015) was also conducted. Levano et al. updated GTAP LULC v.8 using national level land use and land cover data from FAO. Key differences in land cover and land use between the databases were traced back to differences in AEZ classifications, regional aggregation, versions of FAO land cover and land use and GTAP land rents as well as author specific assumptions (see Appendix V).

share-out land rents (an assumption from previous GTAP LULC versions) results in strong deviations in livestock land rents between v.8 and v.9. Unlike crop and livestock, distribution of land input purchases by the forestry sector remain the same between both versions since – in the absence of new data – v.9 uses the shares of forestry land rent generated in v.6.

IV. Summary and conclusion

Unlike previous releases, GTAP LULCv.9 is created directly from publicly available high-resolution (i.e. 5-minute) spatial land cover and land use maps. By following the steps outlined in this memorandum, users can now replicate the creation of the land use and land cover information. More importantly, with better capacity to handle spatial data within the Center, future versions of the GTAP LULC can incorporate new geospatial information allowing us to have a better understanding of the tensions and trade-offs in the land-environment-energy nexus. In the future, the 108 AEZ version of the GTAP LULCv.9 will be constructed and will be accessible to users upon request. Newer versions of the upcoming land use and land cover database will be immediately incorporated when it becomes available. Finally, better information on forest output distribution is needed to improve the existing information on forest rent distribution.

References

FAO. (2016). *FAO Statistical Database*. Rome, Italy: Food and Agriculture Organisation of the UN. Retrieved from http://faostat.fao.org/

Global ADMinistrative Areas (GADM). (2016). Global Administrative Areas. Retrieved February 2, 2017, from http://gadm.org/country

Golub, A. A., Henderson, B. B., Hertel, T. W., Gerber, P. J., Rose, S. K., & Sohngen, B. (2012). Global climate policy impacts on livestock, land use, livelihoods, and food security. *Proceedings of the National Academy of Sciences*, 1–6. https://doi.org/10.1073/pnas.1108772109

Hertel, T., Golub, A., Jones, A., O'Hare, M., Plevin, R., & Kammen, D. (2010). Effects of US Maize Ethanol on Global Land Use and Greenhouse Gas Emissions: Estimating Market-mediated Responses. *Bioscience*, *60*(3).

IIASA/FAO. (2012). *Global Agro-ecological Zones (GAEZ v3.0)* (p. 196). IIASA, Laxenburg, Austria; FAO, Rome, Italy. Retrieved from http://www.gaez.iiasa.ac.at/docs/GAEZ_Model_Documentation.pdf

Lee, H. L., Hertel, T. W., Rose, S., & Avetsiyan, M. (2009). An Integrated Land Use Data Base for CGE Analysis of Climate Policy Options. In S. R. and R. T. T.W. Hertel (Ed.), *Economic Analysis of Land Use in Global Climate Change Policy*. UK: Routledge Press.

Levano, L. M. P., Taheripour, F., & Tyner, W. (2015). *Development of the GTAP Land Use Data Base for 2011* (GTAP Research Memorandum No. 28). Department of Agricultural Economics, Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/download/7744.pdf

Liu, J., Hertel, T. W., Taheripour, F., Zhu, T., & Ringler, C. (2014). International trade buffers the impact of future irrigation shortfalls. *Global Environmental Change*, *29*, 22–31. https://doi.org/10.1016/j.gloenvcha.2014.07.010

Monfreda, C., Ramankutty, N., & Hertel, T. W. (2009). Global Agricultural Land Use Data for Climate Change Analysis. In T. W. Hertel, S. Rose, & R. Tol (Eds.), *Economic Analysis of Land Use in Global Climate Change Policy*. UK: Routledge Press.

Monfreda, Chad, Ramankutty, N., & Foley, J. A. (2008). Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles*, *22*, 19 PP. https://doi.org/200810.1029/2007GB002947

Panagos, P., Van Liedekerke, M., Jones, A., & Montanarella, L. (2012). European Soil Data Centre: Response to European policy support and public data requirements. *Land Use Policy*, *29*(2), 329–338. https://doi.org/10.1016/j.landusepol.2011.07.003

Ramankutty, N., Evan, A. T., Monfreda, C., & Foley, J. A. (2008). Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Retrieved from http://www.agu.org/pubs/crossref/2008/2007GB002952.shtml

Ramankutty, N., & Foley, J. A. (1999). Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles*, *13*(4), PP. 997-1027. https://doi.org/199910.1029/1999GB900046

Schneider, A., Friedl, M. A., & Potere, D. (2009). A new map of global urban extent from MODIS satellite data. *Environmental Research Letters*, *4*(4), 044003. https://doi.org/10.1088/1748-9326/4/4/044003

Schneider, A., Friedl, M. A., & Potere, D. (2010). Mapping global urban areas using MODIS 500-m data: New methods and datasets based on [`]urban ecoregions'. *Remote Sensing of Environment*, *114*(8), 1733–1746. https://doi.org/10.1016/j.rse.2010.03.003

Sohngen, B., Tennity, C., Hnytka, M., & Meeusen, K. (2008). *Global Forestry Data for the Economic Modeling of Land Use*. Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. Retrieved from http://ideas.repec.org/p/gta/workpp/2602.html

Stevenson, J. R., Villoria, N., Byerlee, D., Kelley, T., & Maredia, M. (2013). Green Revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. *Proceedings of the National Academy of Sciences*, *110*(21), 8363–8368. https://doi.org/10.1073/pnas.1208065110

Taheripour, F., Hertel, T. W., Tyner, W. E., Beckman, J. F., & Birur, D. K. (2010). Biofuels and their by-products: Global economic and environmental implications. *Biomass and Bioenergy*, *34*, 278–289.

Taheripour, Farzad, & Tyner, W. E. (2012). Induced land use emissions due to first and second generation biofuels and uncertainty in land use emission factors. Presented at the Agricultural and Applied Economics Association annual meeting.

Wint, G. R. W., & Robinson, T. P. (2007). *Gridded Livestock of the World* (p. 131). Rome, Italy: Food and Agriculture Organization of the United Nations.

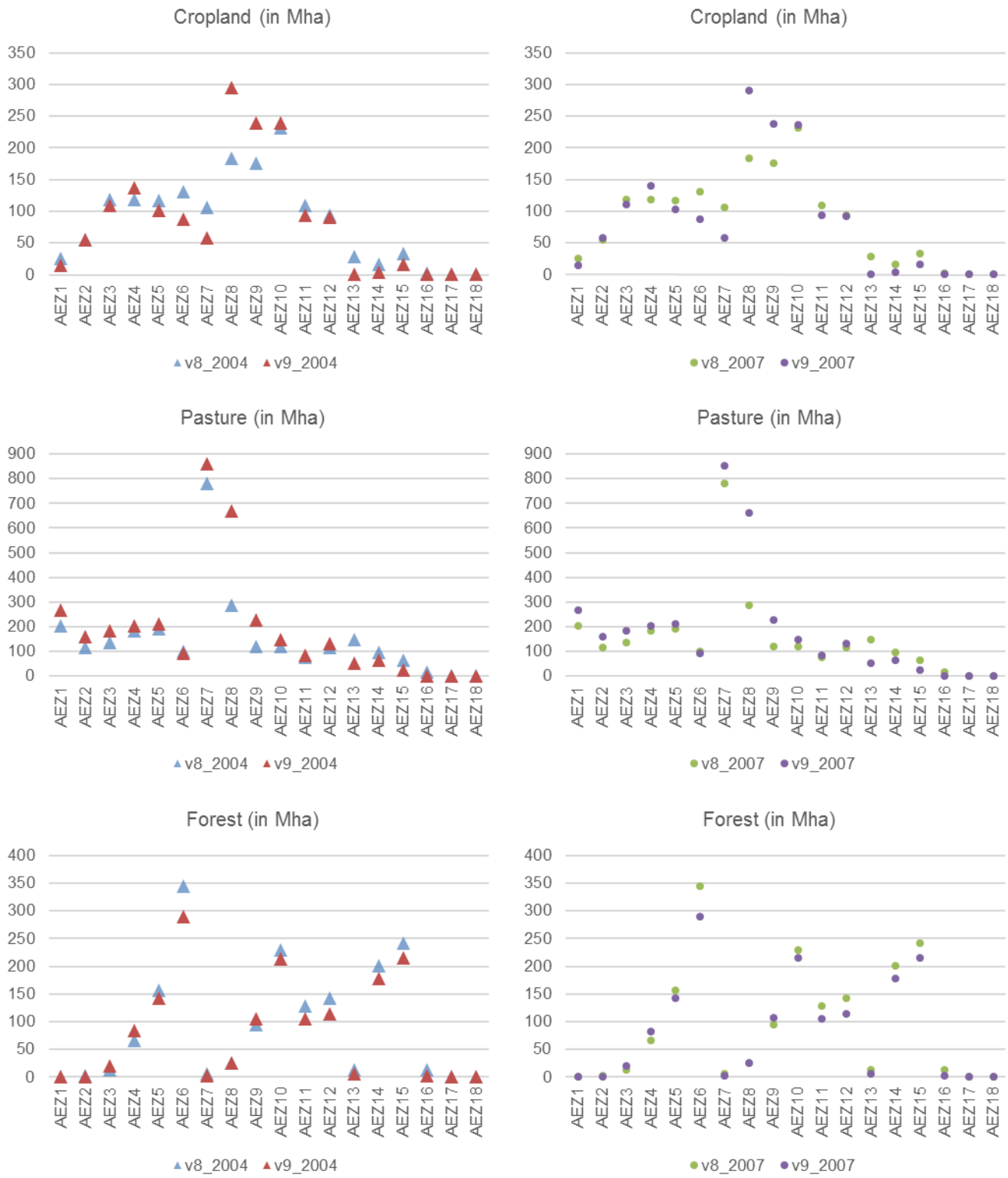


Figure 9. Cropland, pasture and forest land cover by AEZ: 2004 2007 2011

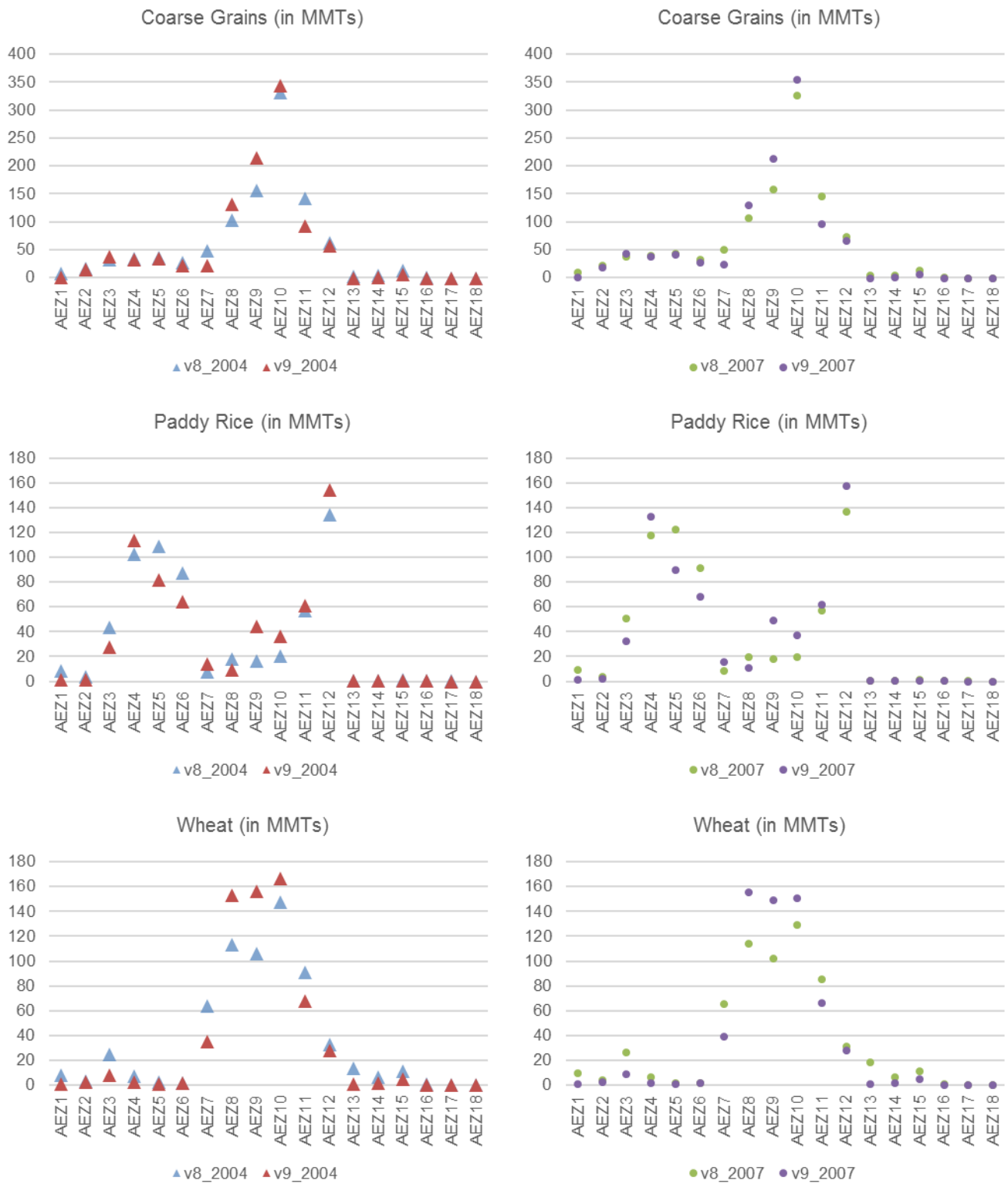


Figure 10. Production of coarse grains, paddy rice and wheat by AEZ: 2004 2007 2011

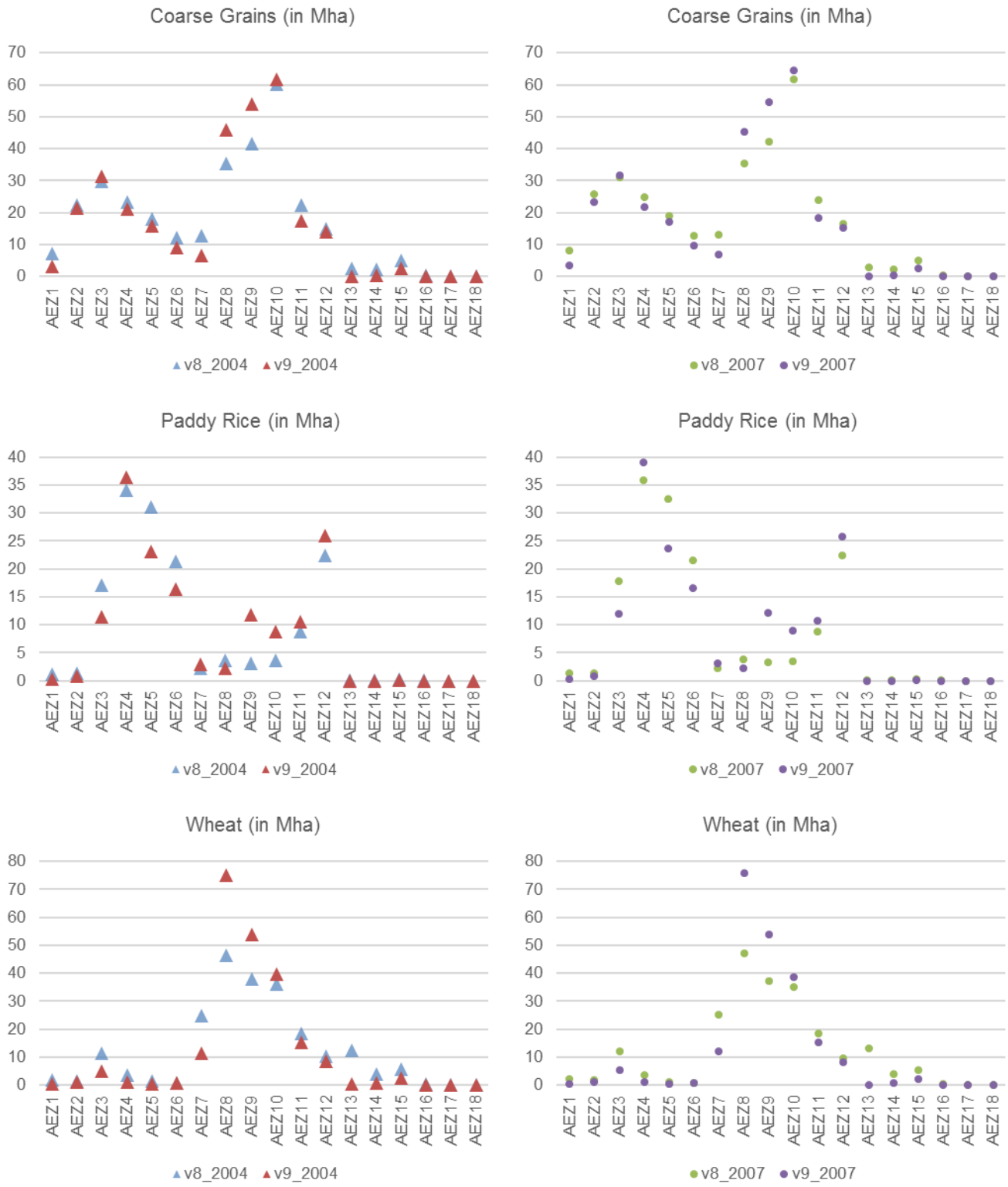


Figure 11. Harvested area of coarse grains, paddy rice and wheat by AEZ: 2004 2007 2011

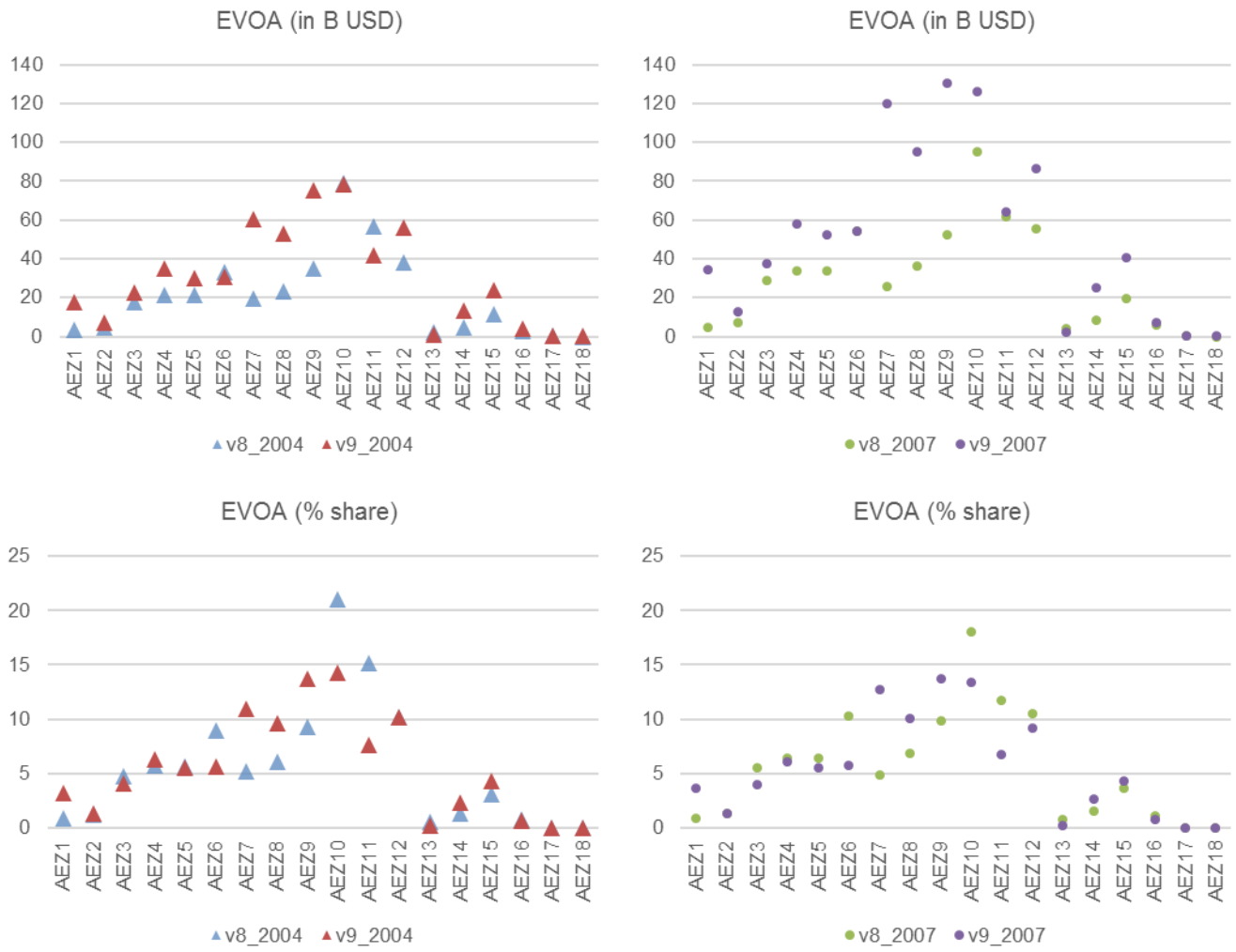


Figure 12. Value of land endowments at agent's prices (EVOA) in B USD and in % global share by AEZ: 2004 2007 2011

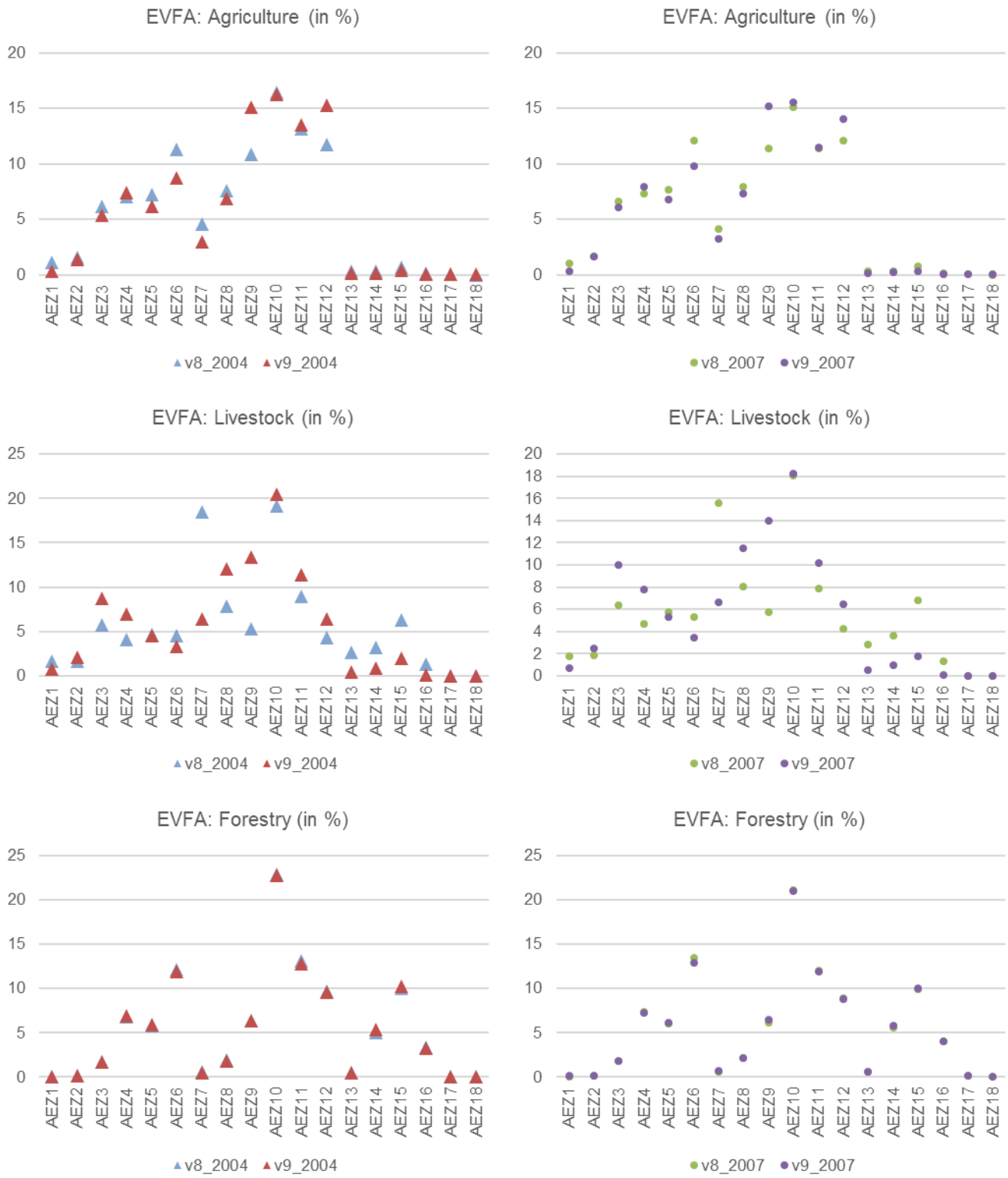


Figure 13. Value of producer expenditure on land inputs at agent's prices (EVFA) of agriculture, livestock and forestry sectors by AEZ: 2004 2007 2011

V. Appendices

Appendix I. Country mapping

GTAP	GTAP226	GTAP140	GTAP141	GADM	FAO NAMES
1	abw	XCB	XCB	ABW	Aruba
2	afg	XSA	XSA	AFG	Afghanistan
3	ago	XAC	XAC	AGO	Angola
4	aia	XCB	XCB	----	----
5	alb	ALB	ALB	ALB	Albania
6	and	XER	XER	AND	Andorra
7	ant	XCB	XCB	----	----
8	are	ARE	ARE	ARE	United Arab Emirates
9	arg	ARG	ARG	ARG	Argentina
10	arm	ARM	ARM	ARM	Armenia
11	asm	XOC	XOC	ASM	American Samoa
12	atg	XCB	XCB	ATG	Antigua and Barbuda
13	aus	AUS	AUS	AUS	Australia
14	aut	AUT	AUT	AUT	Austria
15	aze	AZE	AZE	AZE	Azerbaijan
16	bdi	XEC	XEC	BDI	Burundi
17	bel	BEL	BEL	BEL	Belgium
18	ben	BEN	BEN	BEN	Benin
19	bfa	BFA	BFA	BFA	Burkina Faso
20	bgd	BGD	BGD	BGD	Bangladesh
21	bgr	BGR	BGR	BGR	Bulgaria
22	bhr	BHR	BHR	BHR	Bahrain
23	bhs	XCB	XCB	BHS	Bahamas
24	bih	XER	XER	BIH	Bosnia and Herzegovina
25	blr	BLR	BLR	BLR	Belarus
26	blz	XCA	XCA	BLZ	Belize
27	bmu	XNA	XNA	BMU	Bermuda
28	bol	BOL	BOL	BOL	Bolivia (Plurinational State of)
29	bra	BRA	BRA	BRA	Brazil
30	brb	XCB	XCB	BRB	Barbados
31	brn	BRN	BRN	BRN	Brunei Darussalam
32	btn	XSA	XSA	BTN	Bhutan
33	bwa	BWA	BWA	BWA	Botswana
34	caf	XCF	XCF	CAF	Central African Republic
35	can	CAN	CAN	CAN	Canada
36	che	CHE	CHE	CHE	Switzerland
37	chl	CHL	CHL	CHL	Chile
38	chn	CHN	CHN	CHN	China
39	civ	CIV	CIV	CIV	C“te d'Ivoire
40	cmr	CMR	CMR	CMR	Cameroon
41	cod	XAC	XAC	COD	Democratic Republic of the Congo
42	cog	XCF	XCF	COG	Congo
43	cok	XOC	XOC	COK	Cook Islands
44	col	COL	COL	COL	Colombia
45	com	XEC	XEC	COM	Comoros
46	cpv	XWF	XWF	CPV	Cabo Verde
47	cri	CRI	CRI	CRI	Costa Rica
48	cub	XCB	XCB	CUB	Cuba
49	cym	XCB	XCB	CYM	Cayman Islands
50	cyp	CYP	CYP	CYP	Cyprus
51	cze	CZE	CZE	CZE	Czechia
52	deu	DEU	DEU	DEU	Germany
53	dji	XEC	XEC	DJI	Djibouti
54	dma	XCB	XCB	DMA	Dominica
55	dnk	DNK	DNK	DNK	Denmark
56	dom	DOM	DOM	DOM	Dominican Republic
57	dza	XNF	XNF	DZA	Algeria
58	ecu	ECU	ECU	ECU	Ecuador
59	egy	EGY	EGY	EGY	Egypt
60	eri	XEC	XEC	ERI	Eritrea
61	esp	ESP	ESP	ESP	Spain
62	est	EST	EST	EST	Estonia
63	eth	ETH	ETH	ETH	Ethiopia

64	fin	FIN	FIN	FIN	Finland
65	fji	XOC	XOC	FJI	Fiji
66	flk	XSM	XSM	FLK	Falkland Islands (Malvinas)
67	fra	FRA	FRA	FRA	France
68	fro	XER	XER	FRO	Faroe Islands
69	fsm	XOC	XOC	FSM	Micronesia (Federated States of)
70	gab	XCF	XCF	GAB	Gabon
71	gbr	GBR	GBR	GBR	United Kingdom
72	geo	GEO	GEO	GEO	Georgia
73	gha	GHA	GHA	GHA	Ghana
74	gib	XER	XER	----	----
75	gin	GIN	GIN	GIN	Guinea
76	glp	FRA	FRA	GLP	Guadeloupe
77	gmb	XWF	XWF	GMB	Gambia
78	gnb	XWF	XWF	GNB	Guinea-Bissau
79	gnq	XCF	XCF	GNQ	Equatorial Guinea
80	grc	GRC	GRC	GRC	Greece
81	grd	XCB	XCB	GRD	Grenada
82	grl	XNA	XNA	GRL	Greenland
83	gtm	GTM	GTM	GTM	Guatemala
84	guf	XSM	XSM	GUF	French Guiana
85	gum	XOC	XOC	GUM	Guam
86	guy	XSM	XSM	GUY	Guyana
87	hkg	HKG	HKG	HKG	China, Hong Kong SAR
88	hnd	HND	HND	HND	Honduras
89	hrv	HRV	HRV	HRV	Croatia
90	hti	XCB	XCB	HTI	Haiti
91	hun	HUN	HUN	HUN	Hungary
92	idn	IDN	IDN	IDN	Indonesia
93	ind	IND	IND	IND	India
94	irl	IRL	IRL	IRL	Ireland
95	irn	IRN	IRN	IRN	Iran (Islamic Republic of)
96	irq	XWS	XWS	IRQ	Iraq
97	isl	XEF	XEF	ISL	Iceland
98	isr	ISR	ISR	ISR	Israel
99	ita	ITA	ITA	ITA	Italy
100	jam	JAM	JAM	JAM	Jamaica
101	jor	JOR	JOR	JOR	Jordan
102	jpn	JPN	JPN	JPN	Japan
103	kaz	KAZ	KAZ	KAZ	Kazakhstan
104	ken	KEN	KEN	KEN	Kenya
105	kgz	KGZ	KGZ	KGZ	Kyrgyzstan
106	khm	KHM	KHM	KHM	Cambodia
107	kir	XOC	XOC	KIR	Kiribati
108	kna	XCB	XCB	KNA	Saint Kitts and Nevis
109	kor	KOR	KOR	KOR	Republic of Korea
110	kwt	KWT	KWT	KWT	Kuwait
111	lao	LAO	LAO	LAO	Lao People's Democratic Republic
112	lbn	XWS	XWS	LBN	Lebanon
113	lbr	XWF	XWF	LBR	Liberia
114	lby	XNF	XNF	LBY	Libya
115	lca	XCB	XCB	LCA	Saint Lucia
116	lie	XEF	XEF	LIE	Liechtenstein
117	lka	LKA	LKA	LKA	Sri Lanka
118	lso	XSC	XSC	LSO	Lesotho
119	ltu	LTU	LTU	LTU	Lithuania
120	lux	LUX	LUX	LUX	Luxembourg
121	lva	LVA	LVA	LVA	Latvia
122	mac	XEA	XEA	----	----
123	mar	MAR	MAR	MAR	Morocco
124	mco	XER	XER	MCO	Mexico
125	mda	XEE	XEE	MDA	Republic of Moldova
126	mdg	MDG	MDG	MDG	Madagascar
127	mdv	XSA	XSA	MDV	Maldives
128	mex	MEX	MEX	MEX	Mexico
129	mhl	XOC	XOC	MHL	Marshall Islands
130	mkd	XER	XER	MKD	The former Yugoslav Republic of Macedonia
131	mli	XWF	XWF	MLI	Mali
132	mlt	MLT	MLT	MLT	Malta
133	mmr	XSE	XSE	MMR	Myanmar
134	mng	MNG	MNG	MNG	Mongolia

135	mnp	XOC	XOC	MNP	Northern Mariana Islands
136	moz	MOZ	MOZ	MOZ	Mozambique
137	mrt	XWF	XWF	MRT	Mauritania
138	msr	XCB	XCB	MSR	Montserrat
139	mtq	FRA	FRA	MTQ	Martinique
140	mus	MUS	MUS	MUS	Mauritius
141	mwi	MWI	MWI	MWI	Malawi
142	mys	MYS	MYS	MYS	Malaysia
143	myt	XEC	XEC	MYT	Mayotte
144	nam	NAM	NAM	NAM	Namibia
145	ncl	XOC	XOC	NCL	New Caledonia
146	ner	XWF	XWF	NER	Niger
147	nfk	AUS	AUS	NFK	Norfolk Island
148	nga	NGA	NGA	NGA	Nigeria
149	nic	NIC	NIC	NIC	Nicaragua
150	niu	XOC	XOC	NIU	Niue
151	nld	NLD	NLD	NLD	Netherlands
152	nor	NOR	NOR	NOR	Norway
153	npl	NPL	NPL	NPL	Nepal
154	nru	XOC	XOC	NRU	Nauru
155	nzl	NZL	NZL	NZL	New Zealand
156	omn	OMN	OMN	OMN	Oman
157	pak	PAK	PAK	PAK	Pakistan
158	pan	PAN	PAN	PAN	Panama
159	per	PER	PER	PER	Peru
160	phl	PHL	PHL	PHL	Philippines
161	plw	XOC	XOC	PLW	Palau
162	png	XOC	XOC	PNG	Papua New Guinea
163	pol	POL	POL	POL	Poland
164	pri	PRI	PRI	PRI	Puerto Rico
165	prk	XEA	XEA	PRK	Democratic People's Republic of Korea
166	prt	PRT	PRT	PRT	Portugal
167	pry	PRY	PRY	PRY	Paraguay
168	pse	XWS	XWS	PSE	Occupied Palestinian Territory
169	pyf	XOC	XOC	PYF	French Polynesia
170	qat	QAT	QAT	QAT	Qatar
171	reu	FRA	FRA	REU	R,union
172	rom	ROU	ROU	ROU	Romania
173	rus	RUS	RUS	RUS	Russian Federation
174	rwa	RWA	RWA	RWA	Rwanda
175	sau	SAU	SAU	SAU	Saudi Arabia
176	scg	XER	XER	SRB	Serbia and Montenegro
177	sdn	XEC	XEC	SDN	Sudan (former)
178	sen	SEN	SEN	SEN	Senegal
179	sgp	SGP	SGP	SGP	Singapore
180	shn	XWF	XWF	SHN	Saint Helena, Ascension and Tristan da Cunha
181	slb	XOC	XOC	SLB	Solomon Islands
182	sle	XWF	XWF	SLE	Sierra Leone
183	slv	SLV	SLV	SLV	El Salvador
184	smr	XER	XER	SMR	San Marino
185	som	XEC	XEC	SOM	Somalia
186	spm	XNA	XNA	SPM	Saint Pierre and Miquelon
187	stp	XCF	XCF	STP	Sao Tome and Principe
188	sur	XSM	XSM	SUR	Suriname
189	svk	SVK	SVK	SVK	Slovakia
190	svn	SVN	SVN	SVN	Slovenia
191	swe	SWE	SWE	SWE	Sweden
192	swz	XSC	XSC	SWZ	Swaziland
193	syc	XEC	XEC	SYC	Seychelles
194	syr	XWS	XWS	SYR	Syrian Arab Republic
195	tca	XCB	XCB	TCA	Turks and Caicos Islands
196	tcd	XCF	XCF	TCD	Chad
197	tgo	TGO	TGO	TGO	Togo
198	tha	THA	THA	THA	Thailand
199	tjk	XSU	TJK	TJK	Tajikistan
200	tkl	XOC	XOC	TKL	Tokelau
201	tkm	XSU	XSU	TKM	Turkmenistan
202	tls	XSE	XSE	TLS	Timor-Leste
203	ton	XOC	XOC	TON	Tonga
204	tto	TTO	TTO	TTO	Trinidad and Tobago
205	tun	TUN	TUN	TUN	Tunisia

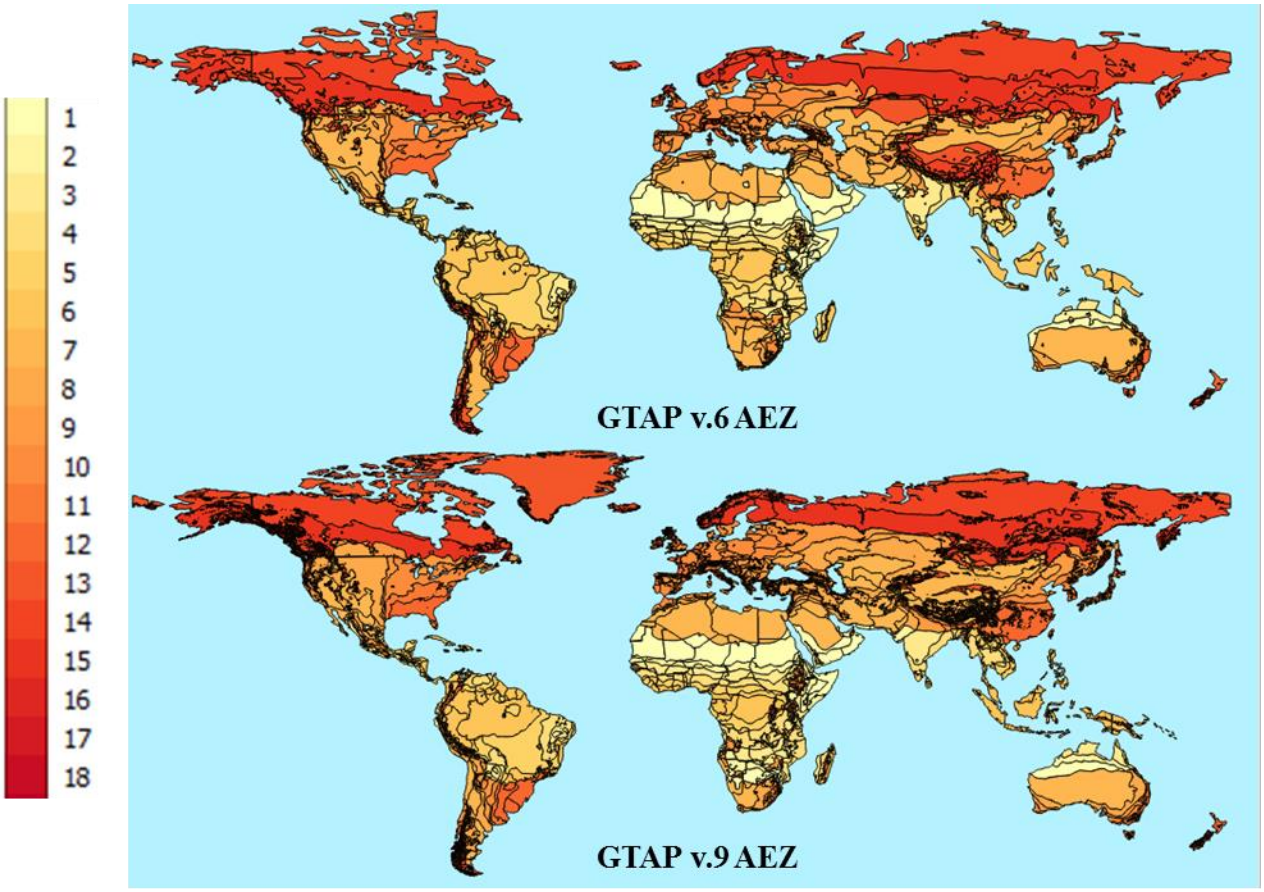
206	tur	TUR	TUR	TUR	Turkey
207	tuv	XOC	XOC	TUV	Tuvalu
208	twn	TWN	TWN	TWN	China, Taiwan Province of
209	tza	TZA	TZA	TZA	United Republic of Tanzania
210	uga	UGA	UGA	UGA	Uganda
211	ukr	UKR	UKR	UKR	Ukraine
212	ury	URY	URY	URY	Uruguay
213	usa	USA	USA	USA	United States of America
214	uzb	XSU	XSU	UZB	Uzbekistan
215	vct	XCB	XCB	VCT	Saint Vincent and the Grenadines
216	ven	VEN	VEN	VEN	Venezuela (Bolivarian Republic of)
217	vgb	XCB	XCB	VGB	British Virgin Islands
218	vir	XCB	XCB	VIR	United States Virgin Islands
219	vnm	VNM	VNM	VNM	Viet Nam
220	vut	XOC	XOC	VUT	Vanuatu
221	wlf	XOC	XOC	WLF	Wallis and Futuna Islands
222	wsm	XOC	XOC	WSM	Samoa
223	yem	XWS	XWS	YEM	Yemen
224	zaf	ZAF	ZAF	ZAF	South Africa
225	zmb	ZMB	ZMB	ZMB	Zambia
226	zwe	ZWE	ZWE	ZWE	Zimbabwe

Appendix III. AEZ mapping

AEZ18	AEZ108	Length of Growing Days		Thermal Climate
AEZ1	AEZ1	0	9	Tropics
AEZ1	AEZ2	10	19	Tropics
AEZ1	AEZ3	20	29	Tropics
AEZ1	AEZ4	30	39	Tropics
AEZ1	AEZ5	40	49	Tropics
AEZ1	AEZ6	50	59	Tropics
AEZ2	AEZ7	60	69	Tropics
AEZ2	AEZ8	70	79	Tropics
AEZ2	AEZ9	80	89	Tropics
AEZ2	AEZ10	90	99	Tropics
AEZ2	AEZ11	100	109	Tropics
AEZ2	AEZ12	110	119	Tropics
AEZ3	AEZ13	120	129	Tropics
AEZ3	AEZ14	130	139	Tropics
AEZ3	AEZ15	140	149	Tropics
AEZ3	AEZ16	150	159	Tropics
AEZ3	AEZ17	160	169	Tropics
AEZ3	AEZ18	170	179	Tropics
AEZ4	AEZ19	180	189	Tropics
AEZ4	AEZ20	190	199	Tropics
AEZ4	AEZ21	200	209	Tropics
AEZ4	AEZ22	210	219	Tropics
AEZ4	AEZ23	220	229	Tropics
AEZ4	AEZ24	230	239	Tropics
AEZ5	AEZ25	240	249	Tropics
AEZ5	AEZ26	250	259	Tropics
AEZ5	AEZ27	260	269	Tropics
AEZ5	AEZ28	270	279	Tropics
AEZ5	AEZ29	280	289	Tropics
AEZ5	AEZ30	290	299	Tropics
AEZ6	AEZ31	300	309	Tropics
AEZ6	AEZ32	310	319	Tropics
AEZ6	AEZ33	320	329	Tropics
AEZ6	AEZ34	330	339	Tropics
AEZ6	AEZ35	340	349	Tropics
AEZ6	AEZ36	350	365	Tropics
AEZ7	AEZ37	0	9	Tropics cool + subtropics + temperate cool
AEZ7	AEZ38	10	19	Tropics cool + subtropics + temperate cool
AEZ7	AEZ39	20	29	Tropics cool + subtropics + temperate cool
AEZ7	AEZ40	30	39	Tropics cool + subtropics + temperate cool
AEZ7	AEZ41	40	49	Tropics cool + subtropics + temperate cool
AEZ7	AEZ42	50	59	Tropics cool + subtropics + temperate cool
AEZ8	AEZ43	60	69	Tropics cool + subtropics + temperate cool
AEZ8	AEZ44	70	79	Tropics cool + subtropics + temperate cool
AEZ8	AEZ45	80	89	Tropics cool + subtropics + temperate cool
AEZ8	AEZ46	90	99	Tropics cool + subtropics + temperate cool
AEZ8	AEZ47	100	109	Tropics cool + subtropics + temperate cool
AEZ8	AEZ48	110	119	Tropics cool + subtropics + temperate cool
AEZ9	AEZ49	120	129	Tropics cool + subtropics + temperate cool
AEZ9	AEZ50	130	139	Tropics cool + subtropics + temperate cool
AEZ9	AEZ51	140	149	Tropics cool + subtropics + temperate cool
AEZ9	AEZ52	150	159	Tropics cool + subtropics + temperate cool
AEZ9	AEZ53	160	169	Tropics cool + subtropics + temperate cool
AEZ9	AEZ54	170	179	Tropics cool + subtropics + temperate cool
AEZ10	AEZ55	180	189	Tropics cool + subtropics + temperate cool
AEZ10	AEZ56	190	199	Tropics cool + subtropics + temperate cool
AEZ10	AEZ57	200	209	Tropics cool + subtropics + temperate cool
AEZ10	AEZ58	210	219	Tropics cool + subtropics + temperate cool
AEZ10	AEZ59	220	229	Tropics cool + subtropics + temperate cool
AEZ10	AEZ60	230	239	Tropics cool + subtropics + temperate cool
AEZ11	AEZ61	240	249	Tropics cool + subtropics + temperate cool
AEZ11	AEZ62	250	259	Tropics cool + subtropics + temperate cool
AEZ11	AEZ63	260	269	Tropics cool + subtropics + temperate cool
AEZ11	AEZ64	270	279	Tropics cool + subtropics + temperate cool
AEZ11	AEZ65	280	289	Tropics cool + subtropics + temperate cool
AEZ11	AEZ66	290	299	Tropics cool + subtropics + temperate cool
AEZ12	AEZ67	300	309	Tropics cool + subtropics + temperate cool

AEZ12	AEZ68	310	319	Tropics cool + subtropics + temperate cool
AEZ12	AEZ69	320	329	Tropics cool + subtropics + temperate cool
AEZ12	AEZ70	330	339	Tropics cool + subtropics + temperate cool
AEZ12	AEZ71	340	349	Tropics cool + subtropics + temperate cool
AEZ12	AEZ72	350	365	Tropics cool + subtropics + temperate cool
AEZ13	AEZ73	0	9	Temperate cold to boreal
AEZ13	AEZ74	10	19	Temperate cold to boreal
AEZ13	AEZ75	20	29	Temperate cold to boreal
AEZ13	AEZ76	30	39	Temperate cold to boreal
AEZ13	AEZ77	40	49	Temperate cold to boreal
AEZ13	AEZ78	50	59	Temperate cold to boreal
AEZ14	AEZ79	60	69	Temperate cold to boreal
AEZ14	AEZ80	70	79	Temperate cold to boreal
AEZ14	AEZ81	80	89	Temperate cold to boreal
AEZ14	AEZ82	90	99	Temperate cold to boreal
AEZ14	AEZ83	100	109	Temperate cold to boreal
AEZ14	AEZ84	110	119	Temperate cold to boreal
AEZ15	AEZ85	120	129	Temperate cold to boreal
AEZ15	AEZ86	130	139	Temperate cold to boreal
AEZ15	AEZ87	140	149	Temperate cold to boreal
AEZ15	AEZ88	150	159	Temperate cold to boreal
AEZ15	AEZ89	160	169	Temperate cold to boreal
AEZ15	AEZ90	170	179	Temperate cold to boreal
AEZ16	AEZ91	180	189	Temperate cold to boreal
AEZ16	AEZ92	190	199	Temperate cold to boreal
AEZ16	AEZ93	200	209	Temperate cold to boreal
AEZ16	AEZ94	210	219	Temperate cold to boreal
AEZ16	AEZ95	220	229	Temperate cold to boreal
AEZ16	AEZ96	230	239	Temperate cold to boreal
AEZ17	AEZ97	240	249	Temperate cold to boreal
AEZ17	AEZ98	250	259	Temperate cold to boreal
AEZ17	AEZ99	260	269	Temperate cold to boreal
AEZ17	AEZ100	270	279	Temperate cold to boreal
AEZ17	AEZ101	280	289	Temperate cold to boreal
AEZ17	AEZ102	290	299	Temperate cold to boreal
AEZ18	AEZ103	300	309	Temperate cold to boreal
AEZ18	AEZ104	310	319	Temperate cold to boreal
AEZ18	AEZ105	320	329	Temperate cold to boreal
AEZ18	AEZ106	330	339	Temperate cold to boreal
AEZ18	AEZ107	340	349	Temperate cold to boreal
AEZ18	AEZ108	350	365	Temperate cold to boreal

Appendix III. Comparison of GTAP LULC v.6 and v.9 AEZs



Appendix IV. Crop commodity mapping

GTAP	GTAPNAMES	FAOCODE	FAONAME
1	Barley	44	Barley
2	Buckwheat	89	Buckwheat
3	CanarySeed	101	Canary seed
4	Cerealsnes	108	Cereals, nes
5	Fonio	94	Fonio
6	Maize	56	Maize
7	Millet	79	Millet
8	MixedGrain	103	Mixed grain
9	Oats	75	Oats
10	PopCorn	68	Popcorn
11	Quinoa	92	Quinoa
12	PaddyRice	27	Rice, paddy
13	Rye	71	Rye
14	Sorghum	83	Sorghum
15	Triticale	97	Triticale
16	Wheat	15	Wheat
17	Abaca_M_H	809	Manila Fibre (Abaca)
18	AgaveFibrNES	800	Agave Fibres Nes
19	Coir	813	Coir
20	FibreCropNES	821	Fibre Crops Nes
21	FlaxFibr_Tow	773	Flax fibre and tow
22	HempFibr_Tow	777	Hemp Tow Waste
23	Jute	780	Jute
24	JuteLikeFibr	782	Other Bastfibres
25	KapokFibre	778	Kapok Fibre
26	KapksdShell	311	Kapokseed in Shell
27	Ramie	788	Ramie
28	SeedCotton	328	Seed cotton
29	Sisal	789	Sisal
30	Alff4FrgSlg	641	Alff4FrgSlg
31	Beets4Fodder	647	Beets4Fodder
32	Cabbage4Fddr	644	Cabbage4Fddr
33	Carrots4Fddr	648	Carrots4Fddr
34	Clovr4FrgSlg	640	Clovr4FrgSlg
35	FrgProdNES	651	FrgProdNES
36	GrsNESFrgSlg	639	GrsNESFrgSlg
37	GrnOlsd4Fddr	642	GrnOlsd4Fddr
38	LgmNESFrgSlg	420	Leguminous vegetables, nes
39	Maize4FrgSlg	636	Maize4FrgSlg
40	MxGrss_Lgm	645	MxGrss_Lgm
41	RyeGrsFrgSlg	638	RyeGrsFrgSlg
42	Srgm4FrgSlg	637	Srgm4FrgSlg
43	Swedes4Fddr	649	Swedes4Fddr
44	Turnips4Fddr	646	Turnips4Fddr
45	Vgt_RootFddr	655	Vgt_RootFddr
46	Apples	515	Apples
47	Apricots	526	Apricots
48	Avocados	572	Avocados
49	Bananas	486	Bananas
50	Berriesnes	558	Berries Nes
51	Blueberries	552	Blueberries
52	Carobs	461	Carobs
53	Cashewapple	591	Cashewapple
54	Cherries	531	Cherries
55	CitrusFrtNES	512	Citrus fruit, nes
56	Cranberries	554	Cranberries
57	Currants	550	Currants
58	Dates	577	Dates
59	Figs	569	Figs
60	FrtFrshNES	619	Fruit Fresh Nes
61	FrtTrpFrNES	603	Fruit, tropical fresh nes
62	Gooseberries	549	Gooseberries
63	Grpfrt_Pmlos	507	Grapefruit (inc. pomelos)
64	Grapes	560	Grapes
65	KiwiFruit	592	Kiwi fruit
66	Lmn_Lme	497	Lemons and limes
67	Mangoes	571	Mangoes, mangosteens, guavas

68	Oranges	490	Oranges
69	Papayas	600	Papayas
70	Peach_Nctrn	534	Peaches and nectarines
71	Pears	521	Pears
72	Persimmons	587	Persimmons
73	Pineapples	574	Pineapples
74	Plantains	489	Plantains
75	Plums	536	Plums and sloes
76	Quinces	523	Quinces
77	Raspberries	547	Raspberries
78	SourCherries	530	Sour cherries
79	StnFrtNESFrh	541	Stone fruit, nes
80	Strawberries	544	Strawberries
81	TngMndClmnt	495	Tangerines, mandarins, clem.
82	CastorBeans	265	Castor oil seed
83	Coconuts	249	Coconuts
84	GrndntWShll	242	Groundnuts, with shell
85	Hempseed	336	Hempseed
86	KrtNtSheant	263	Karite Nuts (Sheanuts)
87	Linseed	333	Linseed
88	Melonseed	299	Melonseed
89	MustardSeed	292	Mustard seed
90	OilPalmFruit	254	Oil palm fruit
91	Oilseedsnes	339	Oilseeds, Nes
92	Olives	260	Olives
93	PoppySeed	296	Poppy seed
94	Rapeseed	270	Rapeseed
95	SfflwrSeed	280	Safflower seed
96	SesameSeed	289	Sesame seed
97	Soybeans	236	Soybeans
98	SnflwrSeed	267	Sunflower seed
99	TungNuts	275	Tung Nuts
100	Ans_bdn_fnnl	711	Anise, badian, fennel, corian.
101	ArcNtBtl	226	Arecanuts
102	ChicoryRoots	459	Chicory roots
103	CnnmnCnlla	693	Cinnamon (canella)
104	cloves	698	Cloves
105	CocoaBeans	661	Cocoa beans
106	CoffeeGreen	656	Coffee, green
107	ginger	720	Ginger
108	Hops	677	Hops
109	Kolanuts	224	Kolanuts
110	Mate	671	Maté
111	NaturalGums	839	Gums Natural
112	NatRubber	836	Natural rubber
113	Ntmg_Mc_Crdm	702	Nutmeg, mace and cardamoms
114	Pepper	687	Pepper (Piper spp.)
115	Peppermint	748	Peppermint
116	Pimento	689	Chillies and peppers, dry
117	PrthrmDrdFlw	754	Pyrethrum,Dried
118	spicesnes	723	Spices, nes
119	Tea	667	Tea
120	TbccLeaves	826	Tobacco, unmanufactured
121	Vanilla	692	Vanilla
122	BambaraBeans	203	Bambara beans
123	BeansDry	176	Beans, dry
124	BrdBeansDry	181	Broad beans, horse beans, dry
125	ChickPeas	191	Chick peas
126	CowPeasDry	195	Cow peas, dry
127	Lentils	201	Lentils
128	Lupins	210	Lupins
129	PeasDry	187	Peas, dry
130	PigeonPeas	197	Pigeon peas
131	Pulsesnes	211	Pulses, nes
132	Vetches	205	Vetches
133	Cassava	125	Cassava
134	Potatoes	116	Potatoes
135	Root_TbrNES	149	Roots and Tubers, nes
136	SweetPotato	122	Sweet potatoes
137	TaroCocoYam	136	Taro (cocoyam)
138	Yams	137	Yams

139	YautiaCcYam	135	Yautia (cocoyam)
140	SugarBeets	157	Sugar beet
141	SugarCane	156	Sugar cane
142	SugarCrpNES	161	Sugar crops, nes
143	Almonds	221	Almonds, with shell
144	BrazilNuts	216	Brazil nuts, with shell
145	CashewNuts	217	Cashew nuts, with shell
146	Chestnuts	220	Chestnuts
147	HzlntFlbrt	225	Hazelnuts, with shell
148	Nutsnes	234	Nuts, nes
149	Pistachios	223	Pistachios
150	Walnuts	222	Walnuts, with shell
151	Artichokes	366	Artichokes
152	Asparagus	367	Asparagus
153	BeanGreen	414	Beans, green
154	BrdBeanGreen	9003	BrdBeanGreen
155	Cabbages	358	Cabbages and other brassicas
156	Cntlp_othMln	568	Other melons (inc.cantaloupes)
157	Carrots	426	Carrots and turnips
158	Cauliflower	393	Cauliflowers and broccoli
159	Chll_PpprGrn	401	Chillies and peppers, green
160	Ccmbr_Ghrkn	397	Cucumbers and gherkins
161	Eggplants	399	Eggplants (aubergines)
162	Garlic	406	Garlic
163	GrnCornMaize	446	Maize, green
164	Lettuce	372	Lettuce and chicory
165	Mushrooms	449	Mushrooms and truffles
166	Okra	430	Okra
167	OnionDry	403	Onions, dry
168	OnionShlltGn	402	Onions (inc. shallots), green
169	PeasGreen	417	Peas, green
170	PmpknSqshGrd	394	Pumpkins, squash and gourds
171	Spinach	373	Spinach
172	StringBeans	423	String beans
173	Tomatoes	388	Tomatoes
174	VgtbFrshNES	463	Vegetables fresh nes
175	Watermelons	567	Watermelons

Appendix V. Differences in assumptions in the 2011 land use and land cover database in Levano et al. (2015) and the database documented in this memo.

Levano et al. (2015)	Database documented in this memorandum
General adjustments in land use data	
• Adjust production of U.S. alfalfa based on USDA data • Set grass and ray grass for silage and forage equal to zero • Drop production for crops with no harvested area information: oilseeds NES, mushroom, coir, forage NES, sugar beet, kapokseed in shell, fiber crop NES, Brazil nut and pumpkin, squash and ground • Kept constant the value of Mixed Grass and Leguminous • The production of Jute like fiber was set equal to zero, because this is a sub product and therefore it has no area. Same for Pop Corn and Natural Gum.	• No adjustments after sharing-out FAO land use data
Country-specific adjustments in land use data	
• Impose AEZ data for countries with missing AEZ information Jam (Jamaica) ~ Dominican Republic (Dom) Pri (Puerto Rico) ~ Cuba Cpv (Cape Verde) ~ Senegal Lux (Luxembourg) ~ Belgium Mlt (Malta) ~ ½ AEZ10 and AEZ11 Bhr (Bahrain) ~ Saudi Arabia Qat (Qatar) ~ Saudi Arabia Mus (Mauritius) ~ AEZ 6 Twn (Taiwan) ~ AEZ 12	• Use AEZ information from gridded data Jam (Jamaica) Pri (Puerto Rico) Lux (Luxembourg) Bhr (Bahrain) Twn (Taiwan) • Drop countries with no AEZ information in the gridded data Mus (Mauritius) Cpv (Cape Verde) Mlt (Malta) Qat (Qatar)
Key assumptions in updating land cover	
• Calculate % changes in national land cover for cropland, pasture and forests from FAO between 2007 and 2011 and apply to 2007 GTAP LULC v.8 • Adjust cover for remaining land cover types given these changes	• Share-out 2011 cropland and pasture cover from FAO using country-AEZ shares from gridded data • Adjust potential vegetation cover at 108 AEZ level given these changes