12-1-2005

Towards An Integrated Land Use Data Base for Assessing the Potential for Greenhouse Gas Mitigation

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GTAP Technical Paper No.25

December, 2005

[*] The authors thank Professor Claudia Kemfert, Dr. Truong Truong, Professor Bruce McCarl, Dr. John Reilly, and colleagues at the Australian Bureau of Agricultural and Resource Economics (ABARE) for their review and comments on the documentation. We would also like to thank the U.S. Environmental Protection Agency (US-EPA) Climate Analysis Branch for funding this effort to produce the data. In particular, Dr. Steven Rose has provided valuable guidance and critical input without which this document would have been far from complete. We also thank Francisco de la Chesnaye of the US-EPA for his leadership and patience and for inspiring us to undertake this work. The authors thank Professor Gerald Shively in the Department of Agricultural Economics, Purdue University, for his assistance in reviewing and finalizing this documentation. Finally, we would like to acknowledge the pioneering work of the late Roy Darwin, who was the first researcher to implement a detailed land use data base in the GTAP framework. His dedication to this work provides continuing inspiration to those of us working on the problem of global land use and climate change. All errors and omissions remain the responsibility of the authors alone.

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Abstract

This paper describes the GTAP land use data base designed to support integrated assessments of the potential for greenhouse gas mitigation. It disaggregates land use by agro-ecological zone (AEZ). To do so, it draws upon global land cover data bases, as well as state-of-the-art definition of AEZs from the FAO and IIASA. Agro-ecological zoning segments a parcel of land into smaller units according to agro-ecological characteristics, including: precipitation, temperature, soil type, terrain conditions, etc. Each zone has a similar combination of constraints and potential for land use. In the GTAP-AEZ data base, there are 18 AEZs, covering six different lengths of growing period spread over three different climatic zones. Land using activities include crop production, livestock raising, and forestry. In so doing, this extension of the standard GTAP data base permits a much more refined characterization of the potential for shifting land use amongst these different activities. When combined with information on greenhouse gas emissions, this data base permits economists interested in integrated assessment of climate change to better assess the role of land use change in greenhouse gases mitigation strategies.

Keywords:

Land Use, Agro-Ecological Zoning, Integrated Assessment, Greenhouse Gas Mitigation.

Prologue

This document reports on construction of an analytical data base to support policy analyses related to land use and land use change, in particular as they relate to potential climate policies. While this report focuses on land use, it is intended to be read in conjunction with the companion report on the emissions data base. Both of these reports represent ongoing work aimed at further improvements. Further updates will be posted on the GTAP website when available:

http://www.gtap.agecon.purdue.edu/databases/projects/Land_Use_GHG/default.asp

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1. Introduction

1.1 Background and Motivation

The main goal of the EPA sponsored GTAP project (hereafter, GTAP/EPA project) is to develop a land-use and greenhouse gas (GHG) emissions database for use in global computable general equilibrium (CGE) models aimed at assessing the economic costs of climate change policy. This multi-year project began in January 2002 and has now been completed.

Growing research demands for integrated assessment of GHG issues have motivated construction of a combined database of land use and GHG emissions for use with CGE models. Many economic analyses of climate policies use CGE models of the global economy to track GHG emissions to their source, to evaluate the costs of mitigation, and to assess the spill-over effects of GHG policies via international trade and inter-sectoral interactions. The GTAP model is a building block for many of the global CGE models currently in use today. With a database covering inputs/outputs and bilateral trade of 57 commodities[2] (and producing industries) of each 87 countries/regions[3], GTAP is able to capture both the sectoral interactions within the domestic economy as well as international trade effects of climate change policy.

The Global Trade Analysis Project (GTAP) has filled an important need in the integrated assessment community by providing regular updates of world-wide input-output and bilateral trade data sets with significant disaggregation of regions and sectors, plus energy volume data. GTAP began as a database and modeling framework to assess the global implications of trade policies (Hertel, 1997). However, over the past decade, through a series of grants from the U.S. Department of Energy (US-DOE) and the U.S. Environmental Protection Agency (US-EPA), GTAP has become increasingly central to analyses of the global economic consequences of attempts to mitigate greenhouse gas emissions. The first step in this direction involved integrating the International Energy Agency's database on fossil fuel consumption into GTAP. When coupled with CO_2 emissions coefficients, this permits researchers to more accurately estimate changes in economic activity and fossil-fuel-based emissions in the wake of policies aimed at curbing CO_2 emissions.

In the GTAP/EPA project documented here, we extend the GTAP database to allow it to support analyses of terrestrial sequestration and greenhouse gas emissions and mitigation from sources across the global economy as well as the linkage between land use and net GHG emissions from agriculture and forestry. While this report focuses on the land use portion of the data base, the companion report documents the inclusion of CO_2 emissions, terrestrial sequestration, and non-CO_2 greenhouse gases emissions data—covering methane (CH_4), nitrous oxide (N_2O), and the fluorinated gases (HFC-134a, CF_4, HFC-23, and SF_6) from all sources. These CO_2 and non-CO_2 GHG emissions and sequestration are indirectly linked to the underlying economic drivers of emissions, which are faithfully represented in the core GTAP database.

Land use, land-use change and forestry (LULUCF) activities have been perceived as a relatively cost-effective option to mitigate climate change due to the rapid buildup of greenhouse gases in the atmosphere. LULUCF may contribute to abatement of emissions by increasing

[2] See Table A1 in Appendix A for sector coverage of the GTAP version 6 data base and the description of the sectoral activities.

[3] See Table A2 in Appendix A for world countries/territories and their mapping to the 87 countries/regions covered in the GTAP version 6 data base.

carbon storage in forests and soils (the so-called *sinks*: enhancing afforestation and forest management, while curbing deforestation, and soil management). Article 3 of the Kyoto Protocol makes provision for the Annex I parties to take into account removals and emissions due to LULUCF activities since 1990 (e.g., afforestation, reforestation, deforestation and other agreed land use changes) to meet their commitment targets of greenhouse gas emission abatement. In the seventh Conference of the Parties (COP7) to the UNFCCC held in Marrakesh, October/November 2001, the parties finally agreed to include land-based carbon sequestration in their 2008-2012 GHG emissions reduction targets. The COP9, held in Milan, December 2003, has reached consensus for the rules of accounting for LULUCF projects in the Clean Development Mechanism (CDM) for the first commitment period (2008-2012) of the Kyoto Protocol. Along with such policy commitments, research on Integrated Assessment (IA) of climate change has recently been advancing towards the LULUCF embraced analysis.

At an inaugural project workshop, held at MIT in September, 2002 (GTAP Website, 2002), co-sponsored by the U.S. Environmental Protection Agency (US-EPA), Massachusetts Institute of Technology (MIT), and the Center for Global Trade Analysis (GTAP), the idea of identifying agro-ecological zoning in the GTAP model was sparked in the discussion among the participating experts. The recognition of various agro-ecological zones (AEZ) is believed to be a more realistic approach to modeling land use and land use change in GTAP, whereby land is mobile between crop, livestock and forestry sectors *within AEZ's*. In the standard GTAP model, land is assumed to be transformable between uses of crop growing, livestock raising, or timber production, regardless of climatic or soil constraints. The fact is that most crops can only grow on lands with particular temperature, moisture, soil type, land form, etc. The same concern arises for land use by the livestock and the forestry sectors. Lands that are suitable for growing wheat may not be suitable for rice cultivation. The introduction of agro-ecological zoning in GTAP helps to better inform the issue of land mobility and sharpens the focus on competition among alternative land uses within AEZs.

This report is the first of three reports for this project. It details the land use and land cover data base. The second report covers the associated greenhouse gases (GHG) emissions database. The third report introduces a CGE framework to illustrate how the AEZ distinguished land and GHG emissions/sequestration data could be incorporated in computable general equilibrium models for analyses of climate change related land use and land use change.

1.2 Data products of this project

This project has resulted in the following products:

1. land cover data: physical area (thousands of hectares), ca. 1992, of 7 land cover types, in 160 countries/regions, by 18 agro-ecological zones;
2. crop(land) use data: harvested area (thousands of hectares) for the year 2001, covering 19 crop types, grown in 160 countries/regions, by 18 agro-ecological zones;
3. crop yield data: production (metric tons) per thousand hectare of harvested area, of year 2001, of 19 crop types, grown in 160 countries/regions, by 18 agro-ecological zones;
4. timberland area data: timberland area (thousands of hectares), of circa 1990 – 2000, of three tree species in various management types, in 124 countries/regions, by 18 agro-ecological zones, and by 10-year tree age classes;
5. timberland marginal land rent data: 2000 US$ per hectare per year, of various management types in 124 countries/regions;

6. forest carbon stock data: million metric tons of CO_2, from the year 2000, of 3 tree species in various management types, in 124 countries/regions, by 18 agro-ecological zones, and by 10-year tree age classes;
7. GTAP-compatible land rent (header "VFM" in the GTAP input-output database) data: 2001 US$, of agriculture and forest sectors (totaling 13) in 87 regions, by 18 agro-ecological zones;
8. soil carbon stock data: see Table 1 below for details.
9. GTAP CO_2 emissions data: giga-grams of CO_2 emissions from the year 2001 due to combustion of fossil fuels (domestically-produced and imported) by all GTAP sectors (57) in 66 regions of GTAP database version 6.0 and 78 regions of GTAP database version 5.4[4];
10. CO_2 emissions from non-combustion sources for 2001 (e.g., cement manufacturing), and
11. GTAP non-CO_2 GHG (CH_4, N_2O, and fluorinated gases, including ozone depleting substances) emissions data: tera-gram CO_2-equivalents, for 2001 of years 1990, 1995 and 2000, by all emitting GTAP sectors (57) in all GTAP regions (66)[5].

The first seven of these data products are discussed in this report. The final two are covered in the companion report on greenhouse gas emissions.

We follow the FAO's global agro-ecological zoning concept (FAO, 2000; Fischer *et al*, 2002) to identify lands located in eighteen different agro-ecological zones. In section 2, we introduce the AEZ-identified land use data and how they are used to produce the GTAP AEZ-specific land use database. Section 3 focuses on the validation of the GTAP AEZ land rent data. Here, we compare the average land rents in the U.S. agriculture sector, as implied by combining the GTAP land rent data with the hectares in the land cover data base, with directly observed cash land rent data published by the U.S. Department of Agriculture (USDA). We also compare land rents by AEZ with hedonic estimates of land rents from Mendelsohn *et al.* (2005). This report concludes in section 4 with a summary and an overall evaluation of the data base.

[4] The GTAP database version 6.0, including energy volume data, is released to subscribers Spring 2005. We will recompile the CO_2 data of 2001 for version 6.0's 87 regions in subsequent emissions data updates so as to match the sectors, regions, and benchmark year as in the GTAP version 6.0 database.

[5] In compiling the EPA supplied non-CO_2 emissions data to be matched up with GTAP sector and region aggregation, we used some value shares derived from the GTAP input-output database. At the time when we compiled the CH_4 and N_2O data, the available GTAP input-output database was version 5.0, which has 66 regions and the benchmark year is 1997. The GTAP database version 6.0 was publicly released in the summer of 2005. Like CO_2 emissions data update, we plan to recompile the 2001 CH_4, N_2O, and F-gases data for version 6.0's 87 regions for consistency reasons in the future.

Table 1. Summary of all database products from this project

Data		Year	Dimensions	Comment
Land cover		ca. 1992	7 land cover types, 160 global regions, by 18 AEZs	
Land activity data				
	Crop harvested acreage and yields	2001	19 crops, 160 regions, by 18 AEZs	
	Forest acreage	ca. 1990 – 2000	3 tree species, country specific management types, 124 regions; by 18 AEZs	10-year tree age classes in Sohngen data
	GTAP AEZ land rents ("VFM")	2001	13 crop, livestock, and forest sectors, 87 regions, by 18 AEZs	
Emissions/sequestration (ALL SECTORS - land-using and other)				
	Forest carbon stock	2000	3 tree species, country specific management types, 124 regions; by 18 AEZs	10-year tree age classes in Sohngen data
	Soil carbon stock	ca. 1990 – 2000	7 land cover types, 160 global regions, by 18 AEZs	
	CO2 emissions from energy fossil fuel combustion	2001	57 sectors, 87 regions, domestically-produced and imported	
	Other CO2 emissions	2001	57 sectors, 87 regions, domestically-produced and imported	
	Non-CO2 GHG emissions (CH4, N2O, fluorinated gases, ODS)	2001	57 sectors, 87 regions	

2. *The AEZ-identified GTAP Land Use Data*

2.1 Agro-Ecological Zoning

In constructing the GTAP land use database, we adopt the FAO/IIASA convention of agro-ecological zoning that grew out of pioneering work by the Food and Agriculture Organization (FAO) of the United Nations and the International Institute for Applied Systems Analysis (IIASA). Their Land Use and Land Cover (LUC) project resulted in an agro-ecological zoning methodology that has been steadily refined over the past 20 years (Fischer et al., 2002; Fischer et al., 2000). For global AEZ data, this method is considered State of the Art. Agro-ecological zoning refers to segmentation of a parcel of land into smaller units according to agro-ecological characteristics, e.g., moisture and temperature regimes, soil type, landform, etc. In other words, each zone has a similar combination of constraints and potentials for land use. The FAO/IIASA agro-ecological zoning methodology provides a standardized framework for characterizing climate, soil and terrain conditions pertinent to agricultural production (FAO and IIASA, 2000).

We focus on the "Length of Growing Period" (LGP) data from the IIASA/FAO Global Agro-Ecological Zones (GAEZ) database. Fischer *et al*. (2000) derived the length of growing period by combining climate, soil, and topography data with a water balance model and knowledge of crop requirements. The "length of growing period" (LGP) refers to the period during the year when both soil moisture[6] and temperature are conducive to crop growth. The concept of "length of growing period" (LGP) is brought in to differentiate the agro-ecological zones by attainable crop productivity. Thus, in a formal sense, LGP refers to the number of days within the period of temperatures above 5°C when moisture conditions are considered adequate for crop production (FAO, 2000).

[6] Soil moisture is a function of precipitation, soil type, topography, etc.

2.2 The GTAP Land Use Data Base

We introduce in section 2.2.1 the overview of the GTAP land use database as proposed at the 2002 MIT workshop (GTAP Website, 2002). To build this land use database, we used cropland and timberland data provided by Dr. Navin Ramankutty of the Center for Sustainability and Global Environment (SAGE), University of Wisconsin-Madison and Dr. Brent Sohngen of Ohio State University, respectively. The data inputs from these two sources are described in section 2.2.2 (including land cover data and land use data). Details on how the data inputs are derived to support the construction of the GTAP land use database are described in sections 2.2.2.1 (cropland) and 2.2.2.2 (timberland). In sections 2.2.3.2, 2.2.3.3, and 2.2.3.5, we describe how we compile the GTAP AEZ-distinguished land rent data for crop sectors, livestock sectors, and forestry, based on these two sources of data inputs.

2.2.1 Overview of the GTAP land use data

Figure 1 shows the format of the GTAP land use data that was originally proposed at the 2002 MIT workshop (GTAP Website, 2002). For each region, we identify land located in various agro-ecological zones (the rows in Figure 1) and the uses (sectors or activities) of land (the columns in Figure 1).

	Land use activities in region r								
AEZs	$Crop_1$	….	$Crop_N$	$Livestock_1$	….	$Livestock_H$	$Forest_1$	….	$Forest_v$
AEZ_1									
….									
….									
AEZ_M									
Total									

Figure 1. The GTAP Land Use Matrix

Land used by the GTAP land-based sectors—i.e., crops, livestock and forestry sectors—are distinguished by agro-ecological zones (across the rows in Figure 1). At any one point in time, for a given climate regime, the total endowment of each AEZ land type (row sum) is fixed. That is, land is not assumed to be mobile across AEZs. That is the purpose of the definition. However, in the context of a general equilibrium model, the allocation across land-using sectors will vary based on relative returns.

2.2.2 Cropland and Timberland Data Inputs

The GTAP AEZ-specific land use data are compiled from two sources. The first source includes global land cover and cropland data, provided by Dr. Navin Ramankutty of the Center for Sustainability and Global Environment (SAGE), University of Wisconsin-Madison (Ramankutty *et al.*, 2005). Specifically, the following data items are provided:

(a) land cover data: physical area (thousands of hectares), ca. 1992, of 7 land cover types, in 160 countries/regions, by 18 agro-ecological zones;

(b) (crop)land use data: harvested area (thousands of hectares) of year 2001, of 19 crop types, grown in 160 countries/regions, by 18 agro-ecological zones;

(c) crop yield data: production (ton) per thousand hectares of harvested area, of year 2001, of 19 crop types, grown in 160 countries/regions, by 18 agro-ecological zones.

The second source includes global timber land area and forest carbon stock data, provided by Dr. Brent Sohngen of Ohio State University (Sohngen and Tennity, 2004). Specifically, the following data items are acquired from Dr. Sohngen:

(a) timberland area data: timberland area (thousands of hectares), of circa 1990 – 2000, of three tree species (coniferous, broadleaf, and mixed) in various management types, located in 124 countries/regions, by 18 agro-ecological zone, and by 10-year tree age classes;

(b) timberland marginal land rent data: 2000 US$ per hectare per year, of various management types in 124 countries/regions;

(c) forest carbon stock data: million metric tons of CO_2, of year 2000, of three tree species in various management types, in 124 countries/regions, by 18 agro-ecological zones, and by 10-year tree age classes.

We introduce these two sources of data—abbreviated, respectively, as SAGE and DGTM[7] data hereafter—in sections 2.2.2.1 and 2.2.2.2.

2.2.2.1 Land cover and cropland data from SAGE

The Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin has been developing global databases of contemporary and historical agricultural land use and land cover. SAGE has chosen to focus on agriculture because it is clearly the predominant land use activity on the planet today, and provides a vital service—i.e., food—for human societies.

SAGE has developed a "data fusion" technique to integrate remotely-sensed data on the world's land cover with administrative-unit-level inventory data on land use (Ramankutty and Foley, 1998; Ramankutty and Foley, 1999). The advent of remote sensing data has been revolutionary in providing consistent, global, estimates of the patterns of global land cover. However, remote sensing data are limited in their ability to resolve the details of agricultural land cover from space. Therein lies the strength of the ground-based inventory data, which provide detailed estimates of agricultural land use practices. However, inventory data are limited in not being spatially explicit, and are plagued by problems of inconsistency across administrative units. The "data fusion" technique developed by SAGE exploits the strengths of both the remotely-sensed data as well as the inventory data.

Using SAGE's methodology, Ramankutty and Foley (1998)—RF98 hereafter—developed a global data set of the world's cropland distribution for the early 1990s (Figure 2). This was accomplished by integrating the Global Land Cover Characteristics (GLCC; Loveland *et*

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[7] DGTM refers to the Dynamic Global Timber Model (described originally in Sedjo and Lyon (1990) and expanded in Sohngen et al. (1999), Sohngen and Sedjo (2000), and Sohngen and Mendelsohn (2003)), which is the source for much of the forestry data.

al.(2000)) database at 1 km resolution (derived from the Advanced Very High Resolution Radiometer (AVHRR) instrument), with comprehensive global inventory data (at national and subnational levels) of cropland area. The resulting data set, at a spatial resolution of 5 min (~10 km) in latitude by longitude, describes the percentage of each 5 min grid cell that is occupied by croplands. Leff *et al*. (2004) further disaggregated the RF98 dataset to derive the spatial distribution of 19 crop types of the world (18 major crops and one "other crop" type (see Table 3 for a list); maps of individual crops not shown – see Leff *et al*. (2004) for detailed maps). Ramankutty and Foley (1999)—RF99 hereafter—compiled historical inventory data on cropland areas to extend the global croplands data set back to 1700 (figures not shown). RF99 also derived a global data set of potential natural vegetation (PNV) types; this data set describes the spatial distribution of 15 natural vegetation types that would be present in the absence of human activities (Figure 3). Furthermore, global data sets of the world's grazing lands (Figure 4) and built-up areas (not shown), representative of the early 1990 period, were also developed recently (National Geographic Maps, 2002; Foley *et al.*, 2003).

The SAGE data sets described above are being used for a wide array of purposes, including global carbon cycle modeling (McGuire *et al*., 2001), analysis of regional food security (Ramankutty *et al.*, 2002b), global climate modeling (Bonan, 1999; Brovkin et al., 1999; Bonan, 2001; Myhre and Myhre, 2003), and estimation of global soil erosion (Yang *et al.*, 2003). They also formed part of the BIOME300 effort, initiated by two core projects—LUCC (Land Use and Land Cover Change) and PAGES (Past Global Changes) of the International Geosphere-Biosphere Programme (IGBP). In other words, they are a widely recognized, and widely used data set of global agricultural land use.

The SAGE land cover and agricultural land use data form the core of the GTAP land cover and land use database. In addition to the SAGE data, to derive information on crop yields and irrigation, some ancillary data were obtained from the Food and Agriculture Organization (FAO). In the subsequent section, we describe the procedure used to adapt the SAGE data and the ancillary data to derive land use information for GTAP.

Figure 2. The global distribution of croplands *ca*. 1992 from Ramankutty and Foley (1998)

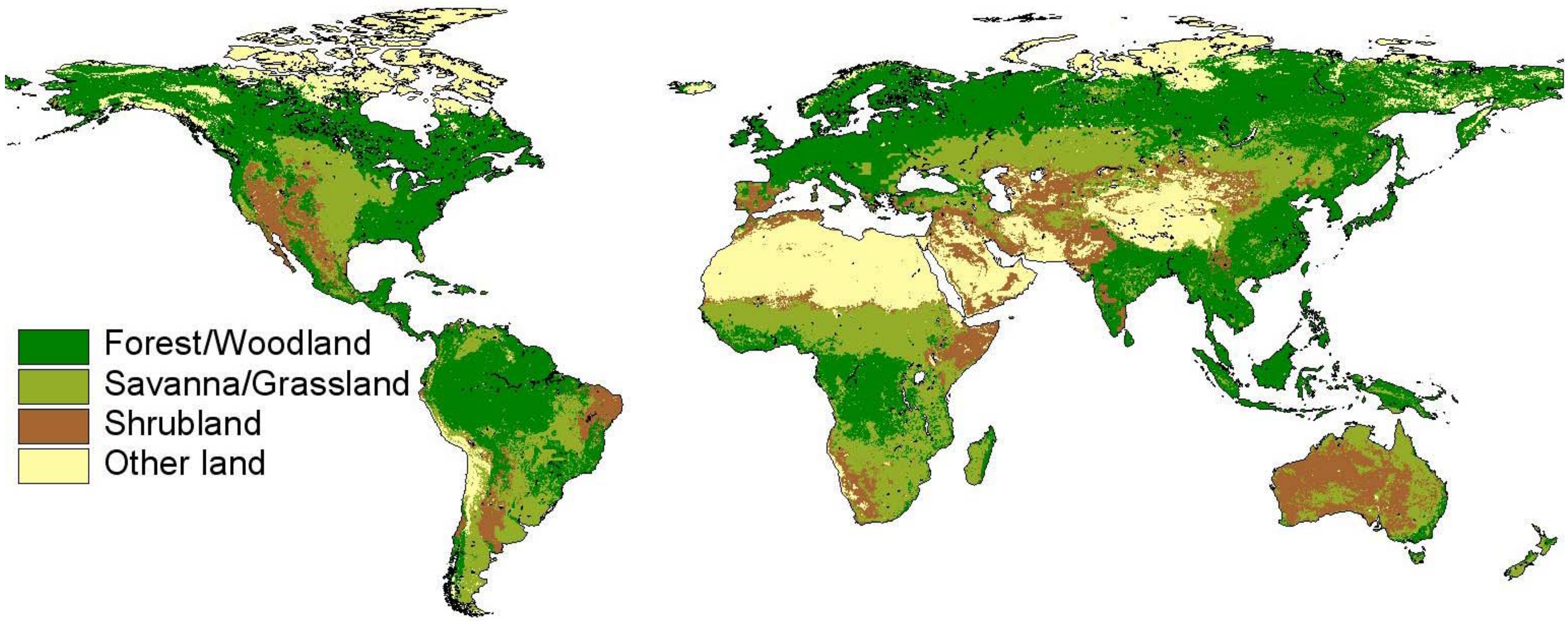

Figure 3. SAGE global land cover map (the original 15 classes have been merged to 4 classes used in GTAP)

Figure 4. The global distribution of grazing lands *ca*. 1992 from Foley *et al*. (2003)

Key Assumptions and Procedures

In order to supply the necessary data for this specification of GTAP, the spatially-explicit land use data sets from SAGE must be aggregated to match up with the format of the GTAP land use data (see Figure 1). The following developments were required:

(1) development of global Agro-Ecological Zones for deriving sub-national information on land endowments;

(2) mapping data to match GTAP crop sectors;

(3) deriving yield (and production) data for the crop sectors; and

(4) mapping spatial SAGE data to AEZs by nation.

These developments are described in detail below.

Definition of AEZs in the SAGE data

SAGE derived 6 global lengths of growing period (LGPs) by aggregating the IIASA/FAO GAEZ data into 6 categories of approximately 60 days each LGP: (1) LGP1: 0-59 days, (2) LGP2: 60-119 days, (3) LGP3: 120-179 days, (4) LGP4: 180-239 days, (5) LGP5: 240-299 days, and (6) LGP6: more than 300 days. These 6 LGPs roughly divide the world along humidity gradients, and is generally consistent with previous studies in global agro-ecological zoning (Alexandratos, 1995). They are calculated as the number of days with sufficient temperature and precipitation/soil moisture for growing crops. These six LGPs are plotted by 0.5 degree grid cell for the world in Figure 5. The colors range from white (shortest LGP) to red (longest LGP). The red tends to be concentrated in the tropics, but not exclusively. The white zones are found in the arctic, the deserts and in the mountain regions.

In addition to the LGP break-down, the world is subdivided into three climatic zones—tropical, temperate, and boreal—using criteria based on absolute minimum temperature and Growing Degree Days, as described in Ramankutty and Foley (1999). Table 2 details definition of global agro-ecological zones used in the GTAP land use database, with the first six AEZs corresponding to tropical climate, the second six to temperate and the last six to boreal. Within each climate grouping, the AEZs progress from short to long LGPs.

A global map of 18 AEZs has been developed by overlaying the 6 categories of LGPs with the 3 climatic zones. Figure 6 shows this 18-AEZ global map by 0.5 degree grid cell. The red shades in the map denote tropical AEZs, with the more intense shades denoting longer growing periods. The green shading denotes temperate AEZs, whereby the darker greens also communicate a longer LGPs. Finally, the boreal climate is portrayed by blue shading.

The beauty of this AEZ approach is that we can simulate shifts in AEZs as a function of changing climate. Furthermore, one could potentially define a suite of feasible land uses within each AEZ, which although infeasible under current conditions could become feasible under future conditions.

Table 2. Definition of global agro-ecological zones used in GTAP

LGP in days	Moisture regime	Climate zone	GTAP class
0-59	Arid	Tropical	AEZ1
		Temperate	AEZ7
		Boreal	AEZ13
60-119	Dry semi-arid	Tropical	AEZ2
		Temperate	AEZ8
		Boreal	AEZ14
120-179	Moist semi-arid	Tropical	AEZ3
		Temperate	AEZ9
		Boreal	AEZ15
180-239	Sub-humid	Tropical	AEZ4
		Temperate	AEZ10
		Boreal	AEZ16
240-299	Humid;	Tropical	AEZ5
		Temperate	AEZ11
		Boreal	AEZ17
>300 days	Humid; year-round growing season	Tropical	AEZ6
		Temperate	AEZ12
		Boreal	AEZ18

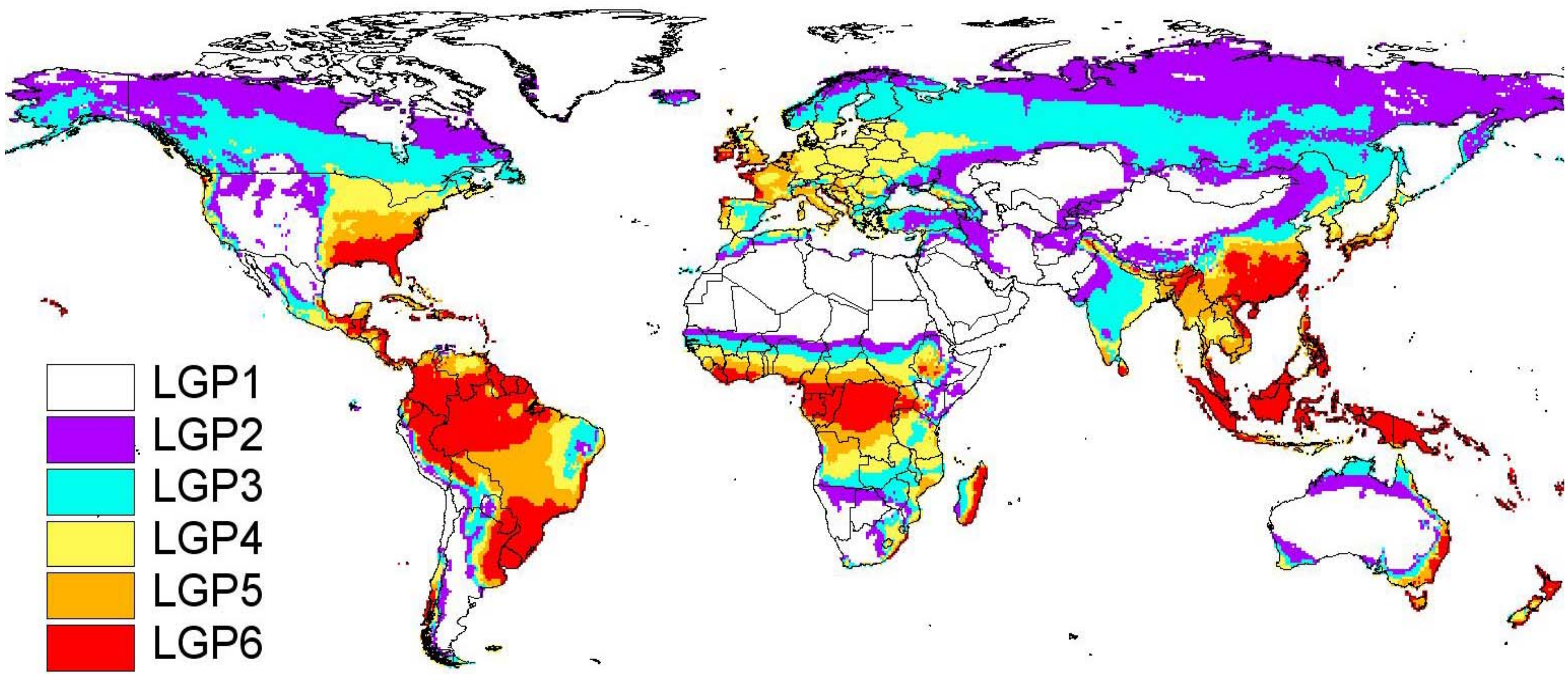

Figure 5. A global map of length of growing periods (LGP)

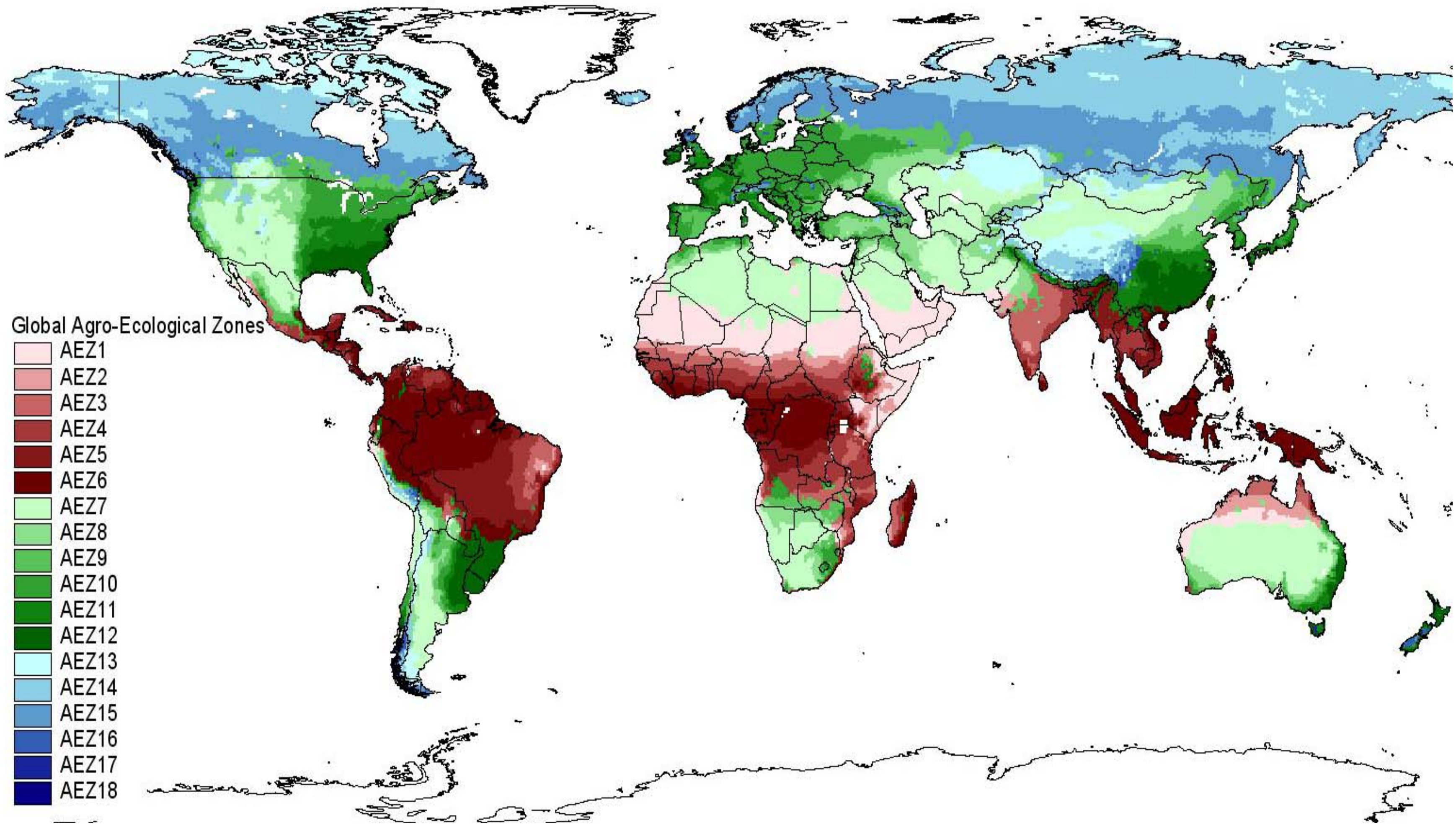

Figure 6. The SAGE global map of the 18 AEZs

The SAGE Global Land Cover Data

A map of global land cover, representative of *ca*. 1992, was first derived by overlaying the SAGE global data set of potential natural vegetation (Figure 3), over the present-day global maps of croplands[8] (see Figure 2), grazing lands (see Figure 4), and built-up areas. The resulting map was overlain with the global AEZ map, to calculate land cover by country, for each of the 18 AEZs Figure 5 is a summary chart with global total numbers as a function of the 6 LGPs, aggregated across tropical, temperate, and boreal zones for clarity of the figure.

Crop harvested area

The SAGE land use data provides information on crop areas (Leff *et al.*, 2004—LEFF04 hereafter). The global distribution of major crops were derived by compiling crop harvested area statistics from national and sub-national sources, estimating the proportions of harvested area of each crop to total harvested area, and then redistributing it using the RF98 croplands map described above.

Harvested area vs. physically cultivated area[9]: Which is appropriate?

The original proposal for splitting the GTAP sectoral land rents into AEZs, involved the conversion of harvested area data from SAGE to physically cultivated area data due to the concern of multiple cropping. This poses a problem due to the absence of a global data set on multiple cropping and/or crop-specific, physically cultivated area. However, upon further reflection, it became clear that, for purposes of disaggregating land rents in GTAP, we do not really need crop-specific physically cultivated area data. In the GTAP Input-Output data, land rents are generated from the activity (or use) on the given parcel of land during the calendar year. Therefore, we are interested in the value of the land in production over the course of the entire year, not just one season.

Consider the case of a farmer in Southern China who grows early double-crop rice from March to July, and then grows "catch crops" (fast growing crops, e.g., vegetables) in the rest of the calendar year. Now the GTAP Input-Output data identify sectors in terms of crops (e.g., the paddy rice sector, the cereal grain sector, the oil seeds sector, etc.), not hectares of land, per se. So the land rents of the crop sectors should accrue to the harvested area, by crop. In this particularly example, we allocate the land rent generated due to the growing of paddy rice to the GTAP paddy

[8] SAGE cropland data follows the FAO definition of croplands, which includes arable land: land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years); and permanent crops: land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber. SAGE pasture land data also follows FAO definition of permanent pasture: land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

[9] The difference between harvested area and physical cultivated area is related to multiple cropping. With harvested area, land that is double cropped or triple cropped is counted two or three times respectively. This variable is normally reported in national statistics for specific crops. Physical cultivated area represents the physical area of land used for cultivation, without double or triple accounting for multiple cropping. This variable is normally not reported, but can be inferred if the extent of multiple cropping is known. "Cropland area" is also reported by national statistics (see footnote 8), and only accounts for physical land area. However, it also includes fallow land and temporary pasture land, and therefore cannot be used to infer physical cultivated area. Even if that were not a problem, cropland area aggregates all the crops, and therefore cannot be used to infer crop-specific physical cultivated area.

rice sector, and allocate the land rents generated due to the growing of vegetables to the GTAP vegetables sector. Thus, while the harvest-based land rents can be allocated to GTAP sectors, the physically cultivated-based land rents cannot.

A final argument in favor of working with harvested acres is due to the fact that land based emissions (e.g., CH_4 emissions from paddy rice cultivation) are mostly tied to the harvested area (IPCC 1996 Guidelines). Fertilizer use is normally proportional to harvested area. So, we conclude that harvested area is a useful, as well as a practical basis for developing the GTAP land use data, rather than the crop-specific physically cultivated area. Soil N_2O and soil CO_2 emissions are tied to cultivated area and crop cycles, not harvested area. For these emissions, we can directly use the SAGE cropland area data.

Next, we introduce how SAGE estimates harvested area and yield of cropland for the GTAP land use database. Because the RF98 croplands and LEFF04 crop area maps represent the "physical" cultivated area on the ground, the distribution of crop harvested area required a conversion to from harvested to physical area on the ground. Therefore, we first recalibrate the LEFF04 data, against the national crop harvested area statistics from FAOSTAT (FAO, 2004), to obtain harvested area by AEZ. The approach used can be described as follows.

Let $A'_{LEFF}(i,mc)$ be the LEFF04 crop area for pixel *i* and major crop *mc*. Note that the original LEFF04 data sets are gridded, at 0.5 degree resolution in latitude by longitude. We recalibrate the LEFF04 data to the FAOSTAT harvested area data $A_{FAO}(l,mc,t_{ref})$ as follows:

$$A_{LEFF}(i,mc) = A'_{LEFF}(i,mc)\, x \frac{A_{FAO}(l,mc,t_{ref})}{\sum_{i \in l} A_{LEFF}(i,mc)},$$

where l = countries in FAOSTAT, $i \in l$, and t_{ref} is the reference time period = 2001 (for consistency with GTAP version 6.0).

The recalibrated LEFF04 data are then overlain with: 1) the global AEZ map; and 2) political boundaries, and aggregated to derive harvested areas of 19 crops for all nations of the world, for 18 AEZs within each nation.

Let this aggregated data be represented by $A_{LEFF}(l,mc,z)$, where,

l is the country, mc is one of 19 LEFF04 major crops, and z = one of 18 AEZs.

This can then be mapped onto GTAP's 8 crop sectors using the mapping in Table 3: $A_{LEFF}(l,mc,z) \to A_{GTAP}(l,s,z)$, where s is one of 8 GTAP crop sectors.

In this first release of the GTAP land use database, we encountered a problem in mapping from SAGE crops to the GTAP crop sectors. As it would take some time to fix the mapping problem in the SAGE data—the basis which we used for the AEZ splitting—we have come up with a discretionary solution to this problem and have planned to fix it in the next release of the GTAP land use data base. We explain the mapping problem below, followed by a discretionary solution we adopted in the first release of the database.

In the GTAP input-output data base, agriculture sectors are defined by reference to the Central Product Classification (CPC), developed by the Statistical Office of the United Nations (United Nations, 1991). Based on this concordance, we mapped potato, cassava, and pulses to the vegetable and fruits sector ("v_f") of GTAP. However, in the SAGE data, fruits and vegetables were not classified as a separate category, but were aggregated with "Others" (see Table 6). As such, we were not able to separate out vegetables and fruits from the SAGE data to map to the "v_f" sector of GTAP. Similarly the SAGE crops poorly mapped to the GTAP other crops ("ocr") sector.

Before updated data is provided by SAGE, we developed a discretionary solution to fix this problem. We used the AEZ shares of the aggregate production of the SAGE crops that are mapped to GTAP's "v_f" and "ocr" sectors to split the AEZs of both the "v_f" and the "ocr" sectors. We plan to fix this crop mapping discrepancy in the next release when we receive the AgroMAPS (FAO/IFPRI/SAGE/CIAT, 2003) data from SAGE. The newly available AgroMAPS data set capitalizes on sub-national production data and offers, for the first time, a global data set with spatially explicit production information. SAGE is developing new global crop maps for the Year 2000 using AgroMAPS, and will define many new crop categories that will be consistent with the GTAP crop sectors.

Table 4 shows the cropland distribution for China, as provided by SAGE. This table contains the harvested area data. Figure 7 charts the distribution of cropland use across AEZ (as from data in Table 4) It indicates that most of the crops in China are grown in temperate area (AEZs 7 to 12).

Table 3. Mapping of crops between SAGE and GTAP data

SAGE No.	SAGE code	GTAP No.	GTAP code	Description
1	barley	3	gro	Cereals grain n.e.c.
2	cassava	4	v_f	Vegetables, fruit, nuts
3	cotton	7	pfb	Plant-based fibres
4	groundnuts	5	osd	Oil seeds
5	maize	3	gro	Cereals grain n.e.c.
6	millet	3	gro	Cereals grain n.e.c.
7	oilpalm	5	osd	Oil seeds
8	others	8	ocr	Crops n.e.c.
9	potato	4	v_f	Vegetables, fruit, nuts
10	pulses	4	v_f	Vegetables, fruit, nuts
11	rape	5	osd	Oil seeds
12	rice	1	pdr	Paddy rice
13	rye	3	gro	Cereals grain n.e.c.
14	sorghum	3	gro	Cereals grain n.e.c.
15	soy	5	osd	Oil seeds
16	sugar beet	6	c_b	Sugar cane, sugar beet
17	sugar cane	6	c_b	Sugar cane, sugar beet
18	sunflower seeds	5	osd	Oil seeds
19	wheat	2	wht	Wheat
Reference: Concordance, HS96 to GSC rev. 2: concordance between the 1996 edition				
of the Harmonized System and revision 2 of the GTAP sectoral classification.				
http://www.gtap.agecon.purdue.edu/resources/download/582.txt				

Table 4. Cropland use (harvested area): China, 2001 (unit: 1000 hectare)

	China cropland (Unit: 1000ha)							
	1	2	3	4	5	6	7	8
	Paddy rice	Wheat	Cereal grains	Vegetables/fruits/ nuts	Oil seeds	Sugar cane/beet	Plant-based fibres	Crops N.E.C.
AEZ1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AEZ2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AEZ3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AEZ4	66.84	4.96	2.67	8.22	15.97	1.82	0.00	51.62
AEZ5	76.44	8.61	10.10	10.01	17.68	2.57	0.15	58.03
AEZ6	2516.49	57.54	263.01	319.21	661.87	270.44	1.30	1851.88
AEZ7	94.06	1406.27	752.65	223.94	426.05	40.25	654.41	419.42
AEZ8	917.33	4277.84	7144.95	1198.28	3949.04	175.02	430.99	4105.76
AEZ9	977.46	4317.75	6562.54	1249.27	3417.01	86.15	954.89	5985.30
AEZ10	1066.33	2586.44	3745.75	1030.96	2347.44	73.58	427.47	2906.26
AEZ11	4151.19	4849.99	2898.51	1310.12	2913.02	95.13	1063.45	7764.89
AEZ12	18806.93	4440.91	5142.22	2982.33	7526.94	898.25	835.06	15386.55
AEZ13	60.29	1067.65	332.39	155.95	461.65	19.21	413.34	262.92
AEZ14	57.44	692.48	158.98	84.10	368.17	4.74	12.12	208.13
AEZ15	177.89	666.10	338.27	120.48	427.85	11.58	7.35	292.73
AEZ16	164.59	280.98	167.78	56.89	119.55	7.54	8.98	253.31
AEZ17	10.78	6.56	9.76	2.97	3.77	0.93	0.23	10.53
AEZ18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	29144.04	24664.06	27529.56	8752.70	22656.01	1687.21	4809.75	39557.33

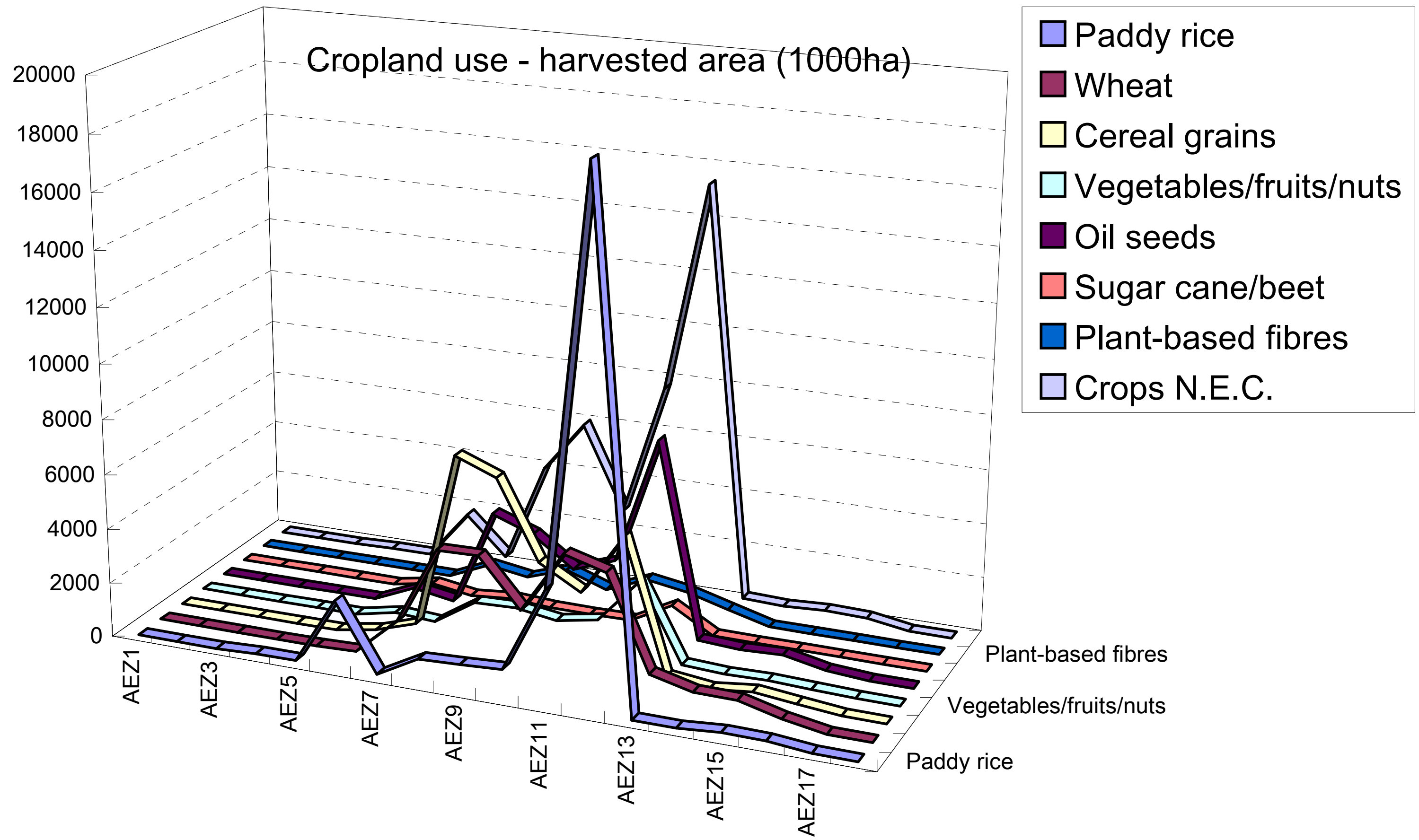

Figure 7. Distribution of cropland use (harvested area): China, 2001

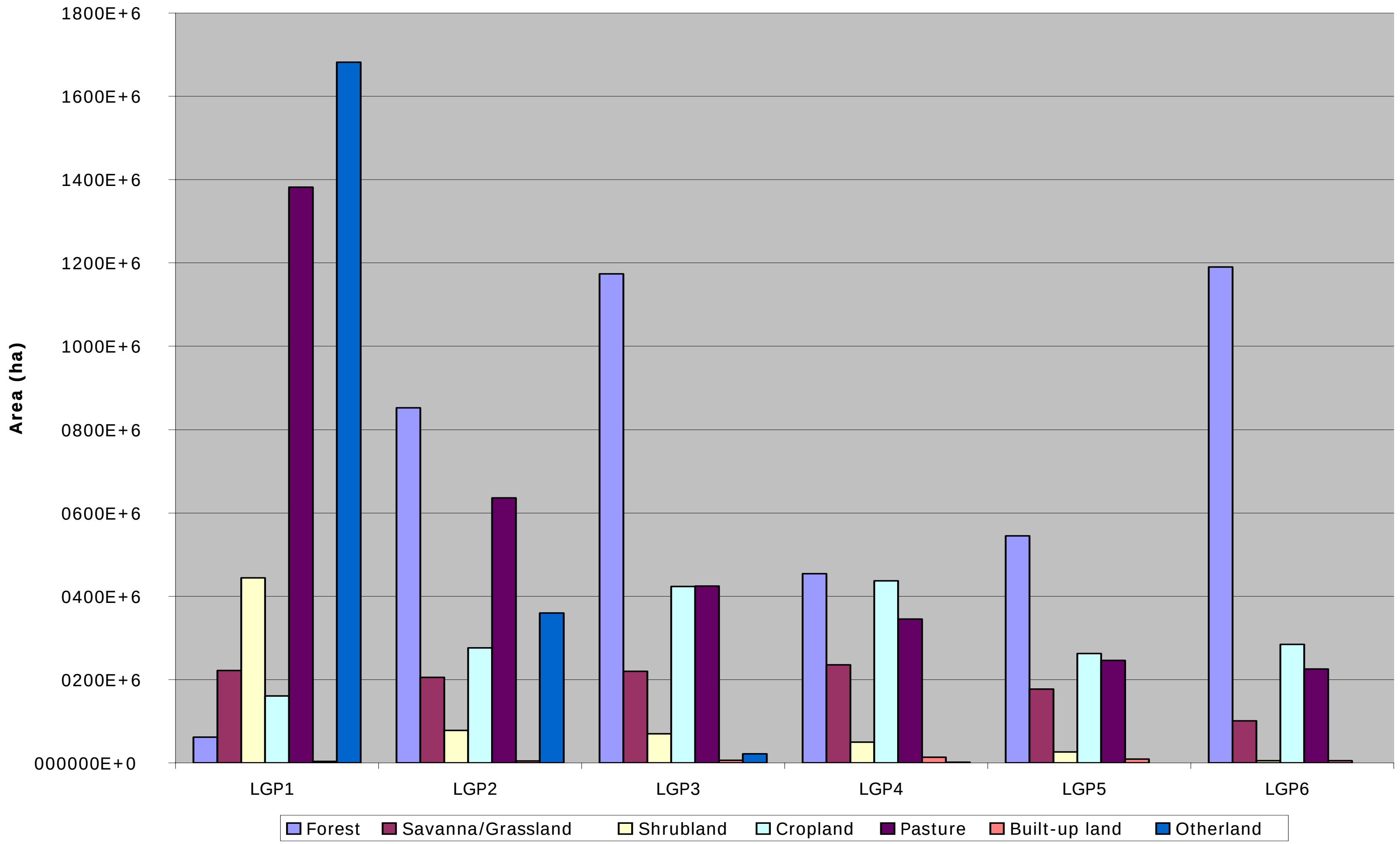

Figure 8. The SAGE global land cover distribution by LGP

The land cover data sets (Figure 8) show that forests dominate in LGP3 (120-179 days) and LGP6 (> 300 days), corresponding primarily to boreal forests and tropical rainforests, respectively. Shrub lands and pastures dominate in LGP1 (the driest AEZ) and their areas decrease as the AEZs get more humid. Savanna/grasslands are distributed fairly uniformly across the six aggregated AEZs. Croplands are distributed with slightly higher proportions in LGP3 and LGP4 (i.e., in areas that are not too dry, but are not heavily forested) (see Ramankutty *et al.* (2002) for a study on climatic constraints on cropland distribution). Built-up lands predominate in LGP4 and LGP5 (also the temperate regions of the world; (Small, 2003), but their total area is very small. The “other land” category, which includes tundra, desert, and polar desert/rock/ice, is dominant in LGP1 (with some additional area in LGP2), as would be expected. Table 5 shows the SAGE land cover data of China as an example.

Table 5. SAGE Land Cover Data: China, ca. 1992 (unit: 1000 hectare)

Unit: 1000ha	1 Forest	2 SavnGrasslnd	3 Shrubland	4 Cropland	5 Pastureland	6 Builtupland	7 Otherland	Total
1 AEZ1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 AEZ2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 AEZ3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 AEZ4	41.71	0.00	0.00	209.13	15.41	19.87	0.00	286.11
5 AEZ5	851.99	0.00	0.00	252.34	29.40	12.75	0.00	1146.48
6 AEZ6	3850.93	818.89	0.00	8168.40	1755.42	51.52	0.00	14645.16
7 AEZ7	380.19	2846.51	15712.78	5423.19	76431.86	112.55	93560.60	194467.69
8 AEZ8	12535.79	8204.33	1517.63	30451.23	38891.08	328.87	0.00	91928.93
9 AEZ9	23488.61	3236.56	12.93	31329.95	9846.51	312.30	130.91	68357.78
10 AEZ10	20113.39	2344.85	1708.09	18806.62	6113.10	167.57	81.56	49335.19
11 AEZ11	29123.68	3085.58	10722.81	33162.16	9531.92	151.34	0.00	85777.50
12 AEZ12	57965.89	5751.70	183.69	75797.70	17176.50	357.77	0.00	157233.25
13 AEZ13	206.34	2299.57	3440.05	3643.21	84475.91	4.68	43269.18	137338.94
14 AEZ14	924.79	2714.68	100.37	2126.64	67327.57	2.22	7563.08	80759.36
15 AEZ15	18073.58	3061.28	90.28	2751.87	33442.67	21.87	2288.73	59730.29
16 AEZ16	890.81	2431.72	1291.78	1425.86	12072.31	1.28	33.60	18147.35
17 AEZ17	0.00	297.67	0.00	61.43	453.60	0.08	0.00	812.77
18 AEZ18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	168447.70	37093.35	34780.42	213609.72	357563.25	1544.66	146927.67	959966.81

Estimating crop yields from FAO data

The FAO provided GTAP with estimates of harvested area, yield, and production, for 94 developing countries, for several FAO agro-ecological zones (including an FAO AEZ labeled "irrigated"). These unpublished data were developed based on primary data obtained in the 1970s, and has been periodically updated since then based on observed aggregates (Jelle Bruinsma, personal communication, 2003). So while the FAO data are not reliable for direct estimation of today's yields, they are the only available data on *relative yields by AEZ* within countries. We have therefore chosen to use the FAO data as a provisional measure, until improved estimates become available in the future. Here we describe how we adapted the FAO data for our purpose.

A. Derive yields from FAO data for 94 developing countries

The FAO data were provided for 6 different agro-ecological zones (Table 7; see also Alexandratos (1995)), defined slightly differently from our AEZs, and for 34 different crops. We therefore had to match the FAO AEZs and crops with GTAP's 18 AEZs and 19 LEFF04 crops.

FAO reports yields separately for four rainfed AEZs (AT1, AT2, AT3, AT4+AT5), one AEZ with fluvisol/gleysol soils (AT6+AT7; naturally flooded soils), and one irrigated AEZ (denoted "Irrigated Land"). In other words, FAO has separated out irrigation and the occurrence of naturally flooded soils into separate AEZs. In this study, we choose to treat AEZs as a *climate only* constraint (including the influence of soil moisture), and therefore irrigation and/or fluvisols/gleysols can occur within each AEZ. As a result, we needed to repartition the irrigated and AT6+AT7 yields into the rainfed zones to estimate the total yields for each AEZ. This procedure is described below.

We first mapped from the 34 FAO crops to the 19 LEFF04 major crops, based on the mapping given in Table 6 (harvested-area weighted averages were calculated when multiple FAO crops mapped into one LEFF04 crop).

Let $Y_{FAO,RF}(n, mc, fz)$ be the FAO reported yield for the four rainfed AEZs '*fz*', for nation '*n*', and crop '*mc*', where,

mc = one of 19 LEFF04 major crops,

fz = FAO AEZs AT1, AT2, AT3, AT4+AT5 (Table 7),

'*RF*' refers to rainfed.

Let $Y_{FAO}(n, mc)$ be the national yield from FAO for each crop (harvested area weighted average of all 6 zones). We calculated *national rainfed* yields for each crop,

$$Y_{FAO,RF}(n, mc) = \frac{\sum_{fz=AT1}^{AT4+AT5} Y_{FAO,RF}(n, mc, fz) x A_{FAO,RF}(n, mc, fz)}{\sum_{fz=AT1}^{AT4+AT5} A_{FAO,RF}(n, mc, fz)},$$

where $A_{FAO,RF}(n, mc, fz)$ = harvested area data from FAO, corresponding to the yield data.

Then, we estimated total yield (rainfed plus irrigated plus fluvisol/gleysol) for each of the FAO AEZs, AT1, AT2, AT3, & AT4+AT5, by applying the ratio of national total yield to national rainfed yield to each AEZ,

$$Y''_{FAO}(n,mc,fz) = Y_{FAO,RF}(n,mc,fz)\, x\, \frac{Y_{FAO}(n,mc)}{Y_{FAO,RF}(n,mc)}, \text{ if } Y_{FAO,RF}(n,mc) > 0.$$

As an average across all countries, the national total yield is ~50% greater than rainfed yields for rice. This is reasonable because paddy rice is heavily irrigated, and irrigated yields are higher than rainfed yields. The national total yield to rainfed yield ratios for cassava and oilpalm is 1.0 because they are not irrigated at all.

This yield is then adjusted to match FAOSTAT national statistics,

$$Y_{FAO}(n,mc,fz) = Y''_{FAO}(n,mc,fz)\, x\, \frac{\overline{Y}_{FAO}(n,mc)}{Y_{FAO}(n,mc)}, \text{ if } Y_{FAO,RF}(n,mc) > 0,$$

where

$\overline{Y}_{FAO}(n,mc)$ = FAOSTAT national statistic on crop yield.

If total rainfed yield is zero (i.e., FAO reports that for a particular crop and country, the crop is entirely irrigated or found in the gleysol/fluvisol AEZ), then we simply repartition the national-level FAOSTAT yields using an estimated global average of the proportion of yield in each AEZ to total yield. This is described in greater detail below in the next section (Note that the estimation of average yields in the next section is executed prior to the calculation below for zero total rainfed yields).

$$Y_{FAO}(n,mc,fz) = \overline{Y}_{FAO}(n,mc)\, x\, \frac{1}{N} \sum_{n=1}^{N} \frac{Y_{FAO}(n,mc,fz)}{Y_{FAO}(n,mc)}, \text{ if } Y_{FAO,RF}(n,mc) = 0,$$

where

N = total number of countries with $Y_{FAO}(n,mc,fz) > 0$ and $Y_{FAO}(n,mc) > 0$. The summation in the above equation is only performed when both numerator and denominator are non-zero.

Table 6. Mapping from FAO crops to SAGE crops

No.	FAO crops	No.	SAGE crops	No.	FAO crops	No.	SAGE crops
1	WHEA	19	Wheat	17	CITR	8	Others
2	RICE	12	Rice	18	FRUI	8	Others
3	MAIZ	5	Maize	19	OILC	8	Others
4	BARL	1	Barley	20	RAPE	11	Rape
5	MILL	6	Millet	21	PALM	7	Oil palm
6	SORG	14	Sorghum	22	SOYB	15	Soy
7	OTHC	13	Rye	23	GROU	4	Groundnuts
8	POTA	9	Potato	24	SUNF	18	Sunflower
9	SPOT	8	Others	25	SESA	8	Others
10	CASS	2	Cassava	26	COCN	8	Others
11	OTHR	8	Others	27	COFF	8	Others
12	BEET	16	Sugar beet	28	TEAS	8	Others
13	CANE	17	Sugar cane	29	TOBA	8	Others
14	PULS	10	Pulses	30	COTT	3	Cotton
15	VEGE	8	Others	31	FIBR	8	Others
16	BANA	8	Others	32	RUBB	8	Others

Table 7. Definition of FAO AEZs

FAO AEZ Class		Moisture regime (LGP in days)	Description
AT1		75-119	Dry semi-arid
AT2		120-179	Moist semi-arid
AT3		180-269	Sub-humid
AT4+AT5	AT4	270+	Humid
	AT5	120+	Marginally suitable land in moist semi-arid, sub-humid, humid-classes
AT6+AT7	AT6	Naturally flooded	Fluvisols/gleysols
	AT7	Naturally flooded	Marginally suitable fluvisols/gleysols
Irrigated Land		Irrigated	Irrigated

Table 8. Mapping from FAO AEZs to GTAP AEZs

FAO AEZs	GTAP AEZs
Estimated (see text)	AEZ1, AEZ7, AEZ13
AT1	AEZ2, AEZ8, AEZ14
AT2	AEZ3, AEZ9, AEZ15
AT3	AEZ4, AEZ10, AEZ16
AT4+AT5	AEZ5, AEZ11, AEZ17
AT4+AT5	AEZ6, AEZ12, AEZ18
AT6+AT7	No separate AEZ (see text)
Irrigated Land	No separate AEZ (see text)

B. Estimate yields for countries without FAO data

As FAO data were available for only 94 countries, we estimated information on yield variation across AEZ for the remaining countries using averages calculated over the 94 countries and applying them to the national statistics for the remaining countries[10]. Note that we did not average the yields themselves, but rather the proportion of yield in each AEZ to national yields. The formula used is as follows.

For each country 'm', without FAO data by AEZ,

$$Y_{FAO}(m, mc, fz) = \bar{Y}_{FAO}(m, mc) x \frac{1}{N} \sum_{n=1}^{N} \frac{Y_{FAO}(n, mc, fz)}{Y_{FAO}(n, mc)},$$

where

$\bar{Y}_{FAO}(m, mc)$ = FAOSTAT national statistic on crop yield, and

N = total number of countries with $Y_{FAO}(n, mc, fz) > 0$ and $Y_{FAO}(n, mc) > 0$. The summation in the above equation is only performed when both numerator and denominator are non-zero. The results in Figure 9 show that generally yields are highest in the AT3 AEZ.

[10] Averaging across all 94 countries may introduce biases. For example, the 94 countries are developing countries, and not representative of developed country yield variations across AEZ. In future versions, proxy data for averaging may be selected based on similarity in climates, as well as socio-economic conditions.

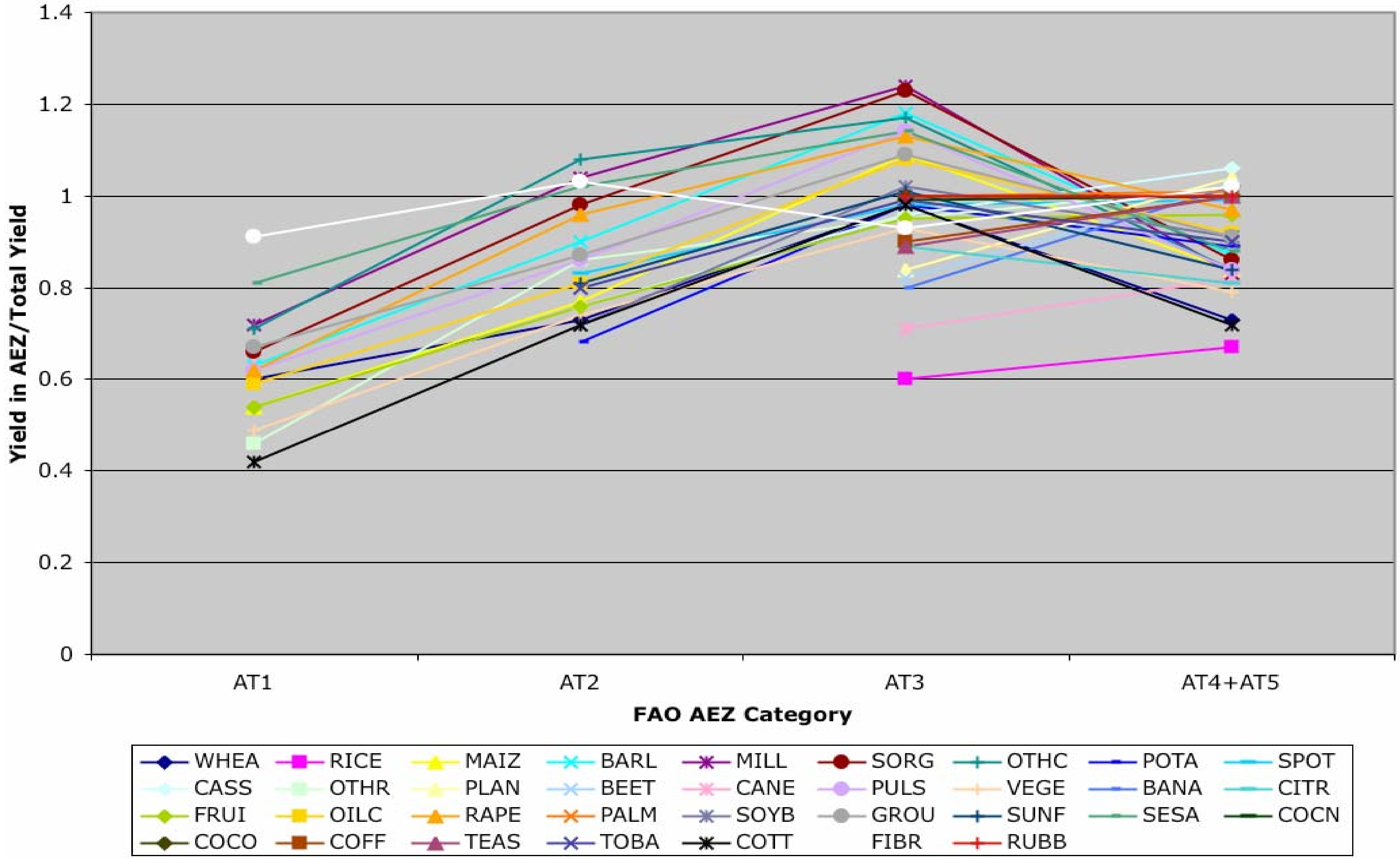

Figure 9. Crop-specific ratio of yield in each AEZ to the total yield, average over the 94 countries with FAO data

C. Merge the data and adjust for consistency with SAGE harvested area

The yields from the 94 countries are merged with the estimated yields for the remaining countries,

$$Y_{FAO}(l,mc,fz) = Y_{FAO}(n,mc,fz) \cup Y_{FAO}(m,mc,fz).$$

FAO does not report yields for GTAP AEZ1, AEZ7, and AEZ13 (see Table 8). Furthermore, often the FAO yield data and the recalibrated LEFF04 harvested area data are inconsistent, with FAO reporting non-zero yields even though recalibrated LEFF04 reports zero harvested areas, and conversely, FAO reporting zero yields while LEFF04 reports non-zero harvested area. In all of these cases, we adjusted the FAO yield data to match the recalibrated LEFF04 harvested area data.

We first mapped the FAO yield data from FAO's AEZs to GTAP AEZs based on Table 8. To fill in gaps in FAO yield data (i.e., zero reported yields when recalibrated LEFF04 harvested area is non-zero), we estimate yields using a regression across all countries and all crops of yields in each rainfed AEZ to total rainfed yields (Figure 10)[11]. For GTAP AEZ1, AEZ7, and AEZ13 (0-60 day LGP, with no data reported by FAO), we assumed that yield is one-tenth of the total rainfed yield for the corresponding crop and country (the value of 0.1 is arbitrary, but meant to represent a small yield in these arid AEZs; because not much is grown in these AEZs (see Figure 11), this assumption shouldn't have significant influence on the final results). In other words,

$$Y_{FAO}(l,mc,z)\begin{cases}\leftarrow Y_{FAO}(l,mc,fz), \text{ based on Table 7}\\ = 0, \text{if } A_{LEFF}(l,mc,z) = 0\end{cases}$$

If $\left(Y_{FAO}(l,mc,z) = 0 \;\&\; A_{LEFF}(l,mc,z) \neq 0\right)$, $Y_{FAO}(l,mc,z) = \alpha_z\, Y_{FAO,RF}(l,mc)\dfrac{Y_{FAO}(l,mc)}{Y_{FAO,RF}(l,mc)}$,

where

$\alpha_z = \alpha_{fz}$ = 0.10 for AEZ1, AEZ7, and AEZ13;

= 0.50 for AT1;

= 0.87 for AT2;

= 1.30 for AT3; and

= 0.82 for AT4+AT5 (based on Figure 10, and Table 8).

Figure 11 shows the distribution of global total harvested area and global average yields across LGPs for a few sample crops. Note that the climatic zones are not differentiated in this figure (i.e., tropical, temperate, and boreal zones are not separated). While rice and soy dominate in humid climates, cassava is grown in intermediate-to-humid climates, maize and pulses are mostly grown in intermediate climates, while millet dominates in semi-arid climates.

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[11] This averaging is done across all crops to maintain a sufficiently large sample size for the regression. For now, this is used here simply as a consistency checker, and therefore will not bias the final results very much. Future versions should consider establishing this relationship for individual crop types.

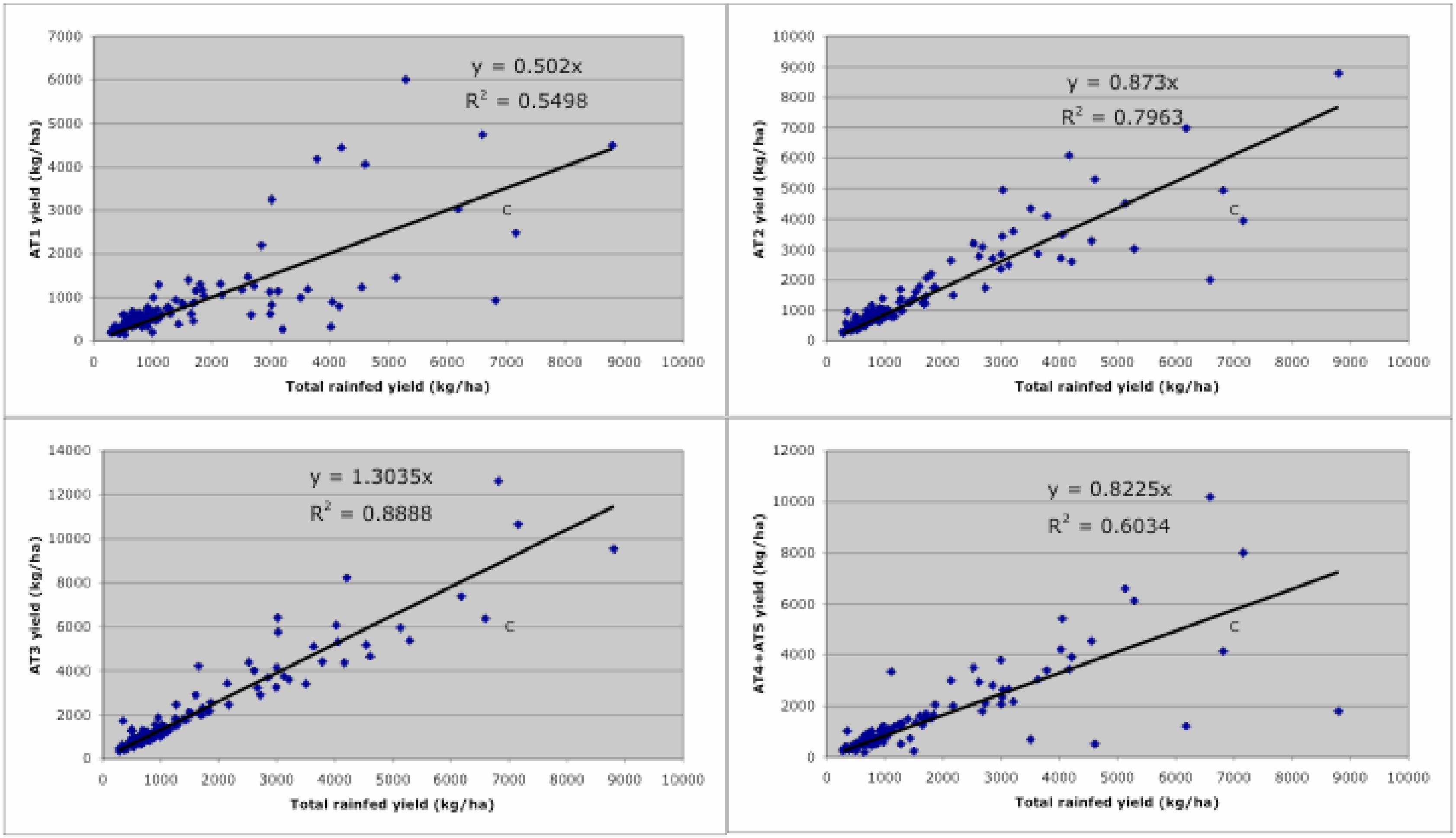

Figure 10. A regression across all countries and all crops of yields in each rainfed AEZ to total rainfed yields

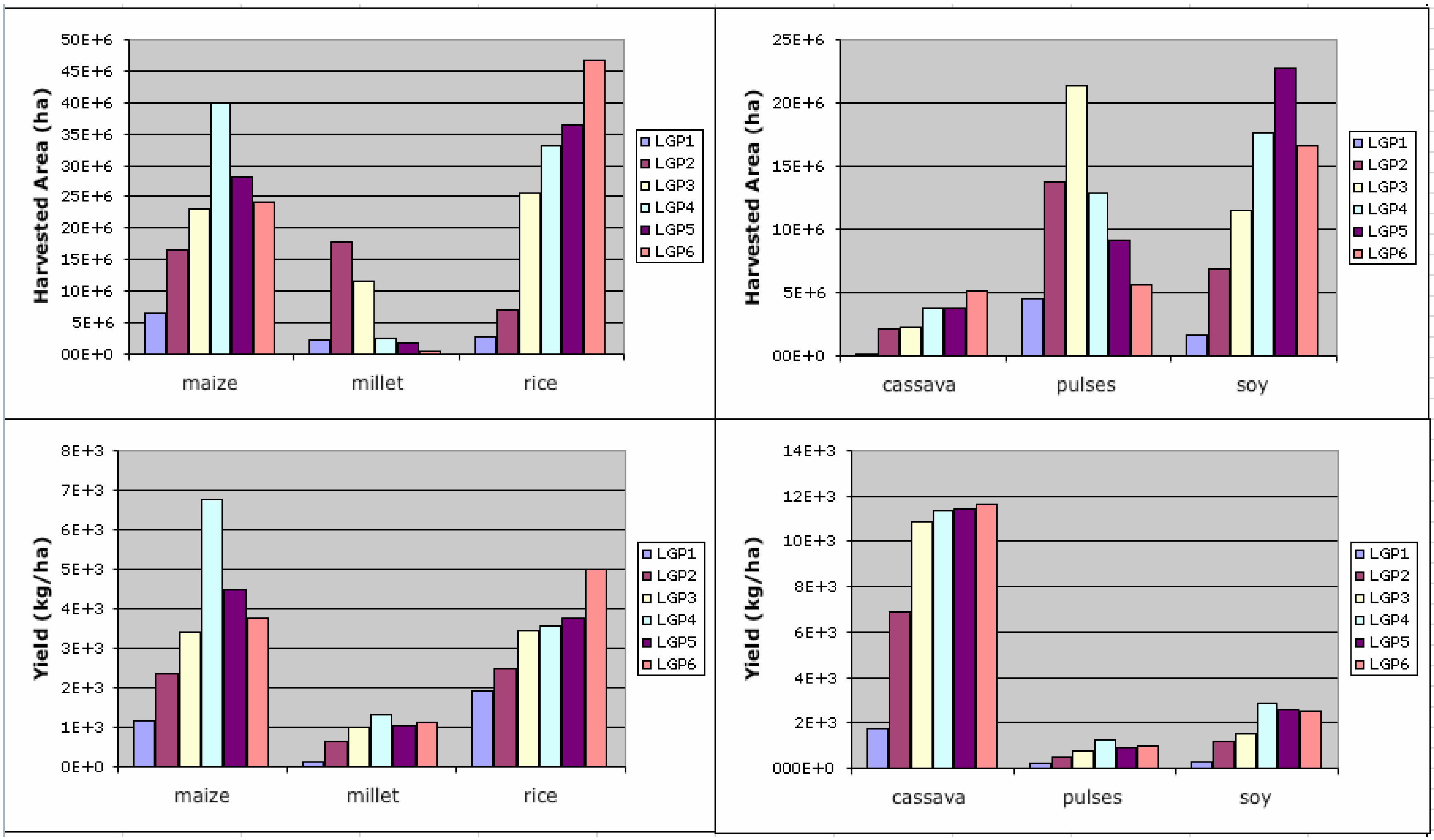

Figure 11. Distribution of global total harvested area and global average yields across LGPs for a few sample crops

D. Recalibrate the yield data to Year 2001 and map to GTAP crop sectors

Finally, because the recalibrated harvested area data by AEZ are derived from LEFF04, and the yield data are from FAO, the re-calculated national yields will change. Also, the yields need to be calibrated to the reference period of 2001. We do this as follows:

$$Y(l,mc,z) = Y_{FAO}(l,mc,z) * \frac{P_{FAO}(l,mc,t_{ref})}{\sum_z Y_{FAO}(l,mc,z) * A_{LEFF}(l,mc,z)},$$

where

$P_{FAO}(l,mc,t_{ref})$ = the FAOSTAT national production for t_{ref} = 2001.

This data can then be mapped onto GTAP's 8 crop sectors:

$Y(l,mc,z) \rightarrow Y_{GTAP}(l,s,z)$ (see Table 3 for mapping)

Table 9 uses China as an example to show the crop yield data estimated by SAGE from the above described procedure.

Table 9. SAGE crop yield data: China (unit: ton per 1000 hectare)

Unit: ton/1000ha	1 barley	2 maize	3 millet	4 rice	5 rye	6 sorghum	7 wheat	8 cassava	9 potat	10 sugarb	11 sugarc	12 pulses	13 grnuts	14 rape	15 oilpalm	16 soy	17 sunfl	18 cotton	19 others
1 AEZ1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 AEZ2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 AEZ3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 AEZ4	5290	8850	2871	7153	2069	5344	4871	22483	19262	0	46149	1710	3132	2017	20109	2106	2586	0	18054
5 AEZ5	4508	5233	1340	6262	1403	3506	4506	17783	15297	45885	61071	1528	3049	1820	15469	1993	2494	4453	15846
6 AEZ6	4508	5233	1340	6262	1403	3506	4506	17783	15297	0	61071	1528	3049	1820	15469	1993	2494	4453	15846
7 AEZ7	443	571	195	660	183	468	464	1809	1510	4413	0	154	306	176	1547	201	250	461	1483
8 AEZ8	2325	2062	1534	3301	913	2338	2322	9043	7552	22065	0	772	1531	930	7734	1005	1252	2307	7413
9 AEZ9	3868	4967	1852	5743	1588	4067	5015	15735	12609	38393	53035	1343	2664	1230	13458	1775	2178	4014	10205
10 AEZ10	5290	8850	2871	7153	2069	5344	4871	22483	19262	41116	46149	1710	3132	2017	20109	2106	2586	4885	18054
11 AEZ11	4508	5233	1340	6262	1403	3506	4506	17783	15297	45885	61071	1528	3049	1820	15469	1993	2494	4453	15846
12 AEZ12	4508	5233	1340	6262	1403	3506	4506	17783	15297	45885	61071	1528	3049	1820	15469	1993	2494	4453	15846
13 AEZ13	443	571	195	660	183	468	464	1809	1510	4413	6096	154	306	176	1547	201	250	461	1483
14 AEZ14	2325	2062	1534	3301	913	2338	2322	9043	7552	22065	30480	772	1531	930	7734	1005	1252	2307	7413
15 AEZ15	3868	4967	1852	5743	1588	4067	5015	15735	12609	38393	53035	1343	2664	1230	13458	1775	2178	4014	10205
16 AEZ16	5290	8850	2871	7153	2069	5344	4871	22483	19262	41116	46149	1710	3132	2017	20109	2106	2586	4885	18054
17 AEZ17	4508	5233	1340	6262	1403	3506	4506	17783	15297	45885	61071	1528	3049	1820	15469	1993	2494	4453	15846
18 AEZ18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Summary of the SAGE data

SAGE combined several global land use data sets to derive land use information at the national level, by 18 different AEZs (Table 10) for use in the GTAP land use database. In particular, SAGE utilized global land use/land cover data sets developed in-house, with the following features: (1) spatially-explicit maps of croplands, pastures, built-up areas, and potential natural vegetation, (2) covering 18 major crops (plus Other crops) and 18 agro-ecological zones, (3) observing national boundaries, and (4) derived from and made consistent with the FAO data of harvested area, yield, and production for 34 crops grown in 94 developing nations. As described earlier, these data sets are synthesized, adjusted for consistency, and calibrated to the year 2001.

Table 10. Summary of the SAGE land cover/use data set provided to GTAP

Category	Items	Variables (Units)	Specifications	Reference Period
Land Cover	Forest, Savanna/Grassland, Shrubland, Cropland, Pasture, Built-up land, and Other land	Area (1000ha)	160 countries 18 AEZs within each country	ca. 1992
Major Crops	19 LEFF04 crops	Harvested Area (1000ha); Yield (kg/ha)		2001

2.2.2.2 Timberland data

This section introduces the timberland data provided in GTAP. The data is described in more detail in Sohngen and Tennity (2004). The data were originally compiled for use in a Dynamic Global Timber market Model (hence forth DGTM) as described in Sohngen et al. (1999), Sohngen and Sedjo (2000), and Sohngen and Mendesohn (2003). The description below presents general information on the types of data included in the GTAP dataset. Readers are urged to review Sohngen and Tennity (2004) and the data at the following website for more detailed information:

http://aede.osu.edu/people/sohngen.1/forests/GTM/index.htm

Preparation of the timberland data for GTAP

Two types of data are obtained from the DGTM described in Sohngen et al. (1999), including forestland inventories for different timber types in 9 regions of the world, and economic parameters associated with each of these timber types. The 9 regions included in the global timber model are: North America, South and Central America, Europe, the Former Soviet Union, China, Asia-Pacific, India, Oceania (Australia and New Zealand), and Africa. The two types of data, land area inventories and economic (& biophysical growth and carbon) parameters, are disaggregated to different levels of detail. The forestland area data are disaggregated to show inventories of timber types in different agro-ecological zones within a country, while the economic parameters are disaggregated only to the timber type level for specific countries. The methods used to disaggregate the data are shown in Figure 12.

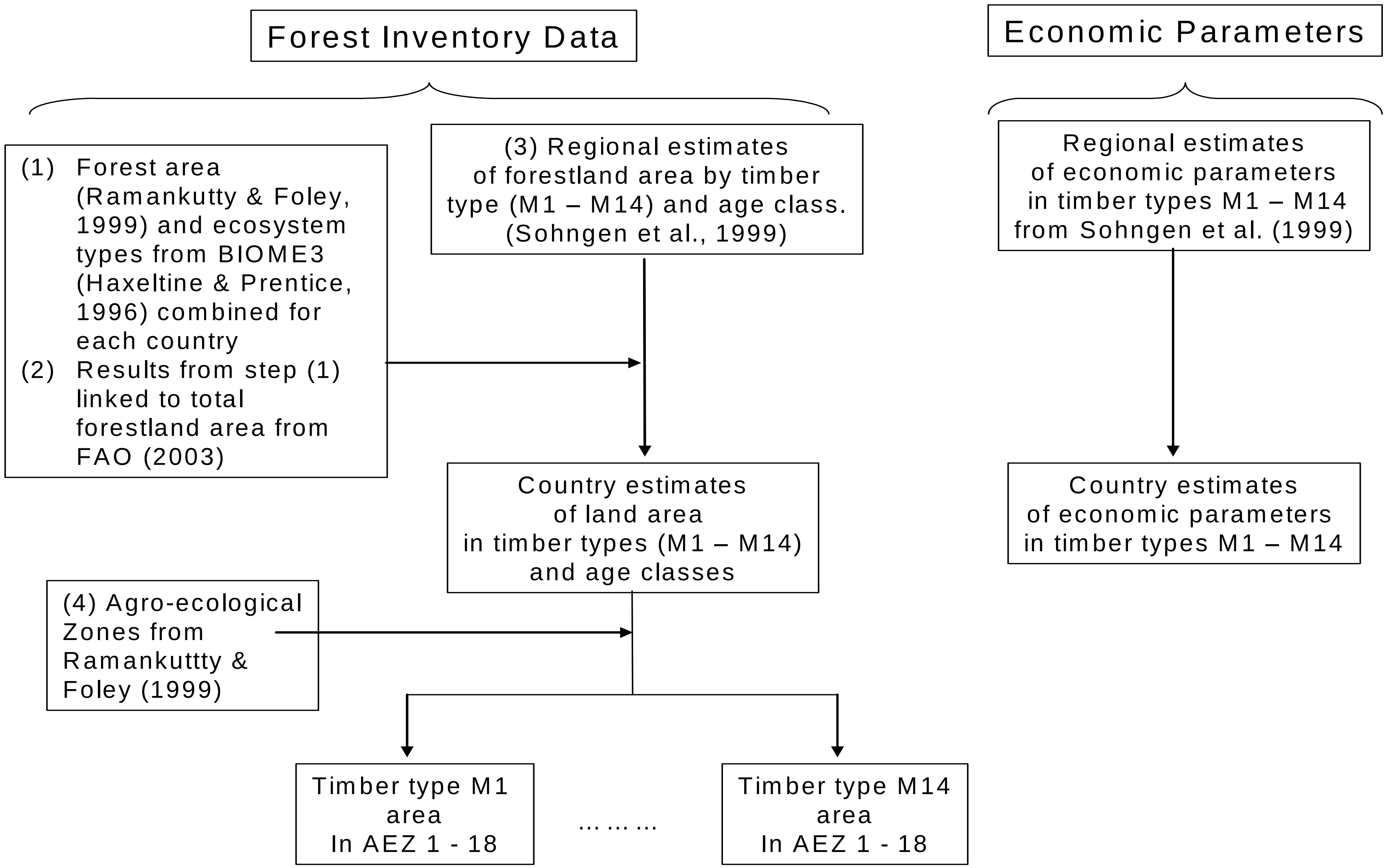

Figure 12. Graphical depiction of methods used to obtain values in the GTAP forestry dataset

The method for disaggregating the forestland area data is as follows (the left hand side of Figure 12). The model in Sohngen et al. (1999) was originally developed so that a number of timber types were linked to spatial distribution of ecosystems presented in the BIOME3 model (Haxeltine and Prentice, 1996). The term "timber types" refers to aggregations of similar species that occur within a given region that have similar growth and market characteristics. In some regions, a single timber type may be defined for each ecosystem type, while in other regions, multiple timber types may be defined for each ecosystem type. For example, in some developed countries, substantial additional detail is available from local inventory sources to break down forests located in ecosystem types defined by BIOME3 into a large number of timber types. In particular, North America and Europe have more timber type classifications than most other regions due to the availability of data sources at the regional and country level.

In order to take the classification of timber types in the global timber model and disaggregate those into specific timber types in particular countries, three steps are taken. First, the BIOME3 model is overlain with a global forest area dataset from Ramankutty and Foley (1999) to estimate the proportion of forestland residing in each timber type in each country. Second, the proportion of forestland in each timber type is then applied to the total forestland estimate from FAO (2003) to estimate the area of forestland in each timber type in each country. Third, the proportion of forestland in each age class and timber type for the region is then applied to the country level estimates of the area of different timber types to determine the age class distribution within the country.

For the most part, age class distributions are available only for developed countries and for the large developing countries. They were originally combined into a global dataset in Sohngen et al. (1999) using a range of inventory sources. One important limitation of the data on age classes is that each country that collects age-class data uses different sampling techniques and methods. For example, they handle mixed-age stands differently, or they classify forests into maturity classes that are only broadly linked to age. The resulting estimates of age class distributions provided in this document are therefore estimates based on judgments made in Sohngen et al. (1999). For countries where FAO (2003) is identified as the inventory source, no age class information is available (except for plantations), and these age classes are arbitrarily assigned age classes. Specifically, we have assigned all these forests into a single age class – typically 50 or 100 years.

In addition to having country level data sources for age class information, additional data on the distribution of species is also available for some countries. For instance, for Europe, North America, and countries of the Former Soviet Union, additional information on hardwood and softwood types within each ecosystem type is available, so that hardwoods and conifers can be considered separately. The methods used here ensure that the total land area in forests in each country is consistent with FAO (2003), but total forestland has been disaggregated to different timber types using the timber types in the global timber model, BIOME3, and other local data sources where additional data are available.

The steps taken provide estimates of the area of land in different types of forests and age classes for each country. In this dataset, however, the area of forestland in different agro-ecological zones (AEZ's) is also estimated. The AEZ map from Ramankutty and Foley (1999) was overlain on the map of ecosystem types from BIOME3, to generate an estimate of the proportion of land in each ecosystem type that resides in each AEZ. As a fourth step, these proportions were used to allocate the timber types in each country to AEZ's. Because we do not have specific age class information on AEZ's, each age class is proportionally allocated by total area to the respective AEZ's for a timber type.

The second type of data relates to parameters that can be used by modelers, such as economic parameters (i.e., prices and costs of harvesting), parameters to calculate biomass growth, or carbon sequestration, and other parameters. These data are obtained from the global timber model, but they are disaggregated only to the timber type level for each country. It was not possible to further disaggregate these parameters to AEZ's, given that data on productivity, prices, etc. is generally not available in a globally consistent database at the AEZ level. Consequently, economic parameters are available only for timber types. For each timber type in a specific country, there is a corresponding timber type in one of the 9 major regions in the global timber model. The parameters for the corresponding timber type from the global timber model are used for each timber type in each country.

Caveats and Limitations of the Forestry Data

There are several caveats that should accompany the forestry data. First, there will be more timber price variation across countries in reality than reflected in this data. The reason for this is that the prices and quality adjustment factors for prices were originally developed for a global model that aggregates the world into just 9 regions: North America, South and Central America, Europe, the Former Soviet Union, China, Asia-Pacific, India, Oceania (Australia and New Zealand), and Africa. Within each of these regions, there will surely be price differentials that are not reflected here. For modelers interested in global analyses, the price differentials contained in this data set appears are adequate for purposes of making broad comparisons across the major producing regions of the world. However, modelers seeking to use the data for more selected, national analyses involving countries within a particular region may consider adjusting the prices used for timber with more recent data from the FAOSTAT database (FAOSTAT, 2004).

A second, and analogous issue, is that there are surely larger differences in forest productivity across countries than reflected in this data set. The reasons are similar to those described above for prices: The productivity (i.e. merchantable yield) of timber types was originally estimated so that it could be applied to large areas of timber in the nine regions of the model in Sohngen et al. (1999). The same parameters have been applied to all timber types in each country located in a particular region. Thus, the productivity estimates may fail to reflect important differences in specific countries. Unlike price data, however, there are no global databases with country specific parameters for the timber yield functions; hence it is not possible at this point to make further corrections to the data for specific countries.

A third qualification is that, in addition to providing country specific data, the data on forestland areas has been further disaggregated to specific AEZ's. Thus, the dataset provides an estimate of the quantity of timber in a timber type in each agro-ecological zone. While the overall estimates of forestland areas in specific agro-ecological zones conform to the aggregate estimates from Ramankutty and Foley (1999), the dataset only provides economic information on the general timber type, not a specific set of parameters for each timber type and agro-ecological zone combination. There are reasons to believe that the same timber type might have different productivity in different agro-ecological zones (i.e. oaks grow at different rates in different ecological zones), but it was not possible with this data to estimate those differences.

Data items derived from DGTM for GTAP use

The information drawn from this work and provided for use in this and future versions of the

GTAP land use data base include the following items, disaggregated across 124 countries/regions:

1. Basic economic and biophysical data on timber types within the region;
2. Inventory data on the hectares of land in each timber type class[12] (M1 up to M14), 10-year age class (where age class information is available), and AEZ;
3. Information on carbon in each timber type, age class, and AEZ – derived from data drawn from items 1 and 2.

Note that all of these data are described fully in Sohngen and Tennity (2004). The timber types, which are country-specific combinations of management and timber species, are designated M1 through M14. Only the United States has 14 timber types. All other regions have fewer types. The main reason for this is that substantial information is available for forest economic modeling within the United States, so disaggregated data for this region has been developed more extensively. It is generally not possible to compare timber types across different countries in different regions, for example, M1 in the United States is not the same forest type as M1 in Argentina.

Timber types within general regions can be compared across countries, with the exception of the "developed, large, and other countries" category. The countries included in this dataset, as well as the general regions to which they are assigned are shown in Table A1 of Sohngen and Tennity (2004). Briefly, the general regions are:

(1) Africa

(2) Central Asia

(3) Southeast Asia

(4) Europe

(5) Central and South America

(6) Developed, Large, and Other Countries.

Note that these 6 "regions" differ from the 9 regions used in the Sohngen et al. (1999) model, from which the data are derived. The grouping of regions above is purely for convenience. Researchers using the data can feel free to group the data in different ways that make economic and ecological sense.

For the readers' information, the differences between the above categories and the 9 regions used in Sohngen et al (1999) are briefly described. First, Sohngen et al. (1999) did not originally use data for Central Asia, so these data were added to this data set. Second, Southeast Asia above includes India, which was included as a separate region in Sohngen et al. (1999). Third, category (6), "Developed, Large, and Other Countries" includes data for several of the regions originally in Sohngen et al. (1999), such as North America (Canada/U.S.), Russia, Oceania (Australia/New Zealand), and China. Category (6) also includes some other countries not included in the original data set, like North and South Korea, and Japan.

Economic data for each timber type is provided in year 2000 US $. The values are obtained from the global timber model developed by Sedjo and Lyon (1990) and Sohngen et al. (1999).

[12] See Tables A2 – A6 in Sohngen and Tennity (2004) for detailed description of the timber type classes.

The inventories (of circa 1990 – 2000) for each of the timber types have been further disaggregated into AEZ’s using the methods described above. As noted, it is currently not possible to take the economic data associated with each forest type and present specific estimates of economic parameters for each AEZ.

To facilitate modeling of different global timber markets, each timber type in each country was mapped into one of three timber species categories—coniferous, broadleaf, or mixed. Table 11 shows the DGTM coniferous timberland area data of the U.S., by 18 AEZs and 10 classes of age. Note that coniferous timberland is spread across both temperate (AEZ7 – 12) and boreal (AEZ 13 – 16) lands, with the largest concentration arising in the long season, temperate AEZ12, dominant in the Southeastern United States, as well as coastal areas in the Northwestern US (recall Figure 6). This is followed in total land area by coniferous timberland in AEZ 14, which is found largely in Alaska, but also in some of the Rocky Mountain range.

Figure 13 charts the distribution of DGTM's U.S. coniferous timberland area data by AEZ and age class (as from Table 11). This shows that the age class distribution between 0 and 90 is relatively uniform in most cases. The large spike in the age category of 100 and above reflects the predominance of old growth forests – particularly in the boreal zone.

Table 12 shows the U.S. all-species timberland acreage data, by 18 AEZ and 14 timber types (i.e., management type coupled with tree species). This is a relatively sparse matrix, indicating that management types are somewhat specialized by AEZ. Another view of these data is offered by Figure 14 which charts the distribution of DGTM's U.S. coniferous timberland area data, by AEZ and management type (from Table 12).

The economic and biophysical data (i.e., "Data Output") includes fundamental economic values associated with forestry activity and carbon sequestration for the particular timber types, e.g., land rents, management costs, timber prices, forest area and area change, yields, production, growth parameters, and carbon accounting values. The data are provided only for the timber types identified as being relevant for each country. The values for particular timber types in countries within a particular region are similar because the data have been obtained from the rather aggregate, global timber model.

Table 11. DGTM coniferous timberland area data of the U.S.: AEZ by age (unit: 1000 hectare)

Unit: 1000ha	1 AGE_10	2 AGE_20	3 AGE_30	4 AGE_40	5 AGE_50	6 AGE_60	7 AGE_70	8 AGE_80	9 AGE_90	10 AGE_100	Total
1 AEZ1	0	0	0	0	0	0	0	0	0	0	0
2 AEZ2	0	0	0	0	0	0	0	0	0	0	0
3 AEZ3	0	0	0	0	0	0	0	0	0	0	0
4 AEZ4	0	0	0	0	0	0	0	0	0	0	0
5 AEZ5	0	0	0	0	0	0	0	0	0	0	0
6 AEZ6	0	0	0	0	0	0	0	0	0	0	0
7 AEZ7	573.2	511.9	399.5	423.1	459.6	463.7	525.7	502.7	768.4	1003.3	5631.3
8 AEZ8	383.8	314.5	251.4	266.8	297.4	323	393.2	391.4	665.8	886	4173.3
9 AEZ9	74	74.4	70.7	84.9	92.6	98.9	104.9	91.9	152.9	231.1	1076.2
10 AEZ10	721.6	801.1	773.5	842	787.3	659.7	547.9	324.9	214	368	6040.2
11 AEZ11	856.1	732.7	834.5	696.7	440.7	220.2	213.1	40.3	17.9	16.6	4068.9
12 AEZ12	5387.5	4442.1	5328	4337.4	2537.5	1099.3	1120.7	0	0	0	24252.5
13 AEZ13	201.6	304	293	297.3	290.2	278.4	304.9	290.5	599	1083.5	3942.3
14 AEZ14	699.3	1284.4	1282.6	1291.4	1228.4	1145.5	1220.3	1147.9	2490.1	4781.7	16571.6
15 AEZ15	916.1	1795.1	1810.8	1819.7	1718.6	1589.7	1679	1572.8	3463.8	6764.4	23130
16 AEZ16	24.9	34.3	32.4	33	32.7	31.8	35.3	33.9	68.1	119.3	445.7
17 AEZ17	0	0	0	0	0	0	0	0	0	0	0
18 AEZ18	0	0	0	0	0	0	0	0	0	0	0
Total	9838.2	10294.5	11076.4	10092.3	7885.1	5910.1	6145.2	4396.2	8440	15253.8	89331.9

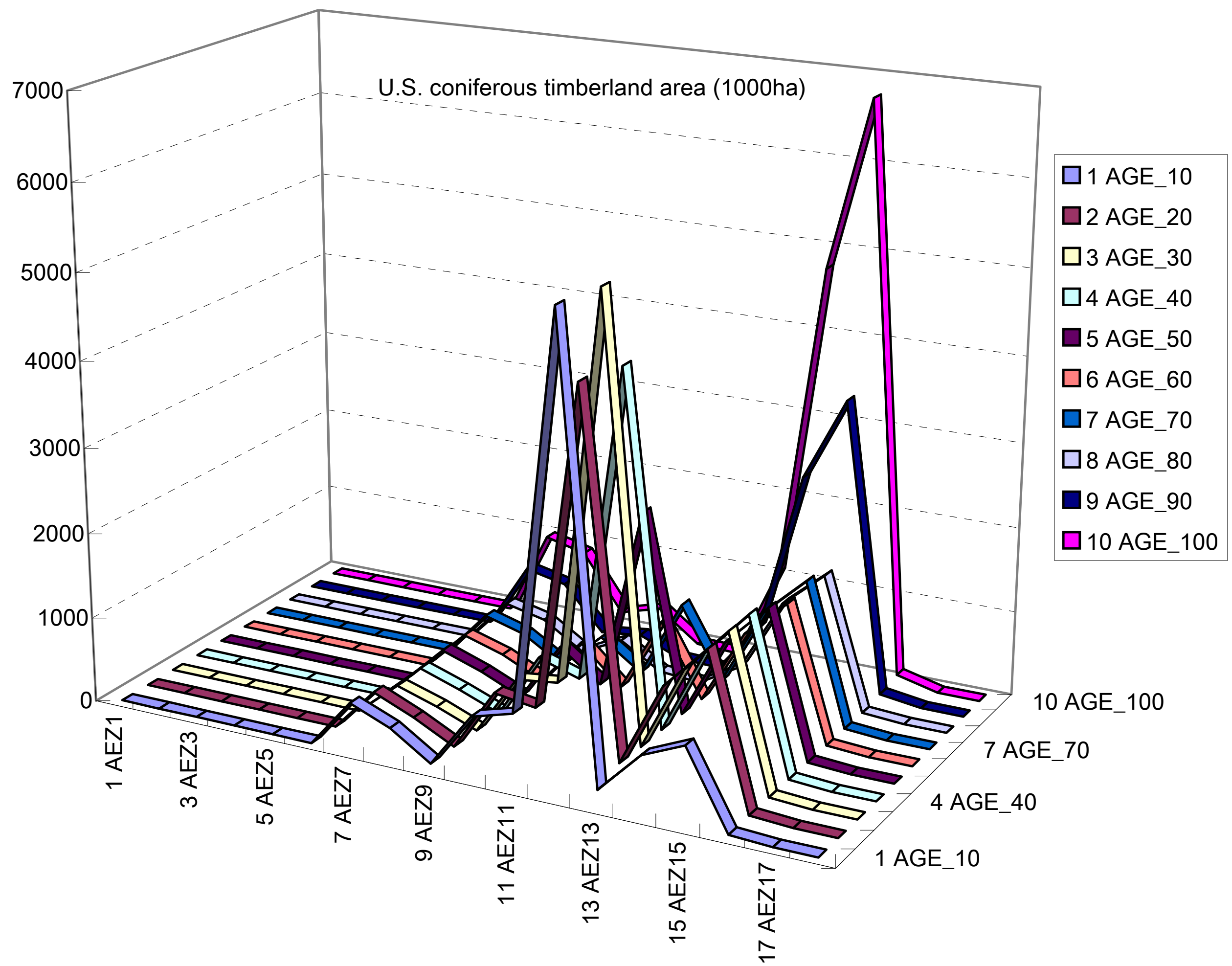

Figure 13. DGTM U.S. coniferous timberland area distribution: AEZ by age

Table 12. DGTM timberland area data of the U.S.: AEZ by timber types (unit: 1000 hectare)

Unit: 1000ha	1 M1	2 M2	3 M3	4 M4	5 M5	6 M6	7 M7	8 M8	9 M9	10 M10	11 M11	12 M12	13 M13	14 M14	Total
1 AEZ1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 AEZ2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 AEZ3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 AEZ4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 AEZ5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 AEZ6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 AEZ7	827.7	0	0	0	1766.5	0	1898.1	1139	0	0	0	0	0	0	5631.3
8 AEZ8	0	0	0	0	1472.1	0	1752	949.2	0	0	0	0	0	0	4173.3
9 AEZ9	0	0	0	46.3	229	142.2	511	147.6	0	134	92.3	85.7	8.8	81.2	1478.1
10 AEZ10	2648.7	400.9	754	390.8	81.8	1200.4	511	52.7	1253.9	1131.3	9226.7	8566.4	877.4	8124.4	35220.4
11 AEZ11	496.6	1202.7	2261.9	0	65.4	0	0	42.2	3761.6	0	12825.1	11907.3	1219.5	11292.9	45075.2
12 AEZ12	0	8419	15833.5	0	0	0	0	0	26331.2	0	1845.3	1713.3	175.5	1624.9	55942.7
13 AEZ13	0	0	0	0	310.8	0	3431.1	200.4	0	0	0	0	0	0	3942.3
14 AEZ14	0	0	0	0	310.8	0	16060.4	200.4	0	0	0	0	0	0	16571.6
15 AEZ15	0	0	0	1.9	32.7	5.7	23068.6	21.1	0	5.4	0	0	0	0	23135.4
16 AEZ16	0	0	0	0	49.1	0	365	31.6	0	0	0	0	0	0	445.7
17 AEZ17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 AEZ18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3973	10022.6	18849.4	439	4318.2	1348.3	47597.2	2784.2	31346.7	1270.7	23989.4	22272.7	2281.2	21123.4	191616

Note: M1-M8 are softwood; M9-M11 are hardwood; M12-M14 are mixed forest.

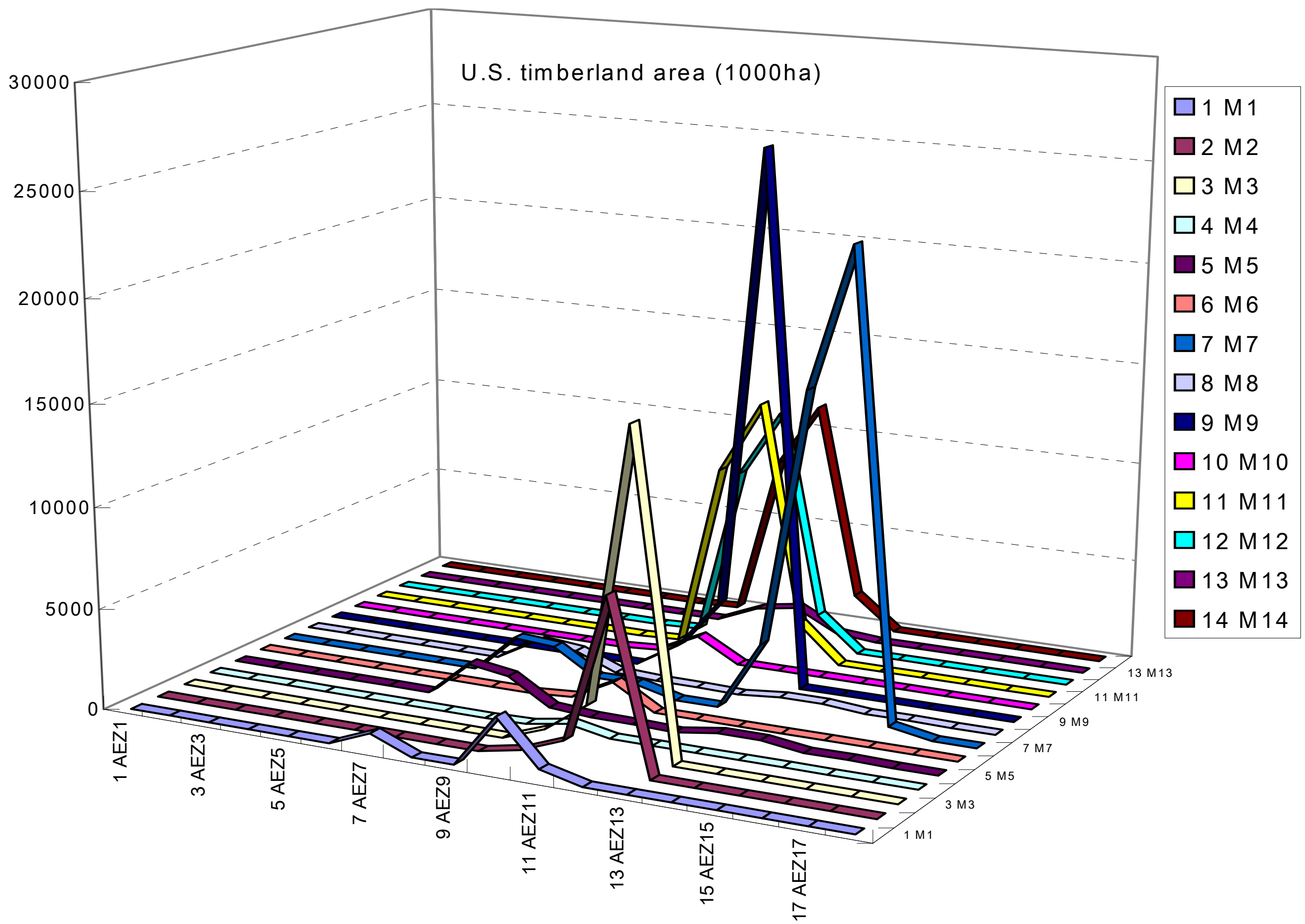

Figure 14. Distribution of DGTM U.S. timberland area data: AEZ by timber types

2.2.3 GTAP AEZ land rents

2.2.3.1 Development of GTAP land rent data

Land rents represent a very important part of the GTAP-AEZ data base. This is because the GTAP model, as with all general equilibrium models, is expressed in terms of value flows. Therefore, prices are used to weight all underlying quantities – be they tons of wheat, numbers of workers, or hectares of land—prior to aggregation and incorporation in the economic model. As such this is a critical section of this paper. Unfortunately, it is also a very difficult problem. Ideally, where an active land rental market is present, we could observe land rents, by use and AEZ. It would then be a simple matter of multiplication (land rents/ha. * total ha.) in order to estimate land rents in each activity/AEZ. However, such data are not readily available in most countries, and where it is available, it is not grouped by detailed use or AEZ.

Furthermore, when it comes to estimating agricultural land rents by economic activity, the GTAP data base reflects the common level of ignorance of the agricultural economics profession. Because of the difficulty in allocating inputs to different activities within the agricultural sector (most farms are multi-product enterprises), all estimates of aggregate cost shares are for the entire farm sector, not for individual crops or livestock activities. Therefore, the only relevant piece of data offered by GTAP is total land rents in agriculture, at the national level. For simplicity, all farm sectors in the GTAP data base inherit the same share of land in total value-added (i.e. the payments to land, labor and capital). However, there is nothing sacred about this assumption, and it would appear that we should alter that assumption for present purposes, in light of the fact that we have observations on total hectares of land in various activities.

In the following sections, we describe how we allocate the GTAP land rents across AEZs. As our data sources differ for crops and livestock, we discuss the associated procedures first for crops (section 2.2.3.2) and then for livestock (section 2.2.3.3). In section 2.2.3.4, we describe how we adjusted sectoral value-added to preserve the estimates of primary factor shares from literature, given that we assumed in section 2.2.3.3 the indirect use of land by non-ruminant sectors. Forest land rent allocation is described in section 2.2.3.5.

2.2.3.2 GTAP cropland rent data by 18 AEZs

We split the GTAP sectoral land rents into 18 AEZs according to the AEZ-specific production shares as derived from the data provided by SAGE and DGTM. Table 3 shows the mapping between SAGE's 19 crops to GTAP's 8 crops. The following formula is used to split the GTAP sectoral land rents into 18 AEZs (L_{ca}). For region r,

$$L_{ca} = L_c * \left[\sum_{i \in SAGECROPS=c} Pi*Yia*Hia \Big/ \sum_{a \in AEZS} \sum_{i \in SAGECROPS=c} Pi*Yia*Hia \right],$$

$$c \in CROPS;\ i \in SAGECROPS;\ a \in AEZS. \qquad (1)$$

where

L_{ca} is the land rent accrued to GTAP crop sector c in AEZ a;

L_c is the original land rent of GTAP crop sector c, that is, with no AEZ distinction;

P_i is the per-ton price of SAGE's crop i;

Y_{ia} is the yield (ton/1000ha) of SAGE's crop i in AEZ a, with $Y_{ia} = \frac{Qia}{Hia}$; and

H_{ia} is the harvested area of SAGE's crop i in AEZ a.

Set SAGECROPS contains SAGE's 19 crops;

Set CROPS contains GTAP's 8 crop types, which are more aggregated than SAGE's.

The mapping between SAGECROPS (index i) and CROPS (index c) is given in Table 3. The $\sum_{i \in SAGECROPS=c}$ operator in (1) aggregates over disaggregated SAGE's crop i, thereby creating the corresponding aggregated GTAP's crop c.

Additional note the following: The per-ton crop price (P_i) is invariant to AEZs

Data source of L_c = coefficients VFM for land from the GTAP database;

Data source of P_i = 2001 crop prices from the FAOSTAT database;

Data source of Y_{ia} = SAGE, as described earlier; and

Data source of H_{ia} = SAGE, as described earlier.

Discretionary solution to the mapping inconsistency for "Other crops"

As noted earlier in section 2.2.2.1, in this first release of the GTAP land use database, we encountered a problem in mapping between SAGE crops and the GTAP crop sectors of vegetables and fruits ("v_f") and other crops ("ocr"). We have come up with a discretionary solution to this problem and have planned to fix it in the next release of the GTAP land use data base.

We used the AEZ shares of the aggregate production of the SAGE crops that are mapped to GTAP's "v_f" and "ocr" sectors to split the AEZs of both the "v_f" and the "ocr" sectors. We plan to fix this crop mapping discrepancy in the next release when we receive the AgroMAPS (FAO/IFPRI/SAGE/CIAT, 2003) data from SAGE.

Some special treatment for Belgium and Luxembourg

Note that we moved the land rents of the crop sectors of Belgium and Luxembourg to be the capital rentals of the corresponding sectors. This is to make their crop sector land rents consistent with the SAGE data which show zero harvested area. The same adjustment is made to the "pfb" sector of Japan. For some individual GTAP countries that SAGE does not have data—i.e., Taiwan ("twn") and Hong Kong ("hkg")—we use the AEZ shares of Viet Nam ("vnm") as the proxies to split their cropland rents into 18 AEZs. None of these consistency adjustments are likely to make a large difference in the global results associated with land use changes in the wake of policies aimed at climate change mitigation.

An illustration of the GTAP crop sector land rents by 18 AEZs

Table 13 shows world total value-added, including land rents (header "VFM", from v6.0 database) for the GTAP crop sectors (sectors 1 to 8) split into 18 AEZs. The data show that most of the world's crops (value-basis) are grown in the tropical and temperate AEZs (AEZs 1 - 12). The largest total crop land rents, and estimated $58,786 million, are generated on AEZ 10 – temperate climate with LGP of 180 – 240 days. This is followed by the longer LGP temperate AEZs: 11 and 12. The values of land rents generated in the boreal zones are an order of magnitude smaller, and essentially negligible for the shortest growing period (presumably production in greenhouses generates most of the value of production and hence land rents in these zones).[13]

Figure 15 offers a visualization of the cropland rent allocation among AEZs, as seen in Table 13. This reveals some interesting points about specific crops. For example, we see that paddy rice ("pdr") is mostly grown in AEZs with longer LGPs (e.g., AEZs 3 – 6, and 10 - 12). Vegetables, fruits and nuts ("v_f") are a high value crop and therefore dominate the total land rents picture in most of the AEZs. This can be explained by their shorter cultivation period, which allows for multiple cropping, the widespread irrigation of fruit and vegetable production, as well as the potential for greenhouse production. The dominance of the "v_f" sector in the total cropland rent distribution within each AEZ is further emphasized in Figure 16, which shows a share-based breakout of total land rents in each of the Agro-Ecological Zones, world wide.

[13] The issue of greenhouse production raises some interesting and important questions regarding our imputation of land rents. The use of greenhouses is clearly an attempt to circumvent the natural limitations presented by a given AEZ. This requires substantial investment, the cost of which is confounded with land rents in our present analysis. This highlights the need for independent estimates of land rents, by AEZ. We hope to incorporate such estimates in future versions of this data base.

Table 13. GTAP crop sector land rents: VFM, world total, v6.0 (unit: million US Dollar)

Unit: million USD	1 pdr	2 wht	3 gro	4 v_f	5 osd	6 c_b	7 pfb	8 ocr	Total
1 AEZ1	37	297	133	801	58	43	69	72	1509
2 AEZ2	75	402	252	942	526	94	249	367	2907
3 AEZ3	1678	1922	855	4636	3313	1696	1103	3181	18385
4 AEZ4	3316	672	1103	6292	1419	984	475	4687	18947
5 AEZ5	3984	137	1294	5600	752	766	316	3473	16321
6 AEZ6	5097	140	1932	9445	918	1126	152	5940	24750
7 AEZ7	190	479	232	989	184	109	213	390	2784
8 AEZ8	754	3024	1538	6623	1086	323	525	1679	15552
9 AEZ9	830	3453	2705	8396	2062	620	763	2550	21379
10 AEZ10	3219	8610	12469	18481	4048	944	881	10134	58786
11 AEZ11	4070	5065	4926	13611	2767	381	823	4937	36579
12 AEZ12	4147	1730	1842	17413	2178	562	1037	3949	32859
13 AEZ13	3	47	11	64	11	3	14	20	172
14 AEZ14	16	358	125	725	47	13	8	267	1559
15 AEZ15	77	991	803	2097	290	35	7	741	5041
16 AEZ16	40	273	245	449	82	16	5	159	1267
17 AEZ17	2	2	1	14	0	0	0	1	21
18 AEZ18	0	0	0	1	0	0	0	0	1
19 UnSkLab	34221	23133	25714	156766	21103	10094	9083	66212	346326
20 SkLab	368	629	831	3357	636	232	203	2582	8838
21 Capital	9972	8775	10394	45817	10470	4713	4319	30478	124937
22 NatlRes	0	0	0	0	0	0	0	0	0
Total	72092.95	60138.31	67404.52	302516.91	51950.37	22752.57	20246.77	141818.78	738921

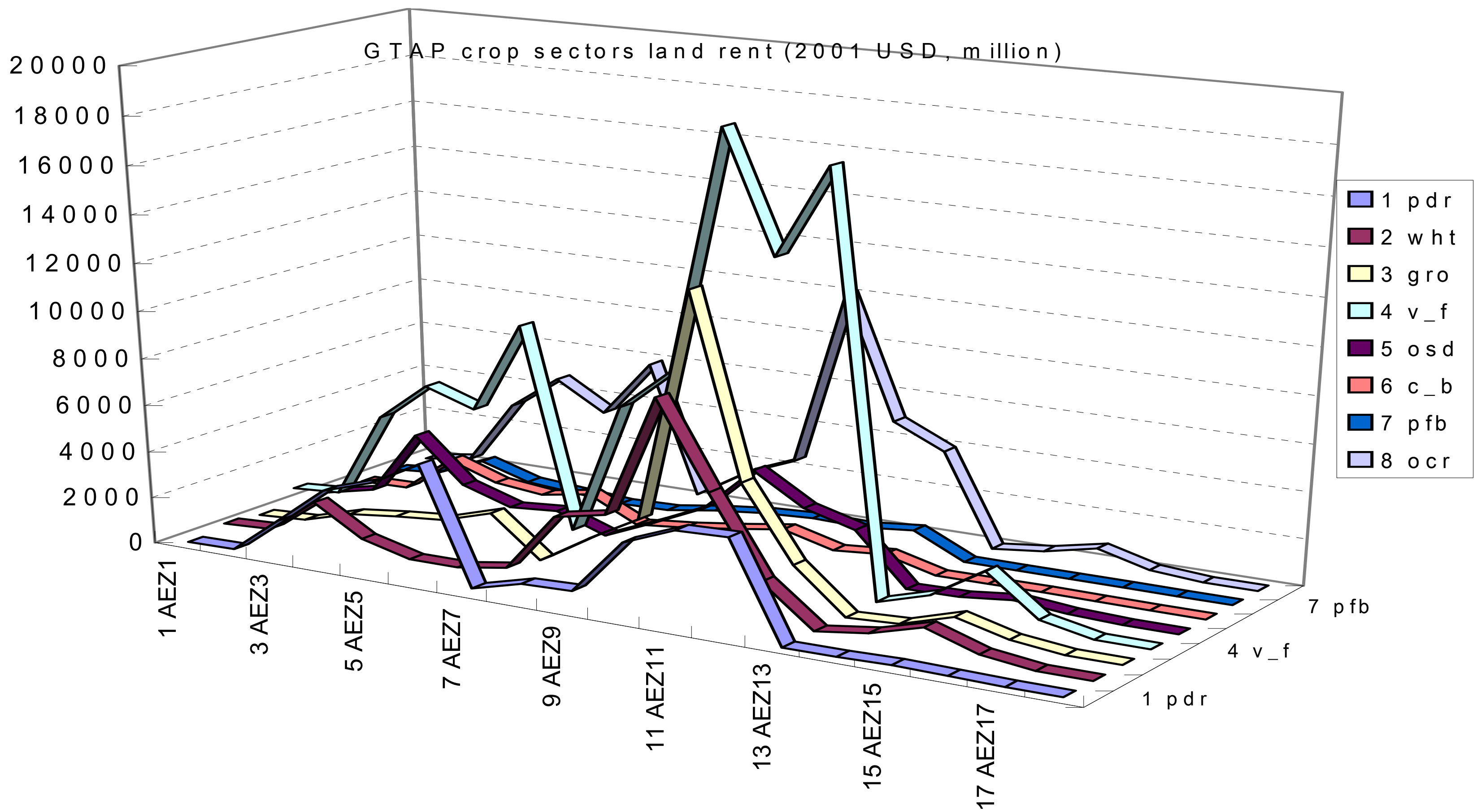

Figure 15. Crop sector land rent allocation among AEZs: world total

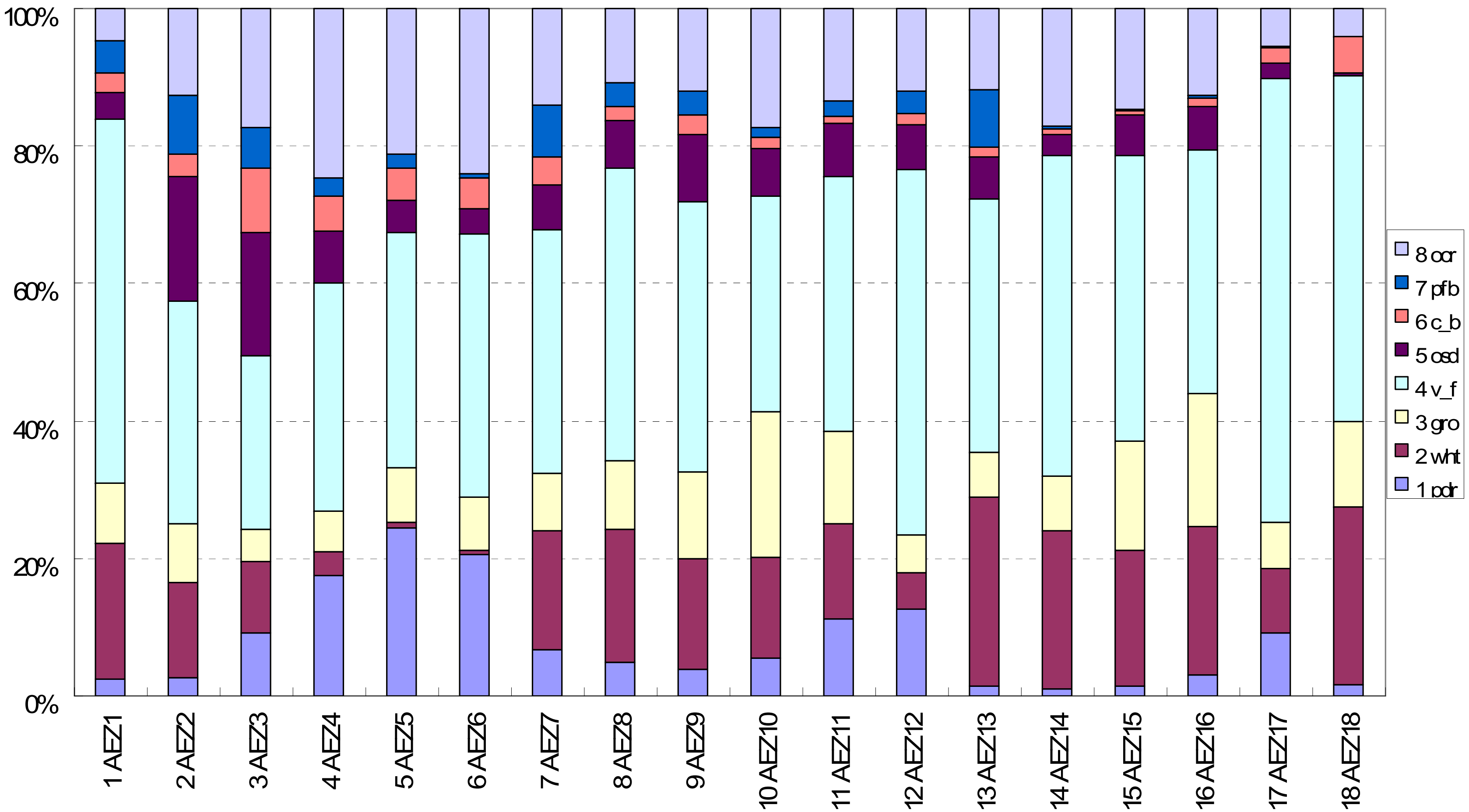

Figure 16. Distribution of crop sector land rent within each AEZ: world total

2.2.3.3 GTAP livestock sector land rent data by 18 AEZs

There are four primary livestock production sectors in the GTAP data base: ruminants (ctl = cattle, sheep and goats), dairy production (rmk), wool (wol) and non-ruminants (oap = pigs and poultry). Only the first two of these sectors are assumed to use land directly in their production process. Since wool production is a by-product of the ruminants sector (sheep and goat production), this does not use land directly. In the case of non-ruminants, the justification is a bit more complex, since these animals may roam freely on the farm in the case of low-intensity production. However, by their very nature, what they consume has already been produced using land somewhere else in the system (e.g., feedgrains). As production intensifies, these animals are confined to a facility which is more nearly akin to a manufacturing sector than a land-using sector. Therefore, we abstract from the direct competition for land between non-ruminant production, ruminant production, crops and forestry. Of course there is indirect competition, insofar as increased production of poultry, for example, will boost the feed requirements and hence increase the demand for land in feed grains. However, we capture this competition via the intermediate demand for feed in non-ruminant production.

In order to estimate land rents by AEZ for the crops sectors, we capitalized on SAGE's estimates of crop harvested area by AEZ, as well as the relative yield estimates from the FAO. However, in the case of the livestock sectors, we do not have a similar allocation of production by AEZ. Therefore, we are forced to resort to a different approach. From the land cover data base, we know how much total grazing land there is in each AEZ. To this, we seek to add an estimate of the relative productivity of these different hectares of land in all types of ruminant production across AEZs. The most natural thing is to use an index of crop yields as a predictor of land productivity in forage. Since there is no single "forage crop" sector in our data base, we use the average yield of GTAP coarse grains sector, i.e., the "gro" sector, of the country/region, multiplied by the SAGE pasture land cover hectares of the 18 AEZs, to split the GTAP livestock sectors' land rents into 18 AEZs.[14] Since we do not have independent estimates of land used for dairy production vs. land used for cattle, sheep and goats, the aggregate land rents in these sectors are divided across AEZs in equal proportions.

A summary of the GTAP livestock sector land rents by 18 AEZs

Table 14 shows world total land rents (header "VFM", from v6.0 database) of the two GTAP land-using livestock sectors (sectors 9 and 11) split into 18 AEZs. As with crop production, the largest total land rents are in AEZ 10. However, the distribution of land rents across AEZs is now much more even, as shown in Figure 17. Note that the tropical AEZs 3 – 6, and the boreal AEZs 14 and 15 show relatively high levels of land rents, worldwide. This reflects the fact that livestock production is more amenable to the shorter growing seasons and sometimes more adverse circumstances characterized by these AEZs. In short, livestock production appears to be more tolerant to severe climate conditions.

When the AgroMAPS (FAO/SAGE/IFPRI, CIAT, 2003) data, mentioned earlier, becomes available, we will be able to extract data on forage crop areas and yields. Therefore, in the next version of this database, we plan to update our livestock land rents.

[14] For Belgium and Luxembourg, we use the Netherlands ("nld") data as proxy for the AEZ split due to a lack of data for the former countries.

Table 14. GTAP livestock sector land rents: VFM, world total, v6.0 (unit: million US Dollar)

Unit: million USD	9 ctl	10 oap	11 rmk	12 wol	Total
1 AEZ1	83	0	161	0	244
2 AEZ2	208	0	643	0	850
3 AEZ3	227	0	3066	0	3293
4 AEZ4	849	0	1970	0	2819
5 AEZ5	1446	0	894	0	2340
6 AEZ6	1362	0	767	0	2130
7 AEZ7	1149	0	1130	0	2280
8 AEZ8	1750	0	2522	0	4272
9 AEZ9	1109	0	1342	0	2451
10 AEZ10	2593	0	4560	0	7153
11 AEZ11	1455	0	2084	0	3539
12 AEZ12	1105	0	810	0	1915
13 AEZ13	152	0	122	0	274
14 AEZ14	663	0	932	0	1596
15 AEZ15	1134	0	1444	0	2578
16 AEZ16	429	0	509	0	938
17 AEZ17	13	0	9	0	22
18 AEZ18	1	0	1	0	2
19 UnSkLab	30127	58281	36372	3668	128447
20 SkLab	1140	1303	1376	73	3892
21 Capital	24095	54798	18304	3309	100506
22 NatlRes	0	0	0	0	0
Total	71090	114382	79020	7049	271540

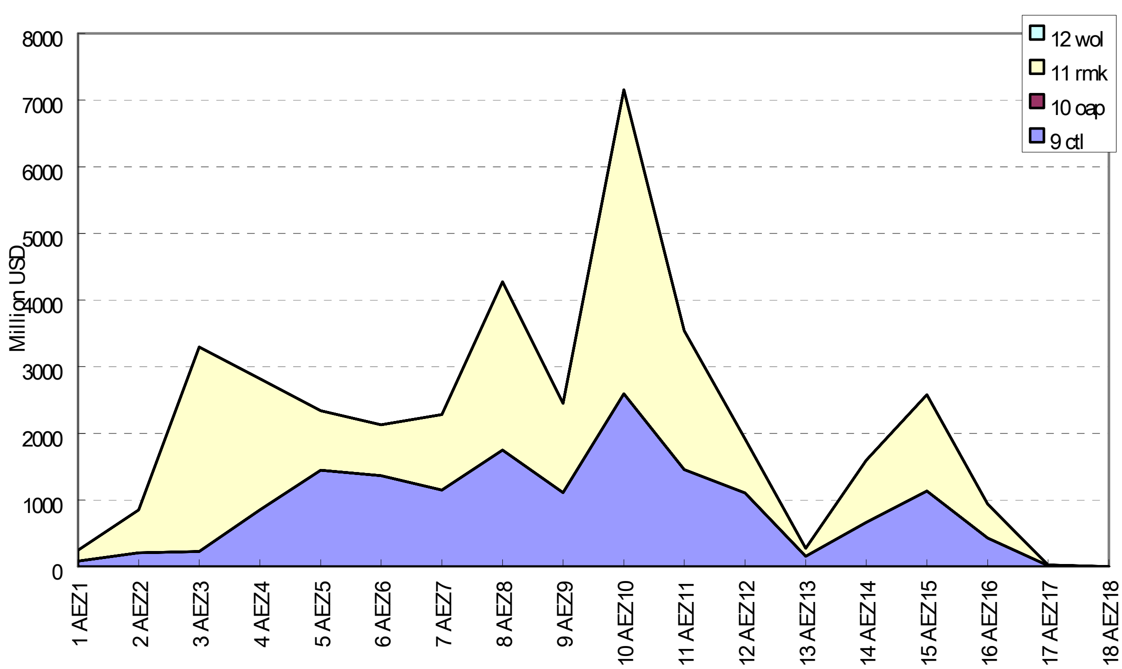

Figure 17. Livestock sector land rent allocation among AEZs: world total

2.2.3.4 Preserving country-specific total valued-added of agriculture in GTAP

The GTAP input-output data base has imposed from available literature country-specific estimates of value-added shares for all of agriculture (including crops and livestock; see Chapter 18.C of Dimaranan and McDougall (2002)). As such, we would like to preserve the value-added shares of agriculture for each GTAP region.

As alluded to in section 2.2.3.3, we assumed "oap" and "wol" sectors do not use land directly. Therefore, we took away land rents of the two sectors and augmented their capital rental by the amount of their land rents to keep the total costs of the two sectors correspond to their total revenue. To preserve the country-specific shares of agriculture value-added, we scaled up land rents of the other agriculture sectors (i.e., crop sectors, "ctl" and "rmk" sectors) by amounts summing up to the total land rents of the two non-ruminants sectors. Again, to preserve the zero-profit condition, we scaled down capital rentals of the other agriculture sectors accordingly.

2.2.3.5 GTAP forest land rent data by 18 AEZs

The standard GTAP database treats agricultural land rents as distinct from forestry land rents. The latter are classified as natural resource rents (see Section 18.C of Chapter 18 in Dimaranan and McDougall, 2002). Accordingly, we reallocate the “natural resource” rent in forestry to become simply land rents. We split the forestry land rent into 18 AEZs according to the rental shares by AEZ. We derive the AEZ-specific forestry land rent shares from the DGTM data of timberland marginal land rent (by tree type and by country), multiplied by timberland area by tree type, by age, by AEZ, and by country.

Table 15 shows world total land rents (header "VFM", from v6.0 database) of the GTAP forest sector ("13 frs") split into 18 AEZs.

Table 15. GTAP land rents: VFM of all land-based sectors, world total, v6.0 (unit: million US Dollar)

Unit: million USD	13 frs
1 AEZ1	30
2 AEZ2	24
3 AEZ3	191
4 AEZ4	479
5 AEZ5	507
6 AEZ6	1141
7 AEZ7	100
8 AEZ8	118
9 AEZ9	564
10 AEZ10	1667
11 AEZ11	1059
12 AEZ12	2008
13 AEZ13	15
14 AEZ14	299
15 AEZ15	720
16 AEZ16	190
17 AEZ17	1
18 AEZ18	0
19 UnSkLab	32898
20 SkLab	914
21 Capital	37713
22 NatlRes	0
Total	80641

3. Validation of the GTAP AEZ land rent data

The construction of the GTAP AEZ land rent data has involved a host of different assumptions. So it is natural to ask: how does this compare with observed land rents, when the rents themselves are divided by the hectares of observed land cover? Ideally we would like to do this for all regions in the GTAP data base. However, we only have the data of observed land rents for the U.S. so far. Therefore, we present here the comparison of per hectare land rents between the GTAP land rent data and the observed cash land rent only for the US, using data published by the U.S. Department of Agriculture (USDA).

Figure 18 shows the data available from the USDA for crop and pasture land rents by state, as well as the national average. Note that there is tremendous variation in cropland rents – with the highest figures in the states where irrigated cropland is predominant. Indeed, the cropland data for Arizona (AZ), Washington (WA) and California (CA) cover only irrigated land. The overall average U.S. cropland cash rent is \$175/hectare, while the average pasture land cash rent is \$23/hectare—about 13% of cropland rents[15]. To compare these estimates to those implied by the GTAP-AEZ data base, we must first perform some intermediate calculations. This is done in Table 16. The first pair of columns in this table report total land rents, by AEZ, in the modified GTAP data base, for both crops and livestock. In order to compute land rents per hectare, we must divide these figures by the SAGE land cover data in the second pair of columns in Table 16. This yields the estimated land rents per hectare, by AEZ, reported in columns E and F. Based on these estimates, the highest land rents per hectare occur for AEZ 10. These are \$226/ha. and \$76/ha., for crops and grazing, respectively. Not surprisingly, the lowest per hectare land rents arise on AEZs 7 and 13 – the shortest growing period land. Here, average crop land rents are just \$21/ha. and pasture land rents are just \$5/ha. For the entire cropland and grazing land in the US, these figures are \$164/ha. and \$20/ha., respectively. These estimates compare very favorably with USDA's cash rent figures of \$175/ha. and \$23/ha., respectively.

It is also of interest to consider the relative land rents for crop and livestock activities within a given AEZ. This ratio is reported in the next column of Table 16 (G). Here, note that the overall ratio of pasture land rents to crop land rents in our data base is 0.12 – remarkably close to the USDA ratio of 0.13. However, this varies widely across AEZ's in the GTAP-AEZ data base. The lowest value is 0.10 in AEZ 16 and the highest value is 0.40 in AEZ 11.

In light of the fact that we do not have cash rents for the US, by AEZ, it is useful to compare our estimates of land rents to those from another source. Towards this end, the latter columns of Table 16 report per hectare land rents from Mendelsohn *et al.* (2005) for the United States. Their aggregate land rents for the entire US are a bit lower than the GTAP-AEZ and USDA estimates: \$147/ha. for crops and \$13/ha. for grazing. The ratio of relative land rents in grazing vs. crops estimated by Mendelsohn *et al.* (2005) is also lower than the USDA one, at just 0.09 (vs. 0.13 for USDA and 0.12 for GTAP-AEZ).

However, unlike the USDA estimates, Mendelsohn's estimates can be mapped to AEZs and this has been done. This mapping gives us a basis of comparison for the distribution of land rents across Agro-Ecological Zones. Here we see much greater differences between the two data bases. These are also illustrated in Figures 19 – 20 in order to facilitate discussion. Begin with the estimate of *total* crop land rents, by AEZ (Figure 19). The largest absolute discrepancy arises on

[15] This USDA cash land rent finding was provided by Alla Golub.

AEZ 12, temperate climate with the maximum LGP. Here, the GTAP-AEZ data base estimates nearly twice as much land rent being generated as does Mendelsohn *et al.* (2005). By contrast, the latter authors' estimates are higher for AEZ 11. Overall, these total land rent estimates aren't too different. This is reassuring, particularly in light of the relatively weak basis for estimating AEZ yield differentials in the GTAP-AEZ data base. (Recall that the FAO data base used to obtain these differential yield estimates was rather dated and furthermore only included developing countries.)

Of course, once we divide these land rents by total hectares in each AEZ, the picture is somewhat different. Now the biggest discrepancies arise in those AEZs with very low levels of overall land rents. To see this, consider the Mendelsohn *et al.* (2005) per hectare land rents reported in columns H and I of Table 17. According to these authors, the highest average crop land rental rates arise in AEZs 10 and 11, amounting to nearly \$200/ha. The lowest average rental rates arise in the boreal zone – AEZs 13 – 16, where rents range from \$30 - \$37/ha. Mendelsohn et al.'s pasture land rents range from \$4/ha. in the boreal zone to more than \$47/ha. in AEZ's 10 and 11.

Now compare these figures from Mendelsohn *et al.* (2005) to those reported in columns E and F derived from the GTAP-AEZ data base. Here, the highest crop land rents arise in the boreal zone! This is clearly absurd, as are the rental rates per hectare in this zone. However, before the reader gives up on this data base altogether, it should be noted that these AEZs are relatively unimportant in the overall economic picture. When combined, they account for just about half a percent of total crop land rents and about one percent of pasture land rents. So this gross error is confined to a relatively small part of the data base.

To understand why this problem might arise, consider how the GTAP-AEZ data base is constructed. We start with information on land use, by AEZ. This is combined with estimates of total land rents, based on the average share of land rents in crop production for the entire United States, and relative yields from the FAO data, in order to infer total land rents by hectare. Not surprisingly, there is a fair amount of high value vegetable production undertaken in the boreal zone (primarily Alaska) – presumably under greenhouses. This leads to a relatively high apparent land rent. Yet the total number of hectares is small. So the implied per hectare land rent is very high. However, this is not really a proper estimate of land rents, as the greenhouse-based production requires considerable infrastructure in order for the land to be productive. Indeed, without these improvements, land productivity would be very low. So these gross errors for the boreal zone are largely a function of our inability to separate returns to capital and land in greenhouse production.

In order to overcome this problem, we need a more direct approach to the estimation of land rents in agriculture. A natural approach would be to build on the work of Mendelsohn *et al.* (2005), applying their estimated land rents by AEZ to the total hectares in the land use data base. However, to date, we have only been able to obtain these data for the US. We understand that Mendelsohn *et al.* (2005) are working on several other countries, and this will greatly facilitate more extensive validation of the data base. However, even having data for four or five countries is insufficient for building a global data base. We are, however, optimistic that improvements in our approach to estimating productivity by AEZ will improve the precision of our overall estimates of the distribution of land rents across AEZs. This will be discussed in greater detail below.

While we do not have independent data with which to validate the GTAP-AEZ land rental estimates for countries other than the US, it is still instructive to examine the pattern of land rents across these countries. The total land rent, land area and average land rents for each of the 87 GTAP-AEZ regions are reported in Table 17, in descending order (highest to lowest per hectare land rents). The results are broadly as expected. The highest land rents arise in the densely populated, high income countries of East Asia: Korea, Japan and Hong Kong, followed by the smaller, high income countries of Europe (e.g., Switzerland). The lowest land rents per hectare arise in Sub-Saharan Africa – amounting to scarcely more than $1/ha. in Botswana, which is sparsely populated and dominated by the Kalahari Desert – an arid area, much of which is extensively grazed by livestock. Australia – a continent dominated by desert and extensive grazing as well, is not far behind at $6/ha. average land rent.

As a simple validity check on this set of average national land rents, we attempt to explain the cross-section variation via a simple regression model. The independent variables are as follows: income (measured by GDP/capita), population density (population/ha.), intensity of agricultural subsidies (Producer Support Estimate rate[16] – for OECD and some European countries only), share of land in grazing, and share of land in each of the 18 AEZs. As we only have PSE rates for 27 OECD/European countries, we put PSE rate variable in a separate regression model. Just this one variable has remarkable explanatory power with respect to variation in per hectare land rents across OECD countries as shown in the results reported in Table 18. The adjusted R-squared is 0.50 and the T-statistic is 5.5. Table 19 reports the regression results encompassing all regions in the data base. Here, we see that higher population density is the most significant variable contributing to higher average per hectare land rent. The other variables are not significant – perhaps due to multi-collinearity of the AEZ shares (a temperate region tends to have high shares in all the temperate AEZs). However, the combined explanatory power of these variables is still quite high – with an adjusted R-squared of 0.59. Overall, it appears that much of the variation in land rents across countries can be explained by just a few simple economic and physical variables. This is reassuring. However, given the ambitious nature of this exercise, there are surely a number of countries for which these estimates do not make sense – either due to peculiarities in their agricultural structure, or due to mis-estimation of the fundamental inputs to this exercise (e.g., the size of the crops sectors in the residual regions for which no national input-output data are available). We hope that the frequency of such occurrences will diminish as we improve the underlying data bases and replace key assumptions with observed data.

[16] PSE rate data of 2001 are derived from "Agricultural Policies in OECD Countries: Monitoring and Evaluation", 2003 edition, OECD.

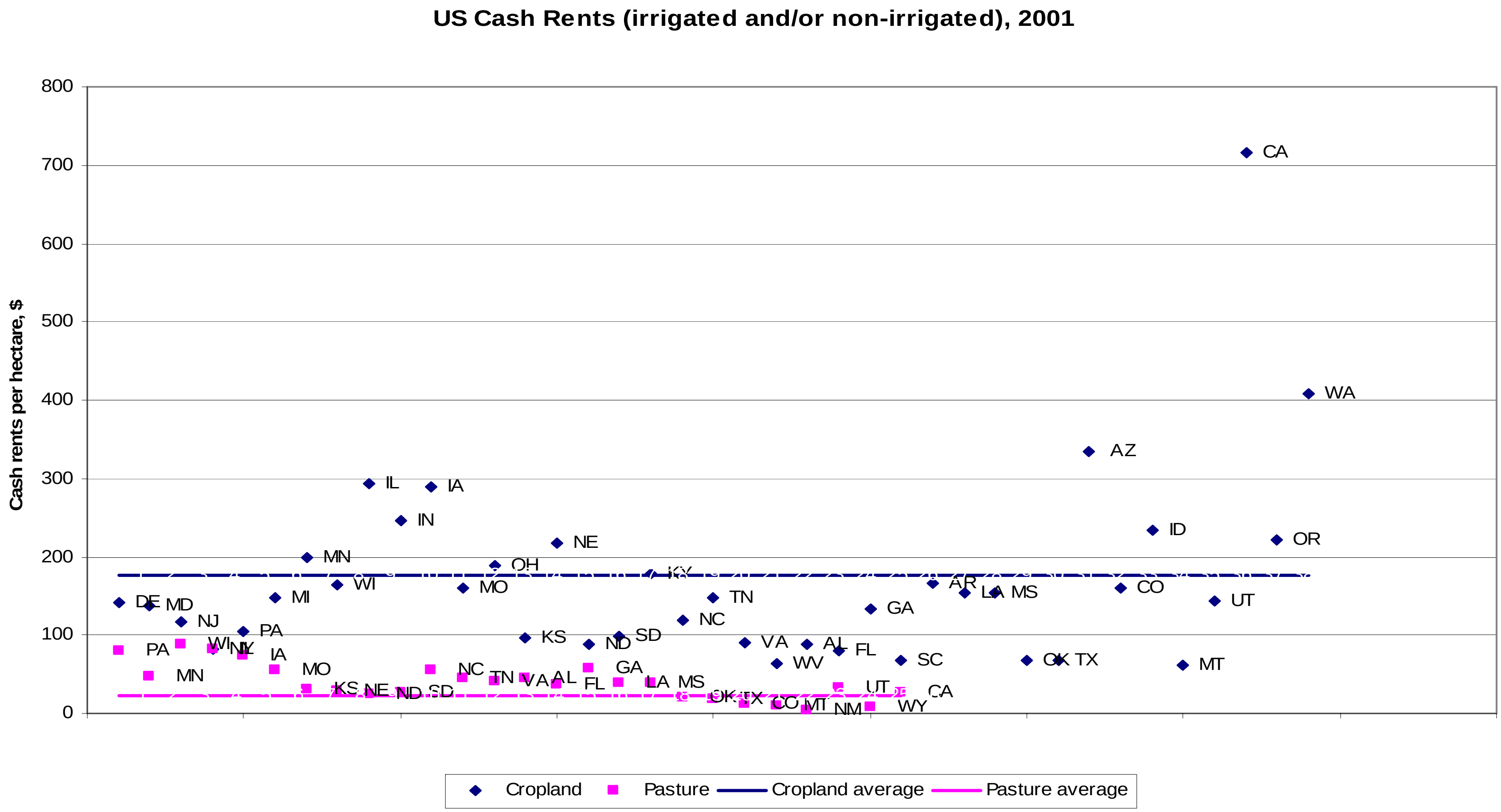

Figure 18. USDA estimated cash rents for cropland and pasture, by state

Note: AZ, WA and CA: only irrigated cropland.

Source: Agricultural Cash Rents, 2001. http://usda.mannlib.cornell.edu/reports/nassr/other/plrbb/rent0701.pdf

Table 16. U.S. per hectare land rent: GTAP v.s. Mendelsohn et al.

	GTAP land rent (VFM), unit: million 2001 US$		SAGE land cover, unit: 1000 ha.		Derived per ha. Land rent, unit: 2001 US$/ha.		Pasture/Cropland per ha. land rent ratio	Mendelsohn, unit: 2001 US$/ha.		Pasture/Cropland per ha. land rent ratio	Mendelsohn, land rent, unit: million 2001 US$	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
							= (F)/(E)			= (I)/(H)	= (H)*(C)	= (I)*(D)
	Cropland	Pastureland	Cropland	Pastureland	Cropland	Pastureland		Cropland	Pastureland		Cropland	Pastureland
AEZ1												
AEZ2												
AEZ3												
AEZ4												
AEZ5												
AEZ6												
AEZ7	589.70	874.06	28104.32	166232.30	20.98	5.26	0.25	67.76	7.79	0.11	1904.42	1294.77
AEZ8	3587.08	1456.16	27864.80	41457.14	128.73	35.12	0.27	95.43	11.06	0.12	2659.24	458.59
AEZ9	2564.66	340.25	14996.95	6434.79	171.01	52.88	0.31	132.41	17.38	0.13	1985.68	111.83
AEZ10	15558.51	1507.08	68842.63	19768.97	226.00	76.23	0.34	196.46	41.82	0.21	13524.82	826.81
AEZ11	6237.91	576.95	43875.98	10097.77	142.17	57.14	0.40	191.16	46.50	0.24	8387.12	469.59
AEZ12	7233.18	247.86	33195.84	4484.70	217.89	55.27	0.25	112.20	37.13	0.33	3724.59	166.53
AEZ13	36.62	26.67	1757.56	5406.68	20.84	4.93	0.24	29.99	4.06	0.14	52.71	21.95
AEZ14	116.05	28.42	591.40	847.03	196.24	33.55	0.17	32.11	3.94	0.12	18.99	3.33
AEZ15	26.23	1.11	53.20	22.33	492.95	49.53	0.10	36.89	5.16	0.14	1.96	0.12
AEZ16	10.78	0.59	16.71	9.27	645.20	63.78	0.10	32.11	12.35	0.38	0.54	0.11
AEZ17												
AEZ18												
All land	35960.73	5059.15	219299.41	254760.99	163.98	19.86	0.12	147.11	13.16	0.09	32260.08	3353.64

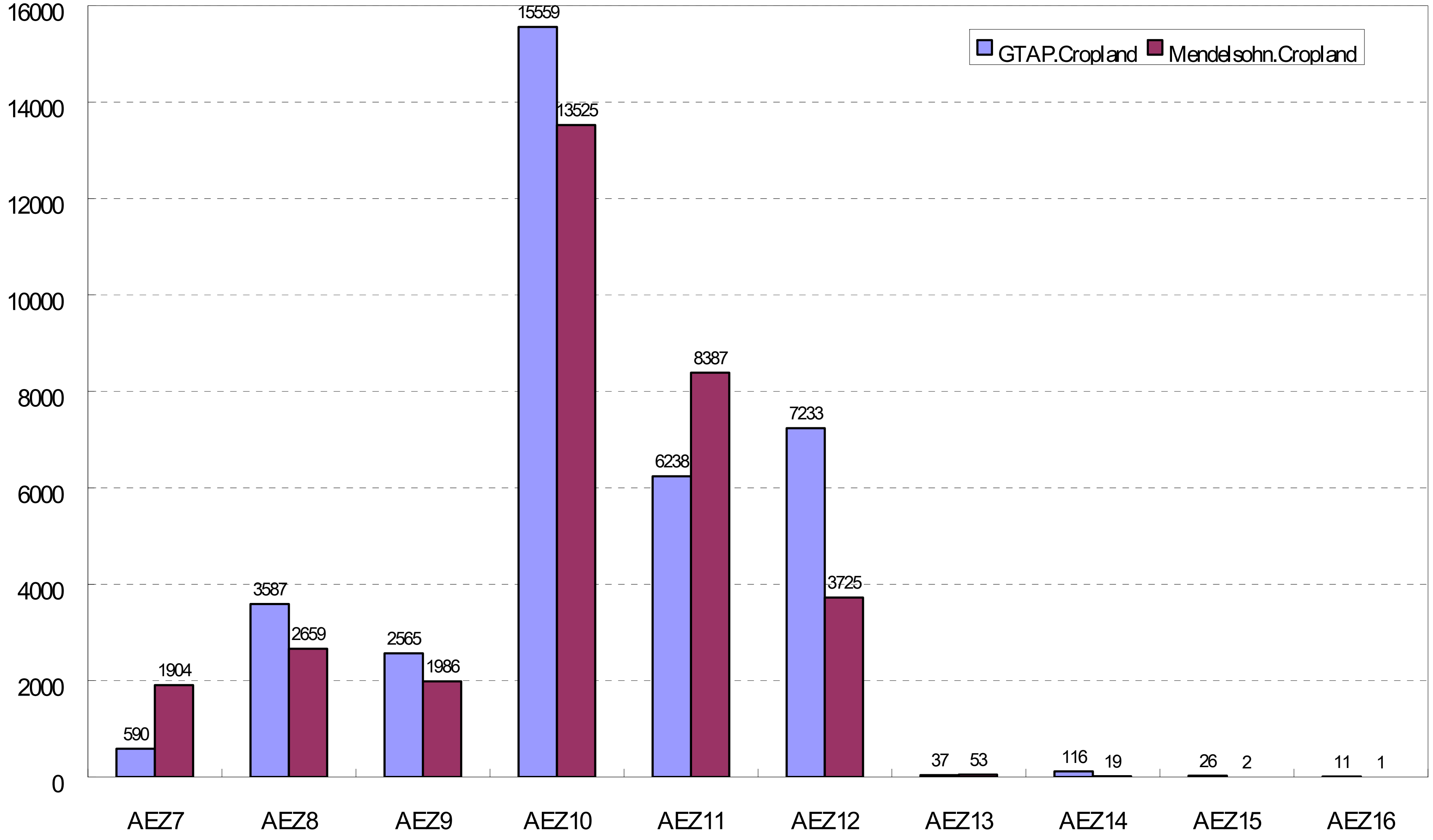

Figure 19. U.S. cropland rents, 2001 US$ million: GTAP v.s. Mendelsohn et al.

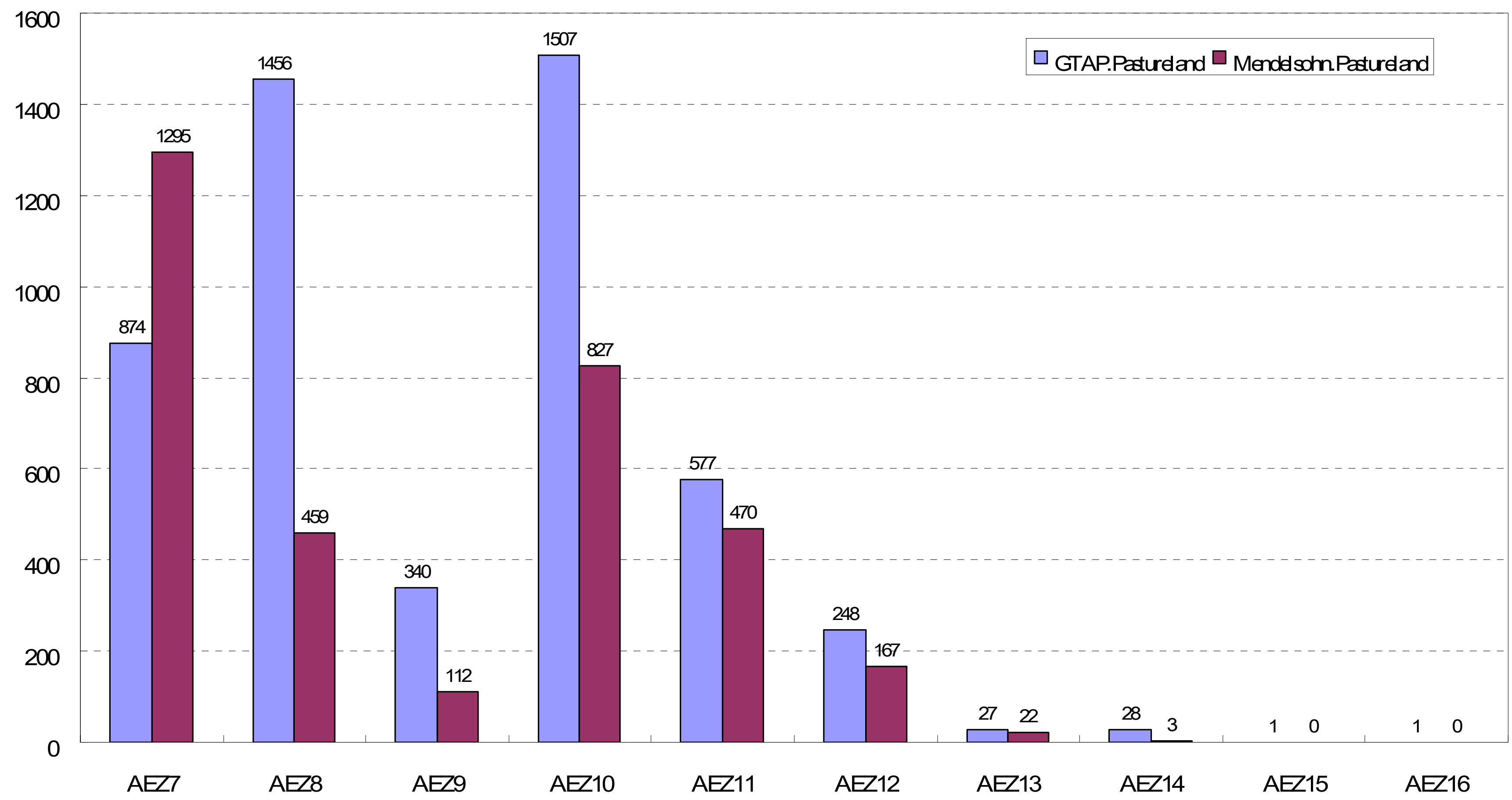

Figure 20. U.S. pasture land rents, 2001 US$ million: GTAP v.s. Mendelsohn et al.

Table 17. GTAP agriculture per hectare land rent, unit: 2001 US$/ha.

GTAP regions	GTAP VFM unit: million 2001 USD	SAGE Land cover unit: 1000ha.	Average per ha. land rent
7 Korean, republic of	8727.24	2515.08	3469.96
5 Hon Kong	402.77	220.87	1823.60
52 Switzerland	1566.46	1219.04	1285.00
6 Japan	8384.37	7616.70	1100.79
48 Netherlands	1094.72	1768.47	619.02
42 Germany	7396.19	14641.29	505.16
40 Finland	792.36	1769.18	447.87
46 Italy	5597.91	13007.80	430.35
37 Austria	1000.76	2526.40	396.12
13 Singapore	85.32	217.21	392.78
19 Sri Lanka	1661.36	4239.57	391.87
51 Sweden	646.81	1862.95	347.20
53 Rest of EFTA	632.86	2058.37	307.46
41 France	7395.18	25998.61	284.45
35 Rest of Free Trade Area of the Americas	1209.28	4312.38	280.42
39 Denmark	935.56	3665.28	255.25
12 Philippines	4487.29	17641.20	254.36
17 Bangladesh	2662.20	11756.34	226.45
43 United Kingdom	3397.84	15795.49	215.11
57 Croatia	533.27	2499.22	213.38
18 India	45882.52	226113.69	202.92
44 Greece	1154.00	6117.42	188.64
14 Thailand	4812.68	25581.40	188.13
59 Czech Republic	796.70	4311.75	184.77
56 Bulgaria	1243.38	7539.03	164.93
10 Indonesia	8343.95	58131.04	143.54
63 Romania	1943.69	14164.36	137.22
49 Portugal	639.68	5008.84	127.71
45 Ireland	691.00	5447.46	126.85
62 Poland	2940.05	25290.60	116.25
65 Slovenia	87.64	757.42	115.71
15 Viet Nam	1749.19	15453.50	113.19

...continued

Table 17 (continued)

GTAP regions	GTAP VFM unit: million 2001 USD	SAGE Land cover unit: 1000ha.	Average per ha. land rent
50 Spain	3386.45	30052.01	112.69
60 Hungary	753.85	6706.12	112.41
36 Rest of the Caribbean	813.82	7312.26	111.30
75 Rest of North Africa	2914.64	26714.68	109.10
34 Central America	2191.61	20323.64	107.84
27 Venezuela	2333.34	23555.98	99.05
64 Slovakia	202.04	2185.15	92.46
16 Rest of Southeast Asia	2587.31	29481.13	87.76
22 U.S.A.	41019.88	474060.41	86.53
25 Colombia	2359.21	28362.74	83.18
4 China	46744.18	571172.97	81.84
11 Malaysia	1021.59	12511.83	81.65
20 Rest of South Asia	8862.91	112527.95	78.76
23 Mexico	8570.87	111875.31	76.61
55 Albania	134.14	1764.63	76.01
38 Belgium	144.73	2255.82	64.16
31 Chile	1490.83	23517.14	63.39
54 Rest of Europe	497.84	8194.44	60.75
21 Canada	3648.39	70851.79	51.49
26 Peru	1356.20	29244.66	46.37
74 Tunisia	213.46	4906.43	43.51
73 Morocco	629.78	14749.47	42.70
66 Estonia	71.50	1880.34	38.02
32 Uruguay	476.65	13893.66	34.31
71 Turkey	1724.26	56340.18	30.60
86 Uganda	329.31	11617.70	28.35
2 New Zealand	443.47	17214.21	25.76
28 Rest of Andean Pact	978.93	42690.42	22.93
29 Argentina	3445.84	155308.95	22.19
68 Lithuania	121.89	5601.60	21.76
72 Rest of Middle East	4190.93	194967.42	21.50
3 Rest of Oceania	158.73	8107.85	19.58
33 Rest of South America	349.26	20282.88	17.22
67 Latvia	46.08	2871.48	16.05

...continued

Table 17 (continued)

GTAP regions	GTAP VFM unit: million 2001 USD	SAGE Land cover unit: 1000ha.	Average per ha. land rent
9 Rest of East Asia	1943.24	124609.77	15.59
70 Rest of Former Soviet Union	5654.56	383581.80	14.74
30 Brazil	3442.64	245458.43	14.03
69 Russia	3638.02	300957.28	12.09
79 Malawi	67.26	5839.10	11.52
81 Tanzania	464.91	43306.47	10.74
77 South Africa	590.25	82239.61	7.18
1 Australia	3060.66	452506.93	6.76
83 Zimbabwe	173.77	25749.54	6.75
87 Rest of Sub-Saharan Africa	2841.21	473251.20	6.00
85 Madagascar	155.33	33593.74	4.62
84 Rest of Southern African Development Community	235.57	84103.17	2.80
80 Mozambique	104.25	42741.14	2.44
82 Zambia	87.91	43670.49	2.01
78 Rest of South African Customs Union	61.42	53253.77	1.15
76 Botswana	40.12	37302.88	1.08
8 Taiwan	1770.05	N/A	N/A
24 Rest of North America	6.60	N/A	N/A
47 Luxembourg	34.92	N/A	N/A
58 Cyprus	24.35	N/A	N/A
61 Malta	10.66	N/A	N/A
Total	297515.83	5104516.50	

Table 18. Summary output of regression: average per ha. Land rent v.s. %PSE

Regression Statistics	
Multiple R	0.734
R^2	0.538
Adjusted R^2	0.500
Standard Error	542.397
Observations	27

ANOVA

	df	SS	MS	F	Significance F
Regression	1	8919760.734	8919760.734	30.319	0.000
Residual	26	7649056.565	294194.483		
Total	27	16568817.298			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
%PSE	16.810	3.053	5.506	0.000	10.535	23.086	10.535	23.086

Table 19. Summary output of regression: average per ha. Land rent v.s. economic and physical variables

Regression Statistics	
Multiple R	0.824
R^2	0.679
Adjusted R^2	0.591
Standard Error	289.221
Observations	82

ANOVA

	df	SS	MS	F	Significance F
Regression	16	11666037.747	729127.359	9.298	0.000
Residual	66	5520833.087	83648.986		
Total	82	17186870.834			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-289.880	1012.790	-0.286	0.776	-2311.981	1732.220	-2311.981	1732.220
GDP/POP	-0.004	0.004	-0.781	0.437	-0.012	0.005	-0.012	0.005
Pop. Dens. (p/ha)	82.083	8.612	9.531	0.000	64.889	99.278	64.889	99.278
pasture/tot	470.140	322.779	1.457	0.150	-174.309	1114.588	-174.309	1114.588
2 AEZ1_2	258.033	1129.114	0.229	0.820	-1996.316	2512.381	-1996.316	2512.381
3 AEZ3	-382.758	1168.463	-0.328	0.744	-2715.670	1950.153	-2715.670	1950.153
4 AEZ4	373.910	1071.907	0.349	0.728	-1766.221	2514.041	-1766.221	2514.041
5 AEZ5	-103.638	1043.337	-0.099	0.921	-2186.729	1979.452	-2186.729	1979.452
6 AEZ6	103.805	1022.880	0.101	0.919	-1938.442	2146.051	-1938.442	2146.051
8 AEZ7_8	13.621	1026.233	0.013	0.989	-2035.320	2062.562	-2035.320	2062.562
9 AEZ9	164.372	1030.236	0.160	0.874	-1892.561	2221.305	-1892.561	2221.305
10 AEZ10	329.943	1032.872	0.319	0.750	-1732.252	2392.138	-1732.252	2392.138
11 AEZ11	495.887	1044.616	0.475	0.637	-1589.757	2581.531	-1589.757	2581.531
12 AEZ12	-120.675	1084.263	-0.111	0.912	-2285.476	2044.127	-2285.476	2044.127
14 AEZ13_14	-59.063	1109.736	-0.053	0.958	-2274.722	2156.596	-2274.722	2156.596
15 AEZ15	959.109	1107.731	0.866	0.390	-1252.548	3170.766	-1252.548	3170.766
18 AEZ17_18	0.000	0.000	65535.000	#NUM!	0.000	0.000	0.000	0.000

4. Concluding remarks and future research directions

This paper described how the GTAP land use database is constructed with source data developed at the Center for Sustainability and Global Environment (SAGE), University of Wisconsin-Madison, for the crop and livestock sectors; and The Ohio State University, for the forest sector and forest carbon stock. For the GTAP land use database, we draw inspiration from Darwin (1999) and follow the FAO fashion of agro-ecological zoning (FAO, 2000; Fischer *et al*, 2002) to identify land located in 18 agro-ecological zones (AEZs)—six AEZs supporting various lengths of growing days each located in three different climatic zones.

As with other pioneering data base efforts, this one suffers from many flaws which we hope to address over time, as the data base matures. Fortunately, the stage is set for remedying one of the greatest of these flaws – the absence of AEZ-specific productivity estimates. The newly available AgroMAPS data set (FAO/IFPRI/SAGE/CIAT, 2003) capitalizes on sub-national production data and offers, for the first time, a global data set with spatially explicit production information. By combining this with the SAGE land use data set, we will be able to replace a key set of assumptions (that of relative productivity differences across AEZs) with real data. This will be a great advance and should help refine our estimates of the distribution of land rents across AEZs and activities.

When combined with the data base on GHG emissions and sequestration (Lee et al., forthcoming), which correlates emissions with GTAP economic activity, the land use and emissions data bases will permit economists interested in Integrated Assessment (IA) of climate change to better assess the role of land use change in GHG mitigation strategies.

References

Alexandratos, N. (1995). *World Agriculture towards 2010*, 488 pp., Food and Agric. Organization of the United Nations, Rome, Italy.

Bonan, G.B. (1999). Frost followed the plow: impacts of deforestation on the climate of the United States, *Ecological Applications*, *9* (4), 1305-1315.

Bonan, G.B. (2001). Observational evidence for reduction of daily maximum temperature by croplands in the Midwest United States, *Journal of Climate*, *14* (11), 2430-2442.

Brovkin, V., A. Ganopolski, M. Claussen, C. Kubatzki, and V. Petoukhov. (1999). Modelling climate response to historical land cover change, *Global Ecology and Biogeography*, *8* (6), 509-517.

Darwin, R. F. (1999). A FARMer's View of the Ricardian Approach to Measuring Effects of Climatic Change on Agriculture, *Climatic Change*, *41* (3-4), 371-411.

Dimarana, B. V., and McDougall, R. A., Edt. (2002). *Global Trade, Assistance, and Production: the GTAP 5 Database.* Center for Global Trade Analysis, Purdue University, West Lafayette, IN 47907, U.S.A.

Dimaranan, B. V. and McDougall, R. A., Edt. (2005, forthcoming). *Global Trade, Assistance, and Production: The GTAP 6 Data Base*, Center for Global Trade Analysis, Purdue University, West Lafayette, IN47907, U.S.A.

FAO. (2000). Land Cover Classification System: Classification Concepts and User Manual (with CD-Rom). Rome: Food and Agriculture Organization (FAO) of the United Nations.

FAO. (2003). State of the World's Forests 2003. Food and Agricultural Organization (FAO) of the United Nations (UN), Rome, Italy. (http://www.fao.org/DOCREP/005/Y7581E/Y7581E00.HTM)

FAO. (2004). FAOSTAT data, Food and Agriculture Organization of the United Nations, (available at http://apps.fao.org).

FAO/IFPRI/SAGE/CIAT (2003) AgroMAPS: A Global Spatial Database of Agricultural Land-Use Statistics Aggregated by Sub-national Administrative Districts, Food and Agriculture Organization (FAO), United Nations; International Food Policy Research Institute (IFPRI); Center for Sustainability and the Global Environment (SAGE), University of Wisconsin-Madison; International Center for Tropical Agriculture (CIAT). Website: http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp.

FAO and IIASA. (2000). Global Agro-Ecological Zones - 2000. Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy, and International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Fischer, G., van Velthuizen, H., Shah, M., and Nachtergaele, F. (2002). Global Agro-Ecological Assessment for Agriculture in the 21st Century: Methodology and Results (Research Report RR-02-02). Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA) and Food and Agriculture Organization (FAO) of the United Nations (UN).

Foley, J.A., M.H. Costa, C. Delire, N. Ramankutty, and P. Snyder. (2003). Green Surprise? How terrestrial ecosystems could affect earth's climate, *Frontiers in Ecology and the Environment*, *1* (1), 38-44.

GTAP Website. (2002). Workshop: Incorporation of Land Use and Greenhouse Gas Emissions into the GTAP Database. Center for Global Trade Analysis (GTAP), Purdue University, West Lafayette, IN 47907, U.S.A. Available: http://www.gtap.agecon.purdue.edu/databases/projects/Land_Use_GHG/MIT_Workshop/default.asp.

Hertel, T. W. (eds.). (1997). *Global Trade Analysis: Modeling and Applications*. Cambridge University Press.

Haxeltine, A. and I. C. Prentice. (1996). "BIOME3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability, and Competition Among Plant Functional Types." *Global Biogeochemical Cycles* 10(4): 693-709.

IPCC. (1996). *Climate Change 1995: The Science of Climate Change*: Intergovernmental Panel on Climate Change (IPCC) Cambridge University Press, Cambridge, United Kingdom.

Lee, H.-L., Hertel, T. W., Sohngen, B., Ramankutty, N., and U.S. Environmental Protection Agency. (2005, forthcoming). GTAP Greenhouse Gases Emissions Data Base. Center for Global Trade Analysis, Purdue University, West Lafayette, IN47907, U.S.A.

Leff, B., N. Ramankutty, and J. Foley, Geographic distribution of major crops across the world, *Global Biogeochemical Cycles*, *18,* GB1009, doi:10.1029/2003GB002108, 2004.

Loveland, T.R., B.C. Reed, J.F. Brown, D.O. Ohlen, J. Zhu, L. Yang, and J.W. Merchant. (2000). Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1-km AVHRR Data, *International Journal of Remote Sensing*, *21* (no. 6/7), 1303-1330.

McGuire, A.D., S. Sitch, J.S. Clein, R. Dargaville, G. Esser, J. Foley, M. Heimann, F. Joos, J. Kaplan, D.W. Kicklighter, R.A. Meier, J.M. Melillo, B.M. III, I.C. Prentice, N. Ramankutty, T. Reichenau, A. Schloss, H. Tian, L.J. Williams, and U. Wittenberg. (2001). Carbon balance of the terrestrial biosphere in the twentieth century: Analyses of CO2, climate and land-use effects with four process-based ecosystem models., *Global Biogeochemical Cycles*, *15*, 183-206.

Mendelsohn, R., P. Kurukulasuriya, A. Basist, F. Kogan, and C. Williams. (2005). Climate Analysis with Satellite versus Weather Station Data. Unpublished working paper.

Myhre, G., and A. Myhre. (2003). Uncertainties in radiative forcing due to surface albedo changes caused by land-use changes, *Journal of Climate*, *16* (10), 1511-1524.

National Geographic Maps. (2002). A World Transformed, Supplement to National Geographic September 2002, National Geographic Society, Washington, D.C.

Ramankutty, N., and J.A. Foley. (1998). Characterizing Patterns of Global Land Use: An Analysis of Global Croplands Data, *Global Biogeochemical Cycles*, 12, 667-685.

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

Ramankutty, N., J.A. Foley, J. Norman, and K. McSweeney. (2002a). The global distribution of cultivable lands: current patterns and sensitivity to possible climate change, *Global Ecology and Biogeography*, *11* (5), 377-392.

Ramankutty, N., J.A. Foley, and N.J. Olejniczak. (2002b). People on the land: Changes in Population and Global Croplands During the 20th Century, *Ambio*, *31 (3)*, 251-257.

Ramankutty, N., Hertel, T. W., Lee, H.-L. and Rose, S. (2005). Global Land Use and Land Cover Data for Integrated Assessment Modeling. Book chapter for the Snowmass Conference, Snowmass, CO, July 2004. Paper available at the GTAP website: http://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1635.

Sedjo, R.A. and K.S. Lyon. (1990). *The Long Term Adequacy of the World Timber Supply*. Washington, D.C.: Resources For the Future.

Small, C. (2003). Global Population Distribution and Urban Land Use in Geophysical Parameter Space. *Earth Interactions*, **8** (Paper 8), doi: 10.1175/1087-3562 (2004) 008 <0001:GPDAUL> 2.0.CO;2.

Sohngen, B., R. Mendelsohn, and R. Sedjo. (1999). "Forest Management, Conservation, and Global Timber Markets." *American Journal of Agricultural Economics*. 81: 1-13.

Sohngen, B., and Tennity, C. (2004). Country Specific Global Forest Data Set V.1. *memo.* Department of Agricultural, Environmental, and Development Economics, Ohio State University, Columbus, OH 43210, U.S.A.

United Nations. (1991). Provisional Central Product Classification, Statistical Paper Series M No. 77, Sales No. E.91.XVII.7. New York: United Nations Publishing Division.

Yang, D.W., S. Kanae, T. Oki, T. Koike, and K. Musiake. (2003). Global potential soil erosion with reference to land use and climate changes, *Hydrological Processes*, *17* (14), 2913-2928.

Appendix A. Sectors and region mappings in the GTAP version 6 data base

Table A1 shows the list of sectors in the GTAP version 6 (Dimaranan and McDougall, 2005 forthcoming) data base and the description of sector activities. Table A2 shows the list of the 87 regions covered in the GTAP version 6 data base and the mapping of the 226 world countries/territories to the 87 countries/regions.

Table A1. Sectors in the GTAP version 6 data base and activity description

No.	Code	Description
1	pdr	Rice, not husked Husked rice
2	wht	Wheat and meslin
3	gro	Maize (corn) Barley Rye, oats Other cereals
4	v_f	Vegetables Fruit and nuts
5	osd	Oil seeds and oleaginous fruit
6	c_b	Plants used for sugar manufacturing
7	pfb	Raw vegetable materials used in textiles
8	ocr	Live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds Beverage and spice crops Unmanufactured tobacco Cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets Plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes Sugar beet seed and seeds of forage plants Other raw vegetable materials
9	ctl	Bovine cattle, sheep and goats, horses, asses, mules, and hinnies, live Bovine semen
10	oap	Swine, poultry and other animals, live Eggs, in shell, fresh, preserved or cooked Natural honey Snails, live, fresh, chilled, frozen, dried, salted or in brine, except sea snails; frogs' legs, fresh, chilled or frozen Edible products of animal origin n.e.c. Hides, skins and furskins, raw Insect waxes and spermaceti, whether or not refined or coloured

...to be continued

Table A1 (continued)

No.	Code	Description
11	rmk	Raw milk
12	wol	Raw animal materials used in textile
13	for	Forestry, logging and related service activities
14	fsh	Hunting, trapping and game propagation including related service activities Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing
15	col	Mining and agglomeration of hard coal Mining and agglomeration of lignite
16	oil	Extraction of crude petroleum and natural gas (part) Service activities incidental to oil and gas extraction excluding surveying (part) Mining and agglomeration of peat
17	gas	Extraction of crude petroleum and natural gas (part) Service activities incidental to oil and gas extraction excluding surveying (part)
18	omn	Mining of uranium and thorium ores Mining of metal ores Other mining and quarrying
19	cmt	Meat of bovine animals, fresh or chilled Meat of bovine animals, frozen Meat of sheep, fresh or chilled Meat of sheep, frozen Meat of goats, fresh, chilled or frozen Meat of horses, asses, mules or hinnies, fresh, chilled or frozen Edible offal of bovine animals, swine, sheep, goats, horses, asses, mules or hinnies, fresh, chilled or frozen Fats of bovine animals, sheep, goats, pigs and poultry, raw or rendered; wool grease
20	omt	Meat of swine, fresh or chilled Meat of swine, frozen Meat and edible offal, fresh, chilled or frozen, n.e.c. Preserves and preparations of meat, meat offal or blood Flours, meals and pellets of meat or meat offal, inedible; greaves Animal oils and fats, crude and refined, except fats of bovine animals, sheep, goats, pigs and poultry
21	vol	Soya-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed rape, colza and mustard oil, crude Palm, coconut, palm kernel, babassu and linseed oil, crude Soya-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and mustard oil and their fractions, refined but not chemically modified; other oils obtained solely from olives and sesame oil, and their fractions, whether or not refined, but not chemically modified Maize (corn) oil and its fractions, not chemically modified Palm, coconut, palm kernel, babassu and linseed oil and their fractions, refined but not chemically modified; castor, tung and jojoba oil and fixed vegetable fats and oils (except maize oil) and their fractions n.e.c., whether or not refined, but not chemically modified Margarine and similar preparations Animal or vegetable fats and oils and their fractions, partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised, whether or not refined, but not further prepared Cotton linters Oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; vegetable waxes, except triglycerides; degras; residues resulting from the treatment of fatty substances or animal or vegetable waxes

...to be continued

Table A1 (continued)

No.	Code	Description
22	mil	Dairy products
23	pcr	Rice, semi- or wholly milled
24	sgr	Sugar
25	ofd	Prepared and preserved fish Prepared and preserved vegetables Fruit juices and vegetable juices Prepared and preserved fruit and nuts Wheat or meslin flour Cereal flours other than of wheat or meslin Groats, meal and pellets of wheat Cereal groats, meal and pellets n.e.c. Other cereal grain products (including corn flakes) Other vegetable flours and meals Mixes and doughs for the preparation of bakers' wares Starches and starch products; sugars and sugar syrups n.e.c. Preparations used in animal feeding Bakery products Cocoa, chocolate and sugar confectionery Macaroni, noodles, couscous and similar farinaceous products Food products n.e.c.
26	b_t	Beverages Tobacco products
27	tex	Manufacture of textiles Manufacture of man-made fibres
28	wap	Manufacture of wearing apparel; dressing and dyeing of fur
29	lea	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
30	lum	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
31	ppp	Manufacture of paper and paper products Publishing of books, brochures, musical books and other publications Publishing of newspapers, journals and periodicals Publishing of recorded media Other publishing (photos, engravings, postcards, timetables, forms, posters, art reproductions, etc.) Printing and service activities related to printing Reproduction of recorded media
32	p_c	Manufacture of coke oven products Manufacture of refined petroleum products Processing of nuclear fuel
33	crp	Manufacture of basic chemicals Manufacture of other chemical products Manufacture of rubber and plastics products
34	nmm	Manufacture of other non-metallic mineral products
35	i_s	Manufacture of basic iron and steel Casting of iron and steel
36	nfm	Manufacture of basic precious and non-ferrous metals Casting of non-ferrous metals
37	fmp	Manufacture of fabricated metal products, except machinery and equipment

...to be continued

Table A1 (continued)

No.	Code	Description
38	mvh	Manufacture of motor vehicles, trailers and semi-trailers
39	otn	Manufacture of other transport equipment
40	ele	Manufacture of office, accounting and computing machinery Manufacture of radio, television and communication equipment and apparatus
41	ome	Manufacture of machinery and equipment n.e.c. Manufacture of electrical machinery and apparatus n.e.c. Manufacture of medical, precision and optical instruments, watches and clocks
42	omf	Manufacturing n.e.c. Recycling
43	ely	Production, collection and distribution of electricity
44	gdt	Manufacture of gas; distribution of gaseous fuels through mains Steam and hot water supply
45	wtr	Collection, purification and distribution of water
46	cns	Construction
47	trd	Sales, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel Wholesale trade and commission trade, except of motor vehicles and motorcycles Non-specialized retail trade in stores Retail sale of food, beverages and tobacco in specialized stores Other retail trade of new goods in specialized stores Retail sale of second-hand goods in stores Retail trade not in stores Repair of personal and household goods Hotels and restaurants
48	otp	Land transport; transport via pipelines Supporting and auxiliary transport activities; activities of travel agencies
49	wtp	Water transport
50	atp	Air transport
51	cmn	Post and telecommunications
52	ofi	Financial intermediation, except insurance and pension funding Activities auxiliary to financial intermediation
53	isr	Insurance and pension funding, except compulsory social security
54	obs	Real estate activities Renting of transport equipment Renting of other machinery and equipment Renting of personal and household goods n.e.c. Computer and related activities Research and development Other business activities
55	ros	Recreational, cultural and sporting activities Other service activities Private households with employed persons
56	osg	Public administration and defence; compulsory social security Education Health and social work Sewage and refuse disposal, sanitation and similar activities Activities of membership organizations n.e.c. Extra-territorial organizations and bodies
57	dwe	Dwellings

Note: n.a. = not available; n.e.c. = not elsewhere classified.
Source of table: Chapter 3 in Dimaranan and McDougall (2005 forthcoming).

Table A2. The 87 countries/regions in the GTAP 6 data base and mapping to world counttries/territories

No.	Code	Name	Member Regions (226)	Code
1	AUS	Australia	Australia	AUS
2	NZL	New Zealand	New Zealand	NZL
3	XOC	Rest of Oceania	American Samoa	ASM
			Cook Islands	COK
			Fiji	FJI
			French Polynesia	PYF
			Guam	GUM
			Kiribati	KIR
			Marshall Islands	MHL
			Micronesia, Federated States of	FSM
			Nauru	NRU
			New Caledonia	NCL
			Norfolk Island	NFK
			Northern Mariana Islands	MNP
			Niue	NIU
			Palau	PLW
			Papua New Guinea	PNG
			Samoa	WSM
			Solomon Islands	SLB
			Tokelau	TKL
			Tonga	TON
			Tuvalu	TUV
			Vanuatu	VUT
			Wallis and Futuna	WLF
4	CHN	China	China	CHN
5	HKG	Hong Kong	Hong Kong	HKG
6	JPN	Japan	Japan	JPN
7	KOR	Korea	Korea, Republic of	KOR
8	TWN	Taiwan	Taiwan	TWN
9	XEA	Rest of East Asia	Macau	MAC
			Mongolia	MNG
			Korea, Democratic People's Republic of	PRK
10	IDN	Indonesia	Indonesia	IDN
11	MYS	Malaysia	Malaysia	MYS
12	PHL	Philippines	Philippines	PHL
13	SGP	Singapore	Singapore	SGP
14	THA	Thailand	Thailand	THA
15	VNM	Viet Nam	Viet Nam	VNM

...to be continued

Table A2 (continued)

No.	Code	Name	Member Regions (226)	Code
16	XSE	Rest of Southeast Asia	Brunei Darussalam	BRN
			Cambodia	KHM
			Lao People's Democratic Republic	LAO
			Myanmar	MMR
			Timor Leste	TLS
17	BGD	Bangladesh	Bangladesh	BGD
18	IND	India	India	IND
19	LKA	Sri Lanka	Sri Lanka	LKA
20	XSA	Rest of South Asia	Afghanistan	AFG
			Bhutan	BTN
			Maldives	MDV
			Nepal	NPL
			Pakistan	PAK
21	CAN	Canada	Canada	CAN
22	USA	United States of America	United States of America	USA
23	MEX	Mexico	Mexico	MEX
24	XNA	Rest of North America	Bermuda	BMU
			Greenland	GRL
			Saint Pierre and Miquelon	SPM
25	COL	Colombia	Colombia	COL
26	PER	Peru	Peru	PER
27	VEN	Venezuela	Venezuela	VEN
28	XAP	Rest of Andean Pact	Bolivia	BOL
			Ecuador	ECU
29	ARG	Argentina	Argentina	ARG
30	BRA	Brazil	Brazil	BRA
31	CHL	Chile	Chile	CHL
32	URY	Uruguay	Uruguay	URY
33	XSM	Rest of South America	Falkland Islands (Malvinas)	FLK
			French Guiana	GUF
			Guyana	GUY
			Paraguay	PRY
			Suriname	SUR
34	XCA	Central America	Belize	BLZ
			Costa Rica	CRI
			El Salvador	SLV
			Guatemala	GTM
			Honduras	HND
			Nicaragua	NIC
			Panama	PAN

...to be continued

Table A2 (continued)

No.	Code	Name	Member Regions (226)	Code
35	XFA	Rest of Free Trade Area of the Americas	Antigua & Barbuda	ATG
			Bahamas	BHS
			Barbados	BRB
			Dominica	DMA
			Dominican Republic	DOM
			Grenada	GRD
			Haiti	HTI
			Jamaica	JAM
			Puerto Rico	PRI
			Saint Kitts and Nevis	KNA
			Saint Lucia	LCA
			Saint Vincent and the Grenadines	VCT
			Trinidad and Tobago	TTO
			Virgin Islands, U.S.	VIR
36	XCB	Rest of the Caribbean	Anguilla	AIA
			Aruba	ABW
			Cayman Islands	CYM
			Cuba	CUB
			Guadeloupe	GLP
			Martinique	MTQ
			Montserrat	MSR
			Netherlands Antilles	ANT
			Turks and Caicos	TCA
			Virgin Islands, British	VGB
37	AUT	Austria	Austria	AUT
38	BEL	Belgium	Belgium	BEL
39	DNK	Denmark	Denmark	DNK
40	FIN	Finland	Finland	FIN
41	FRA	France	France	FRA
42	DEU	Germany	Germany	DEU
43	GBR	United Kingdom	United Kingdom	GBR
44	GRC	Greece	Greece	GRC
45	IRL	Ireland	Ireland	IRL
46	ITA	Italy	Italy	ITA
47	LUX	Luxembourg	Luxembourg	LUX
48	NLD	Netherlands	Netherlands	NLD
49	PRT	Portugal	Portugal	PRT
50	ESP	Spain	Spain	ESP
51	SWE	Sweden	Sweden	SWE
52	CHE	Switzerland	Switzerland	CHE

...to be continued

Table A2 (continued)

No.	Code	Name	Member Regions (226)	Code
53	XEF	Rest of EFTA	Iceland	ISL
			Liechtenstein	LIE
			Norway	NOR
54	XER	Rest of Europe	Andorra	AND
			Bosnia and Herzegovina	BIH
			Faroe Islands	FRO
			Gibraltar	GIB
			Macedonia, the former Yugoslav Republic of	MKD
			Monaco	MCO
			San Marino	SMR
			Serbia and Montenegro	SCG
55	ALB	Albania	Albania	ALB
56	BGR	Bulgaria	Bulgaria	BGR
57	HRV	Croatia	Croatia	HRV
58	CYP	Cyprus	Cyprus	CYP
59	CZE	Czech Republic	Czech Republic	CZE
60	HUN	Hungary	Hungary	HUN
61	MLT	Malta	Malta	MLT
62	POL	Poland	Poland	POL
63	ROM	Romania	Romania	ROM
64	SVK	Slovakia	Slovakia	SVK
65	SVN	Slovenia	Slovenia	SVN
66	EST	Estonia	Estonia	EST
67	LVA	Latvia	Latvia	LVA
68	LTU	Lithuania	Lithuania	LTU
69	RUS	Russian Federation	Russian Federation	RUS
70	XSU	Rest of Former Soviet Union	Armenia	ARM
			Azerbaijan	AZE
			Belarus	BLR
			Georgia	GEO
			Kazakhstan	KAZ
			Kyrgyzstan	KGZ
			Moldova, Republic of	MDA
			Tajikistan	TJK
			Turkmenistan	TKM
			Ukraine	UKR
			Uzbekistan	UZB
71	TUR	Turkey	Turkey	TUR

...to be continued

Table A2 (continued)

No.	Code	Name	Member Regions (226)	Code
72	XME	Rest of Middle East	Bahrain	BHR
			Iran, Islamic Republic of	IRN
			Iraq	IRQ
			Israel	ISR
			Jordan	JOR
			Kuwait	KWT
			Lebanon	LBN
			Palestinian Territory, Occupied	PSE
			Oman	OMN
			Qatar	QAT
			Saudi Arabia	SAU
			Syrian Arab Republic	SYR
			United Arab Emirates	ARE
			Yemen	YEM
73	MAR	Morocco	Morocco	MAR
74	TUN	Tunisia	Tunisia	TUN
75	XNF	Rest of North Africa	Algeria	DZA
			Egypt	EGY
			Libyan Arab Jamahiriya	LBY
76	BWA	Botswana	Botswana	BWA
77	ZAF	South Africa	South Africa	ZAF
78	XSC	Rest of South African Customs Union	Lesotho	LSO
			Namibia	NAM
			Swaziland	SWZ
79	MWI	Malawi	Malawi	MWI
80	MOZ	Mozambique	Mozambique	MOZ
81	TZA	Tanzania	Tanzania, United Republic of	TZA
82	ZMB	Zambia	Zambia	ZMB
83	ZWE	Zimbabwe	Zimbabwe	ZWE
84	XSD	Rest of Southern African Development Community	Angola	AGO
			Congo, the Democratic Republic of the	COD
			Mauritius	MUS
			Seychelles	SYC
85	MDG	Madagascar	Madagascar	MDG
86	UGA	Uganda	Uganda	UGA

...to be continued

Table A2 (continued)

No.	Code	Name	Member Regions (226)	Code
87	XSS	Rest of Sub-Saharan Africa	Benin	BEN
			Burkina Faso	BFA
			Burundi	BDI
			Cameroon	CMR
			Cape Verde	CPV
			Central African Republic	CAF
			Chad	TCD
			Comoros	COM
			Congo	COG
			Cote d'Ivoire	CIV
			Djibouti	DJI
			Equatorial Guinea	GNQ
			Eritrea	ERI
			Ethiopia	ETH
			Gabon	GAB
			Gambia	GMB
			Ghana	GHA
			Guinea	GIN
			Guinea-Bissau	GNB
			Kenya	KEN
			Liberia	LBR
			Mali	MLI
			Mauritania	MRT
			Mayotte	MYT
			Niger	NER
			Nigeria	NGA
			Reunion	REU
			Rwanda	RWA
			Saint Helena	SHN
			Sao Tome and Principe	STP
			Senegal	SEN
			Sierra Leone	SLE
			Somalia	SOM
			Sudan	SDN
			Togo	TGO

Source of table: Chapter 3 in Dimaranan and McDougall (2005 forthcoming).