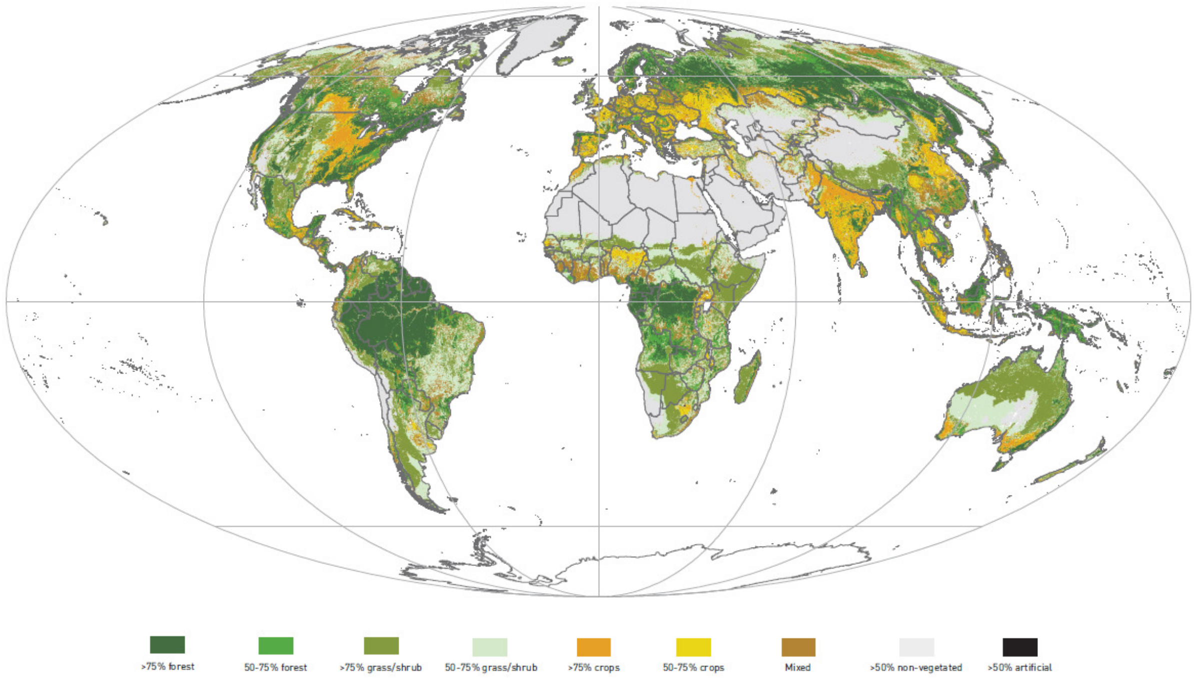
EXPLANATORY NOTE ON THE MAPS PRESENTED IN THE SOLAW REPORT

The SOLAW report contains a limited set of carefully selected global maps. Some of them have appeared in earlier FAO or associated publications, while others have been prepared specifically for SOLAW and are being published for the first time in the report. This note provides information about the maps and describes the methodology used for their preparation.

List of the global maps presented in the SOLAW report

Map 1.1: Dominant land cover and use

This map shows a global distribution of major land cover classes which includes elements of land use in which cropland has been separated from natural grass and shrub categories.



It is extracted from the Global Agro-ecological Zones v3.0 (IIASA/FAO, 2010), and is based on six geographic datasets:

- GLC2000 land cover database at 30 arc-sec (http://www-gvm.jrc.it/glc2000), using regional and global legends (JRC, 2006);
- an IFPRI global land cover categorization providing 17 land cover classes at 30 arc-sec. (IFPRI, 2002), based on a reinterpretation of the Global Land Cover Characteristics Database (GLCC ver. 2.0), EROS Data Centre (EDC, 2000);
- FAO's Global Forest Resources Assessment 2000 and 2005 (FAO, 2001; FAO, 2006) at 30 arc-sec. resolution;
- digital Global Map of Irrigated Areas (GMIA) version 4.0.1 of (FAO/University of Frankfurt) at 5' by 5' latitude/longitude resolution, providing by grid-cell the percentage land area equipped with irrigation infrastructure (Siebert et al., 2007);
- a spatial population density inventory (30-arc seconds) for year 2000 developed by FAO-SDRN, based on spatial data of LANDSCAN 2003, with calibration to UN 2000 population figures.

An iterative calculation procedure has been implemented to estimate land cover class weights, consistent with aggregate FAO land statistics and spatial land cover patterns obtained from (the above mentioned) remotely sensed data, allowing the quantification of major land use/land cover shares in individual 5' by 5' latitude/longitude grid cells. The estimated class weights define for each land cover class the presence of respectively cultivated land and forest. Starting values of class weights used in the iterative procedure were obtained by cross-country regression of statistical data of cultivated and forest land against land cover class distributions obtained from GIS, aggregated to national level. The percentage of urban/built-up land in a grid-cell was estimated based on presence of respective land cover classes as well as regression equations relating built-up land with number of people and population density. Remaining areas were allocated to grassland and other vegetated areas, barren or very sparsely vegetated areas, and water bodies.

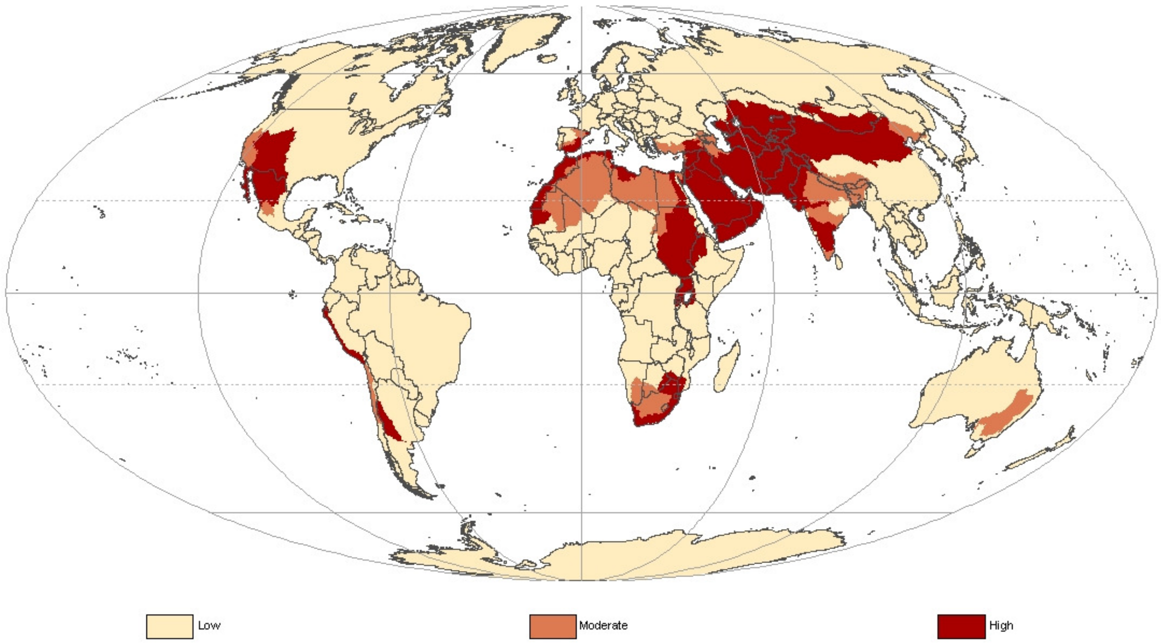
Barren or very sparsely vegetated areas were delineated by using the respective land cover information in GLC 2000 and applying a minimum bio-productivity threshold.

Resulting land use land cover categories shares in individual 5’ resolution grid cells are:
- Rain-fed cultivated land;
- Irrigated cultivated land;
- Forest;
- Pastures and other vegetated land;
- Barren and very sparsely vegetated land;
- Water; and
- Urban land and land required for housing and infrastructure

Source: IIASA/FAO, 2010

Map 1.2: Global distribution of physical water scarcity by major river basin

This map provides a representation of levels of water scarcity by major river basin. It is a first attempt to express water scarcity in terms of *consumptive use of water* rather than on water withdrawal. In this map, water scarcity is calculated as the ratio between irrigation water that is consumed through evapotranspiration and renewable fresh water resources.



Renewable fresh water resources in the river basin are first calculated through a simple water balance model where the soil, acting as a buffer, stores part of the precipitation water which is later available for use by vegetation to satisfy evapotranspiration needs. The surplus of precipitation goes into groundwater recharge and river flow, the two elements of renewable freshwater resources. The model is calibrated against available estimates of internal renewable water resources that are available at country level.

In humid climates, soil moisture is usually maintained at a sufficient level to satisfy the evapotranspiration needs of the vegetation and rainfed agriculture can usually be practiced. In arid climates, or in climates with extended dry periods, irrigation is necessary to compensate for the evaporation deficit due to insufficient or erratic precipitation. Net irrigation water requirements are defined as the volume of water needed to compensate for the deficit between potential evapotranspiration and actual evapotranspiration under natural circumstances over the growing period of the crop. It varies considerably with climatic conditions, seasons, crops and soil types.

- Global map of yearly actual evapotranspiration at 5 arc-min (FAO*)
- Global map of yearly evapotranspiration due to irrigation at 5 arc-min (FAO*)
- Global map of monthly precipitation at 10 arc-min (FAO*)
- World map of the major hydrological basins (FAO, derived from HydroSHEDS*)
- Global Administrative Unit Layers (GAUL 2008*)

The spatial domain for which the renewable water resources have been calculated is a global map with river basins. This map was prepared on the basis of the USGS HydroSHEDS (Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales, database available at:

http://hydrosheds.cr.usgs.gov/) and the USGS Hydro1k database available at: http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30/hydro). The HydroSHEDS database is based on a Digital Elevation Model with a spatial resolution of 3 Arc Seconds (about 100 m), and is available for land areas south of 60 degrees latitude. For the remaining land areas the USGS Hydro1K dataset was used, which has a spatial resolution of 1 kilometer.

The legend used distinguishes three classes:

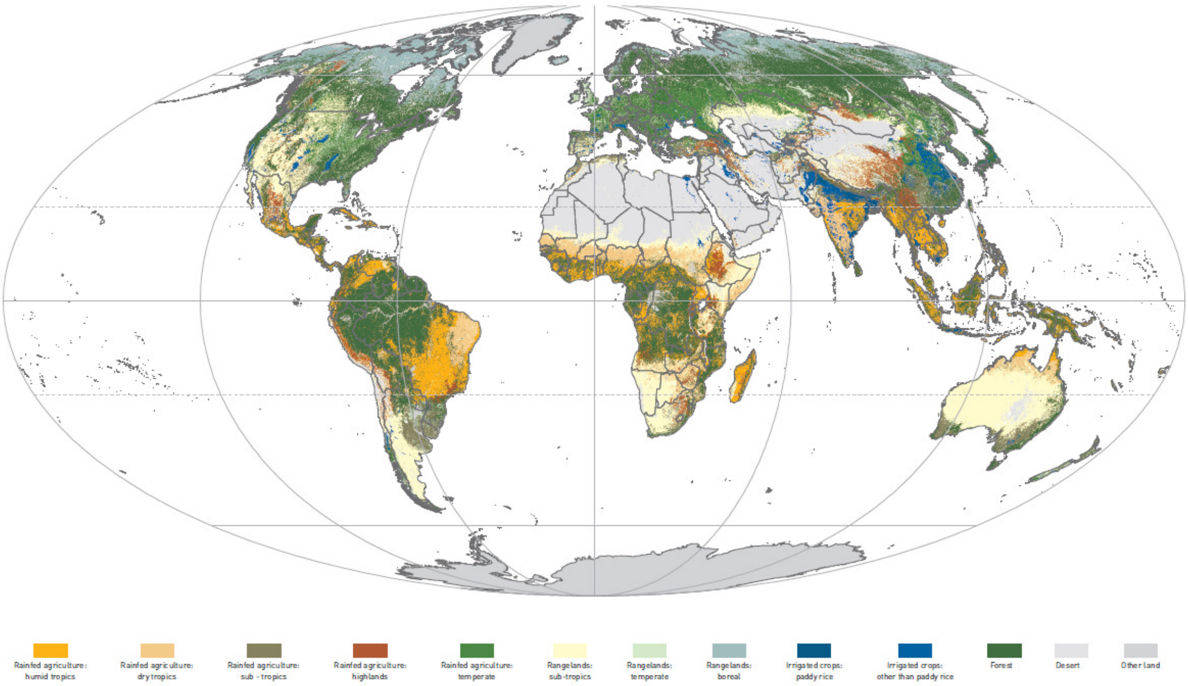
- Water scarcity in river basins where evapotranspiration due to irrigation is less than 10% of the total renewable water resources is classified as low;
- Water scarcity in river basins where evapotranspiration due to irrigation is in between 10% and 20% of the total renewable water resources is classified as moderate;
- Water scarcity in river basins where evapotranspiration due to irrigation is more than 20% of the total renewable water resources is classified as high.

The thresholds used to assess the level of scarcity are consistent with those used in the literature in which countries that withdraw more that 40% of their total available renewable water resources are considered water scarce, and countries that use 20% - 40% are approaching water scarcity. The difference between both classifications lies in the fact that the earlier classification uses total water withdrawals, while the classification used in this report refers to evapotranspiration by irrigated agriculture only. Considering that irrigated agriculture is by far the largest water withdrawing sector, that water consumed by irrigation exceeds by far the water consumed by other water using sectors, and that about 50 percent of all water applied for irrigation is actually consumed through evapotranspiration, the thresholds of 40% and 20% used against water withdrawal correspond approximately to 20% and 10% respectively when dealing with consumptive use of water in irrigation.

The advantage of using river basins to present available water resources, as opposed to for example countries, is that the internal renewable water resources for a river basin equal the total available water resources (unless inter-basin water transfers exist, but this is situation that does not occur often).
Source: this study

Map 1.3: Major agricultural systems

The map of "**Major agricultural systems**" was developed for the SOLAW report to show important agricultural systems with a unique legend for the whole world.



The basis for this map was the work done by Dixon et al. (2001) for the publication 'Farming Systems and Poverty. This publication had identified a series of farming systems for each continent of the developing world. While the approach used in Dixon et al. (2001) is highly relevant to SOLAW, where context-specific issues and solutions are discussed, the maps prepared for this publication have a series of shortcomings: they have a low spatial resolution, they are continental with no harmonized legend, and they do not cover the whole world.

The spatial datasets used for the production of this map consist of:

- GLOBCOVER, global land-cover map for the year 2005 (http://www.gofc-gold.uni-jena.de/sites/globcover.php)
- Paddy rice systems (Ellis and Ramankutty, 2008)
- Median altitude and thermal climates (both datasets are part of the GAEZ v3.0 (IIASA/FAO, 2010)
- Global Map of Irrigation Areas v4.0.1 at 5 arc-min (Siebert at al., 2007*)
- Global Map of Aridity at 10 arc-min (FAO*)
- Global Administrative Unit Layers (GAUL 2008*)
  FAO's Global Livestock Production and Health Atlas (GLiPHA, available at: http://www.fao.org/ag/againfo/home/en/news_archive/AGA_in_action/glipha.html)
- FAO's Agro-MAPS, available at (http://kids.fao.org/agromaps/)
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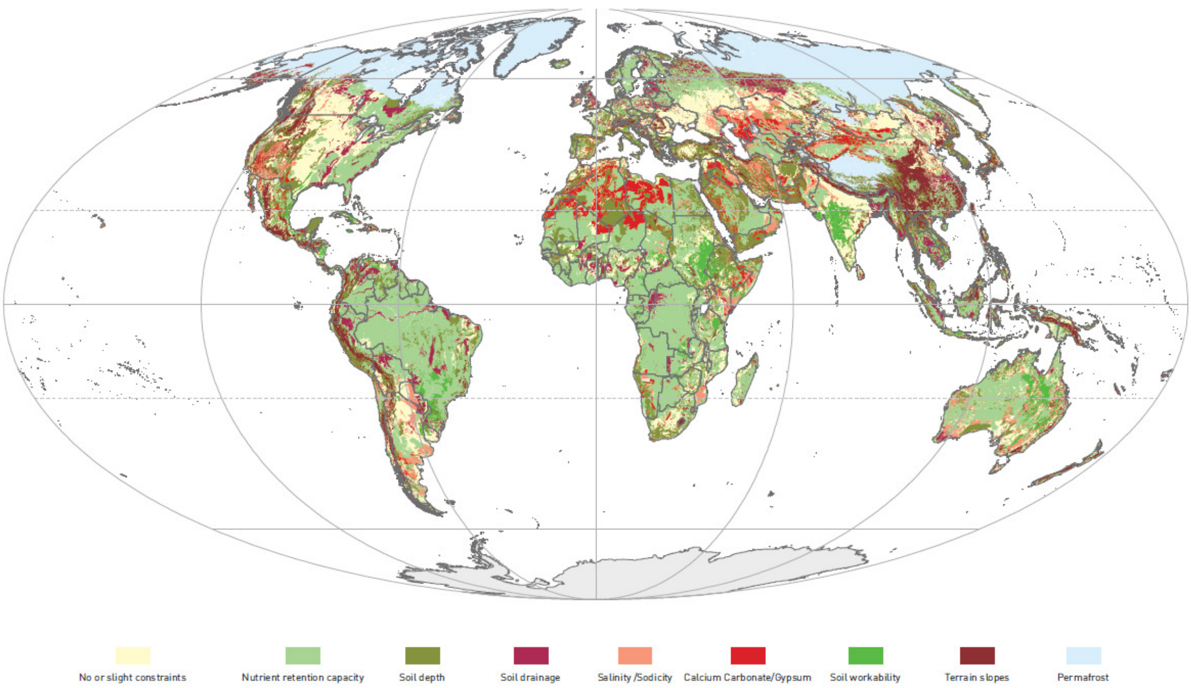
The map was delineated using the stratification scheme as presented in table 1. The main land cover and land use classes are based on the land cover dataset of the GlobCover project. The Global Map of Irrigation Areas was used to identify areas under irrigation (all pixels where irrigation represent more than 25% of total area were classified as "irrigated". Paddy systems were delineated on the basis of the map of "Anthropogenic biomes" published by Ellis and Ramankutty (2008).

In order to differentiate between rainfed agriculture and rangelands, a climate map and a Digital Elevation Model from the Global Agro-ecological Zones version 3.0 were used. A distinction between dry and humid agricultural systems in tropical areas was made by using an FAO map of Aridity Index, classifying areas where A.I. (yearly precipitation divided by yearly reference evapotranspiration) is higher than 0.65 as humid.

The Additional characteristics indicated in Table 1, including geographical distribution, major crops, and crops-livestock integration were obtained from Dixon et al (2001), FAO's Agro-MAPS and FAO's Global Livestock Production and Health Atlas.
Source: this study

Map 1.4: Dominant soil and terrain constraints for low input farming

This map shows dominant soil and terrain constraints for low input farming conditions. The map is part of the IIASA/FAO Global Agro-ecological Zones version 3.0 (IIASA/FAO, 2010). Constraining soil and terrain-slope conditions are accounted for and factored into the analysis by means of soil quality ratings (SQ, %). Soil characteristics are read from 30 arc-second grid-cells from the Harmonized World Soil Databases (IIASA/FAO/ISRIC/ISS-CAS., 2009).



Soil and terrain constraints affecting agricultural production include:

- Nutrient availability: soil fertility level
- Nutrient retention capacity: capacity of the soil to retain nutrients against losses caused by leaching
- Rooting conditions: effective soil depth and volume, affecting rootability.
- Oxygen availability: drainage characteristics of soils affect oxygen availability to roots.
- Excess salts: saline and sodic soil conditions. Salinity inhibiting crop water uptake of the soil and affecting growth and reducing yields. Sodicity causing sodium toxicity and affecting soil structure causing low soil permeability.
- Calcium carbonate and gypsum. Excess calcium carbonate causes micronutrient deficiencies and excess gypsum limits available soil moisture.
- Soil workability constraints: Soil conditions may cause physical hindrance to cultivation.
- Terrain slopes: topsoil erosion reduces soil depth, natural soil fertility and soil moisture.

Seven different SQs are calculated and combined in a soil index rating, which represents the percentage of crop productivity realized in each specific soil type depending on input/management level and sloping conditions. As each grid-cell may contain several soils with dominant and secondary soil types, GAEZ calculates a distribution of possible yields for each grid-cell by considering all possible land utilization types (LUT) and soil-type combinations.

All soil quality ratings are then combined to calculate a single agro-edaphic yield factor named soil unit suitability rating (SR, fractional). The SR for each LUT/soil-unit combination is differentiated by input/management levels: low, intermediate, high. The following five guiding principles form the basis for the rationale used to combine SQs for different levels of input/management:

- Nutrient availability and nutrient retention capacity are key soil qualities
- Nutrient availability is of utmost importance for low level input farming, while nutrient retention capacity is for high level inputs
- Nutrient availability and nutrient retention capacity are considered of equal importance for intermediate level inputs farming
- Nutrient availability and nutrient retention capacity are strongly related to rooting and soil depth
- Oxygen available to roots, excess salts, toxicity and workability are considered as equally important soil qualities.

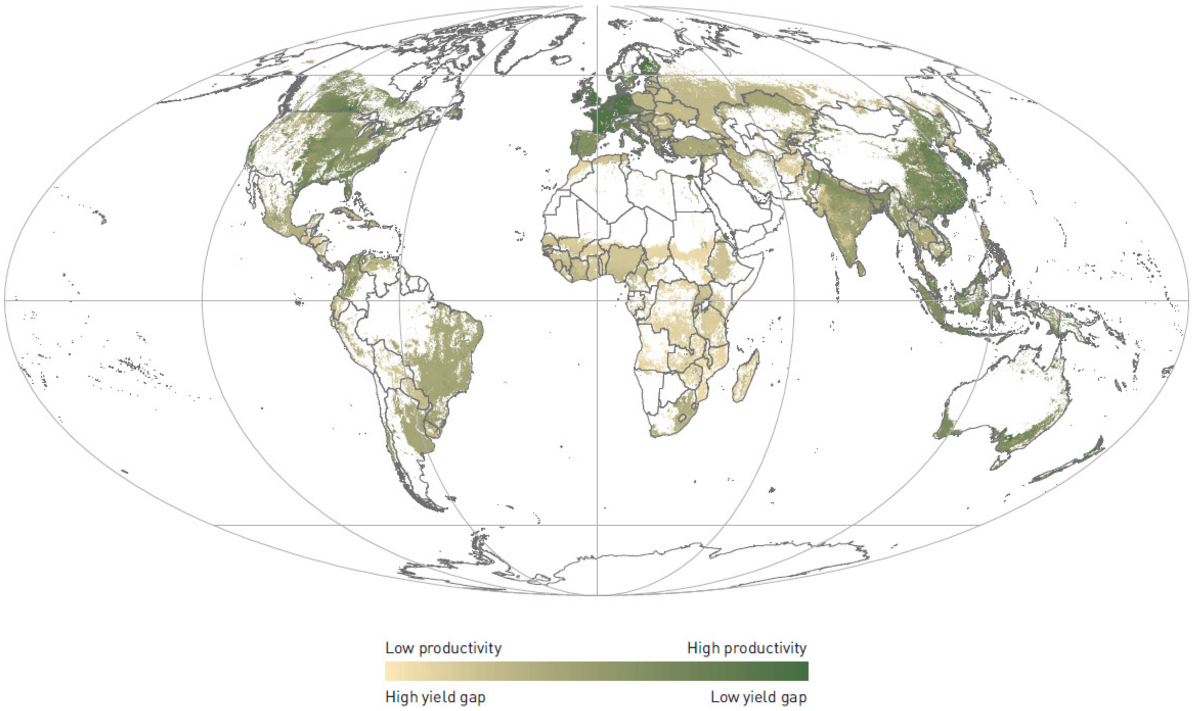
To calculate SR, the combination of SQs is achieved by multiplication of the most limiting SQ with the average of the remaining three less limiting SQs.

Obviously, agricultural input and land management can help to overcome soil and terrain constraints to some degree. This appears clearly when comparing it with a similar map for high input farming. In particular in Eastern Africa, India and Australia, constraints are substantially reduced in situation of high input farming.

Source: IIASA/FAO, 2010

Map 1.5: Yield gap for a combination of major crops

This map presents, for a combination of major crops, the ratio between actual crop production in the year 2000 and that potentially achievable under advanced farming in current cultivated land. It represents the productivity gap due to low levels of inputs and management or the potential gains that could be obtained when moving from current to advanced farming.



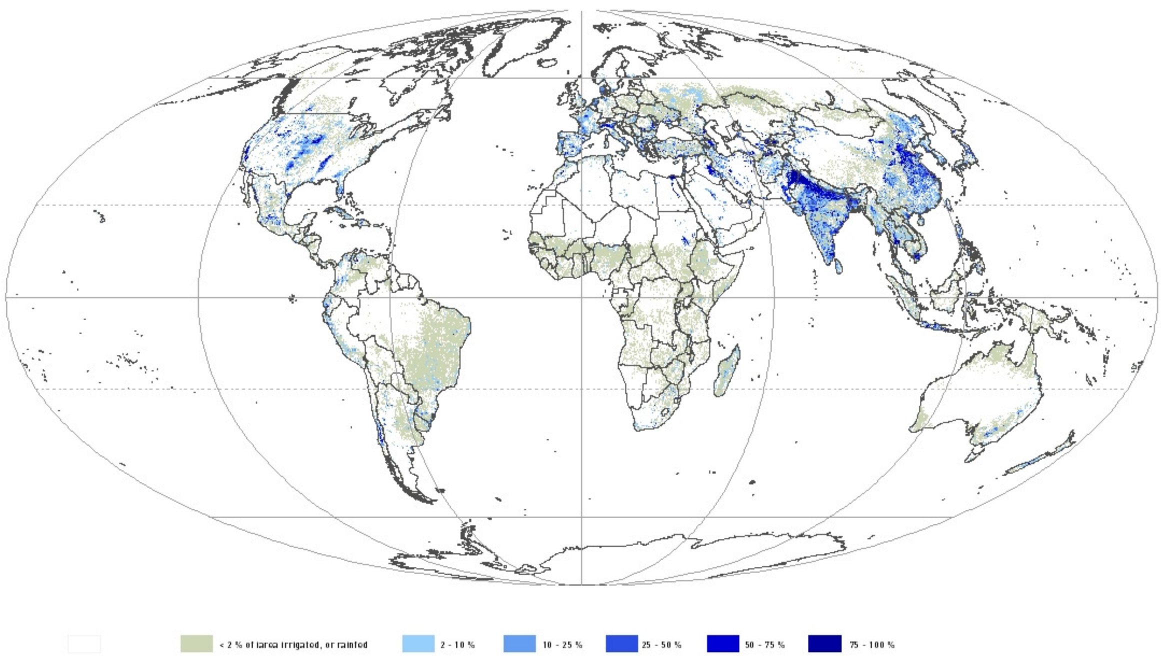
Data sources used in the preparation of this map are:

- Soil and terrain suitability for major crops at high level of inputs, from IIASA/FAO GAEZ v3.0
- Statistics on yield by country for major crops, from FAOSTAT online database.

The yield gaps presented in the map are based on comparisons with cereals, roots and tubers, pulses, oil crops, sugar crops and vegetables. Yield calculations assume the harvested parts and its moisture content as used in FAOSTAT. The potential calculated by GAEZ are expressed in terms of dry yield. It has been adjusted accordingly to allow comparison with FAOSTAT yield data.
Source: IIASA/FAO, 2010

Map 1.6: Area equipped for irrigation as a percentage of land area

This map shows the extent of land area equipped for irrigation around the turn of the 20th century according to the Global Map of Irrigation Areas version 4.0.1, together with areas of rainfed agriculture obtained from map
1.3.



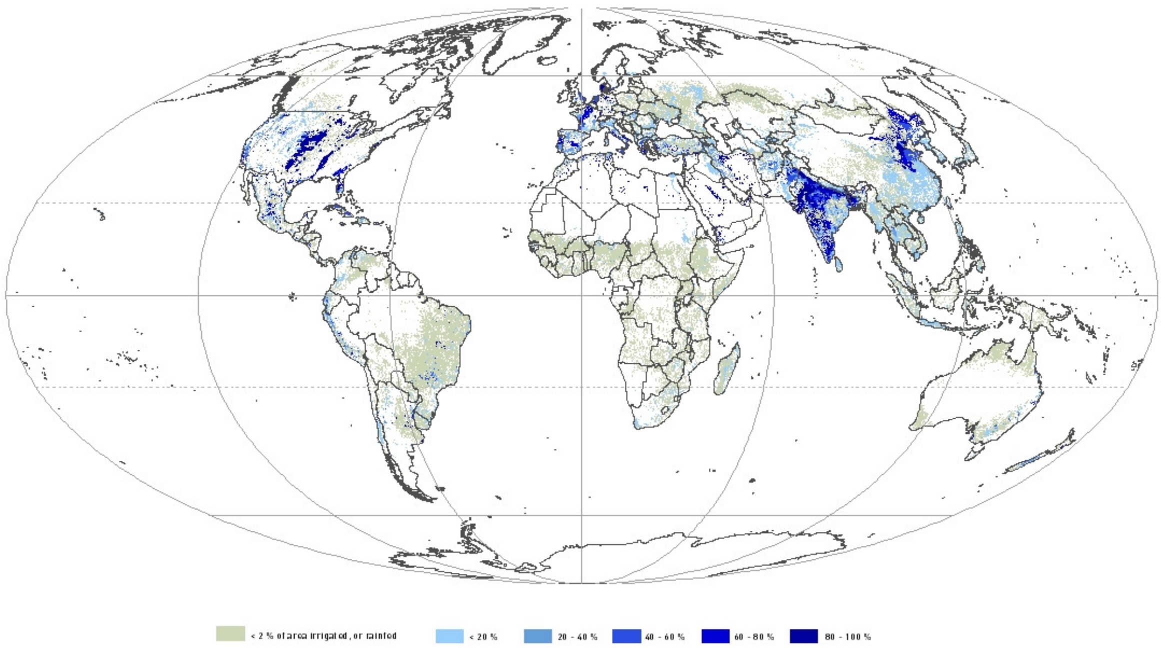
The spatial datasets used to produce this map are:

- The global map of irrigation areas at 5 arc-min (Siebert et al., 2007*)
- The cropland categories of the global agricultural systems map (this study, map 1.3).

All cropland areas where irrigation is either absent or is below the threshold of 2 percent are displayed in beige.

Map 1.7: Percentage of irrigated area serviced by groundwater

This map shows the part of land under irrigation serviced by groundwater. The map was prepared as part of FAO/University of Frankfurt collaboration in mapping areas under irrigation and is described in details in Siebert et al. (2010).



Sources of water in irrigation can be either surface water, groundwater, and in rare cases, non-conventional course of water that include drainage water and wastewater (treated or untreated). Most irrigation systems in the world are serviced either by surface water, by groundwater or by a combination of the two (conjunctive use of water).

Input data for this map include:

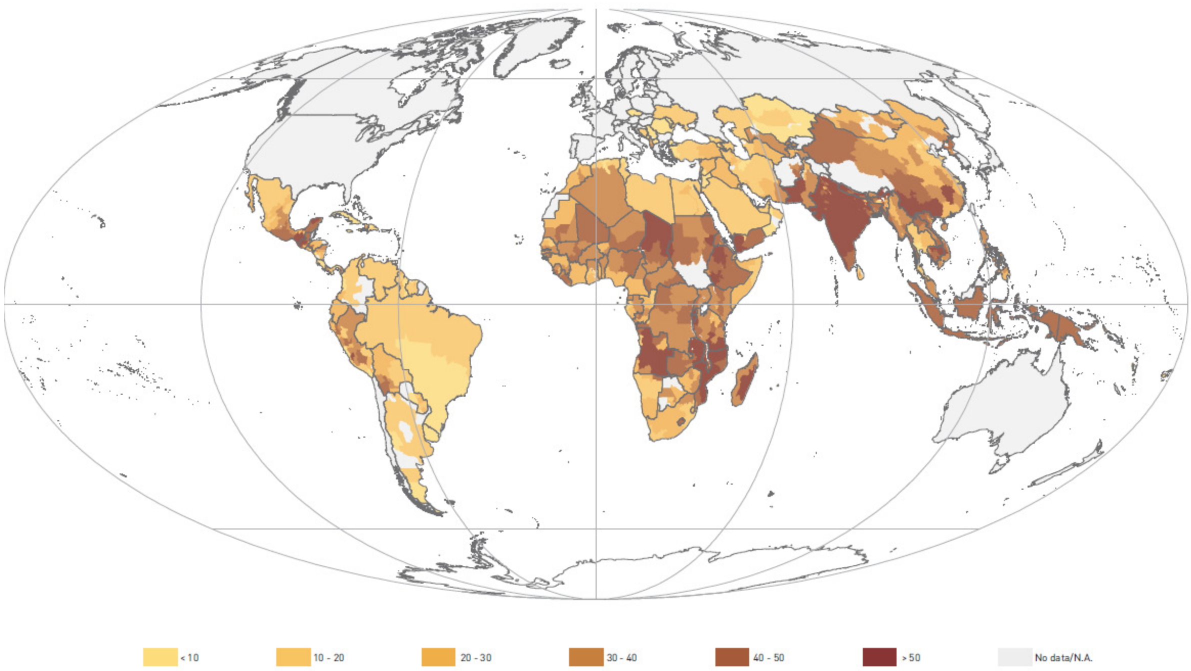
- Global map of irrigation areas at 5 arc-min (Siebert et al., 2007*)
- Data on sources of irrigation water available by country through the FAO AQUASTAT database
- Additional data obtained through desk studies on distribution of sources of irrigation water.

The legend indicates the share of irrigated land serviced by groundwater in each pixel.

This map was initially prepared in the framework of a study aimed at assessing the role and importance of groundwater in irrigation. In the study, areas with conjunctive use of water (the combined use of surface water and groundwater, frequent in many large scale irrigation systems) have been distributed on a 50%-50% basis between surface water and groundwater when more precise information was not available. Therefore, the area under groundwater presented in the map also includes areas under conjunctive use of surface water and groundwater.

Map 2.1: Prevalence of stunting among children in developing countries

This map is adapted from a global GIS database maintained by FAO on food insecurity, poverty and environment global GIS database (FAO, 2007). It is based on stunting data among children under 5 years of age, around year 2000. Stunting among children is used by FAO as an indicator of food insecurity and, indirectly, of poverty.



Input data used to prepare this map are:

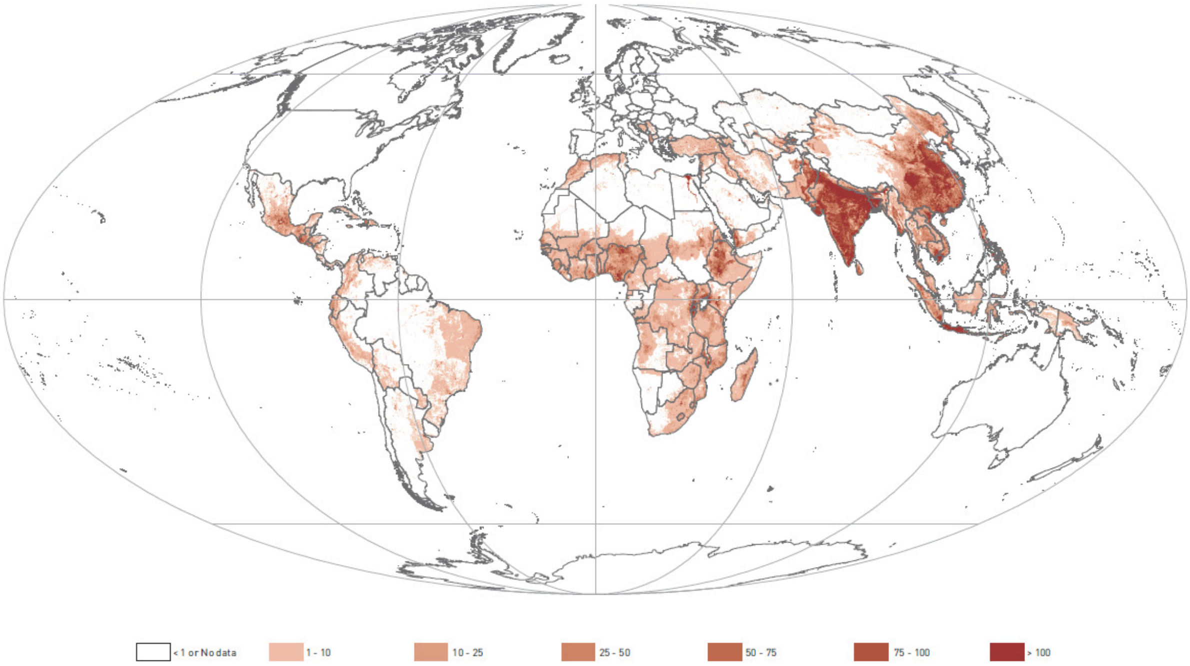
- Global Administrative Unit Layers (GAUL 2008*)
- Stunting data compiled by FAO from different sources: Demographic and Health Surveys (DHS), UNICEF MICS, WHO Global Database on Child Growth and Malnutrition, and national surveys. (FAO, 2007*)

The map presents the prevalence of stunting among children under 5 years of age, displayed against the lowest available administrative unit: all pixels within the unit boundaries will have the same value.

The level of resolution varies among countries and depends on the availability of decentralised information in each country.

Map 2.2: Distribution of poor population in developing countries, based on stunting among children)

Chronic child malnutrition (stunting among children under 5 years of age) represents a good proxy of rural poverty and food insecurity (FAO 2008 and FAO 2003) and, by overlaying stunting rate and population density, this map aims at showing poor population distribution (person/sq km) in developing countries.



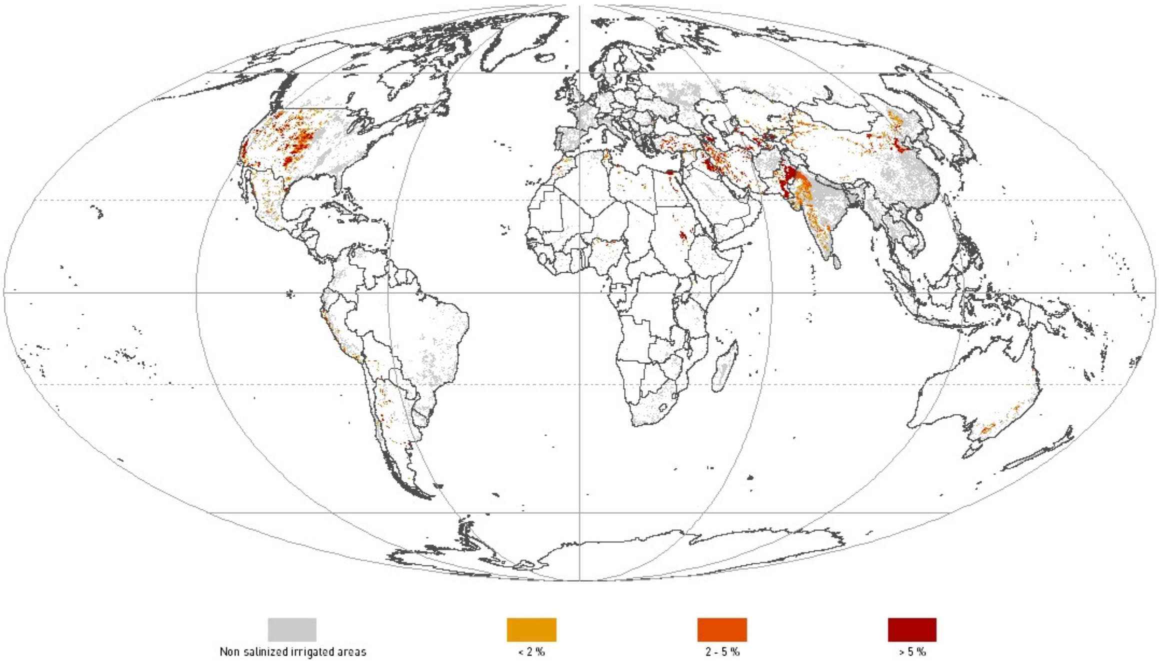
Input data used to prepare this map are:

- Global Administrative Unit Layers (GAUL 2008*)
- Stunting data and population density, at 5 arc-min: Food Insecurity, Poverty and Environment Global GIS Database (FGGD) (FAO, 2007*)

The prevalence of stunting among children under 5 years of age shown in Map 2.1 (expressed in percentage) is multiplied by population density (in persons per km2). The result can be interpreted as a measure of the density distribution of food insecurity and therefore of poverty across the developing world. Areas of higher value are areas of concentration of poor and food insecure people. The map is heavily influenced by density distribution of population.

Map 3.1: Proportion of land salinized due to irrigation

This map represents the spatial distribution of land under irrigation which is affected by some degree of salinization.



The map with the "**extent of irrigated areas affected by salinization**" was produced by combining AQUASTAT country statistics regarding irrigated areas affected by salinization with spatial information on irrigated areas where there is a risk of salinization. Salinization in irrigated agriculture can only occur if precipitation is not sufficient to leach away salt residues that are built up in the soil due to irrigation. It was assumed that the risk of salinization of irrigated areas can occur only in areas with an Aridity Index lower than 0.65 (where the Aridity Index is defined as Yearly Precipitation divided by Yearly Reference Evapotranspiration).

By combining the Global Map of Irrigation Areas with the spatially distributed Aridity Index, irrigated areas could be identified that are potentially at risk of salinization. The AQUASTAT country statistics on areas salinized by irrigation were then distributed over the irrigated areas at risk of salinization to obtain the map with the "**extent of irrigated areas affected by salinization**".

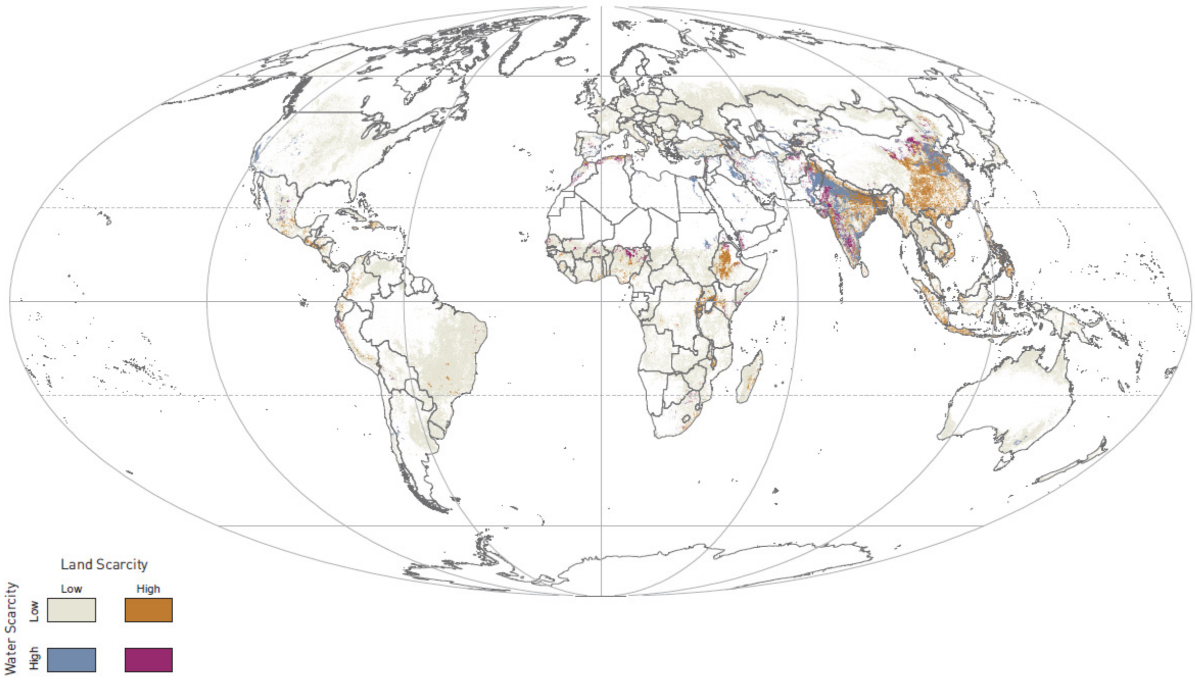
- Global Map of Aridity at 10 arc-min (FAO*)
- Global map of irrigation areas at 5 arc-min (Siebert et al., 2007*)
- Global Administrative Unit Layers (GAUL 2008*)

AQUASTAT data can be found at: http://www.fao.org/nr/aquastat .

The legend indicates the share of land affected by salinization in each pixel. Variations within a country correspond to the variation in the share of land under irrigation. All land under irrigation which is not in arid areas appears in grey on the map.

Map 3.2: Agricultural systems at risk: human pressure on land and water

The map called "**Agricultural systems at risk – human pressure on land and water**" shows to which extent rainfed and irrigated agricultural systems as identified on "**Map 1.3: Major agricultural systems"** suffer from land and / or water scarcity.



Land scarcity in rainfed agriculture was assessed by comparing the rural population density, (obtained from GRUMP 2000, adjusted for UN data, excluding the urban areas indicated on the GRUMP dataset) with the suitability for rainfed crops as mapped for the Global Agro-ecological Zones 2000. Since land that is very suitable for rainfed agriculture can sustain more people than land that is not suitable, it was assumed that each suitability class has its own carrying capacity regarding population. On the map, land is considered scarce if the population density is higher that the highest quintile in the density distribution for each suitability class. Land scarce areas in climates with an Aridity Index lower than 0.5 (where the Aridity Index is defined as Yearly Precipitation divided by Yearly Reference Evapotranspiration) are considered both land and water scarce.

Water scarcity in irrigated areas was assessed by combining "**Map 1.2: Global distribution of physical water scarcity**" with the Global Map of Irrigation Areas. The areas equipped for irrigation are considered water scarce if already 10% or more of the renewable water resources in the river basin is consumed by irrigated crops.

The spatial data used to produce the map are listed below:

- GRUMP – Global Rural-Urban Mapping Project at 30 arc-sec (http://sedac.ciesin.columbia.edu/gpw/)
- Suitability for rain-fed crops at 5 arc-min (Fischer et al., 2002)
- Global Map of Aridity at 10 arc-min (FAO*)
- Global map of irrigation areas at 5 arc-min (Siebert et al., 2007*)
- Global Administrative Unit Layers (GAUL 2008*)

- Global distribution of physical water scarcity (this study, map 1.2*)
- Major agricultural systems (this study, map 1.3*)

** denotes publicly available input datasets, including references, available at FAO's GeoNetwork metadata repository (http://www.fao.org/geonetwork)*

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Table 1.: Stratification scheme for the map of Major Agricultural Systems

Stratification scheme for the map of Global Agricultural Systems

Input strata						Output layer	
Land use objectives & management			Selected biophysical factors influencing crop production			Name of agricultural system	Additional characteristics (crops-livestock integration) and selected examples
Main land use/cover class	Management	Crop type	Altitude	Climate	Aridity Index		
Cropland	Irrigated	Paddy rice				Irrigated crops: paddy rice	Mainly found in South and Southeast Asia, often combined with livestock. In China pigs are the dominant livestock, while in Muslim and Hindu countries such as Indonesia, Bangladesh and India, sheep and goats are much more common.
		Other crops				Irrigated crops: other than paddy rice	Other irrigated crops; medium to high inputs. The most important crops are cereals (mainly wheat and maize), vegetables, cotton and, fodder crops (especially in North Africa and the Near East). Livestock consists of all types of animals.
	Rainfed	Other crops	Highlands			Rainfed agriculture: highlands	Low productivity, small-scale subsistence (low-input) agriculture; a variety of crops on small plots plus few animals.
			Intermediate to Lowlands	Tropics	*Dry*	Rainfed agriculture: dry tropics	Drought-resistant cereals such as maize, sorghum and millet. Livestock consists often of goats and sheep, especially in the Sudano-sahelian zone of Africa, and in India. Cattle is more widespread in southern Africa and in Latin America
					Humid	Rainfed agriculture: humid tropics	Mainly root crops, bananas, sugar cane and notably soybean in Latin America and Asia. Maize is the most important cereal. Sheep and goats are often raised by poorer farmers while cattle are held by wealthier ones.
				Sub-tropics		Rainfed agriculture: sub-tropics	Wheat (is the most important cereal), fruits (e.g. grapes and citrus), and oil crops (e.g. olives). Cattle are the most dominant livestock. Goats are also important in the southern Mediterranean, while pigs are dominant in China and sheep in Australia.
				Temperate		Rainfed agriculture: temperate	Main crops include wheat, maize, barley, rapeseed, sugarbeet, and potatoes. In the industrialised countries of Western Europe, the United States and Canada, this agricultural system is highly productive and often combined with intensive, penned livestock
Rangeland				(sub) Tropics		Rangelands: (sub) tropics	Mainly goats and sheep for meat production. Cattle also raised in Eastern and Southern Africa, and in North and South America.
				Temperate		Rangelands: temperate	Mainly found in the Northern hemisphere and includes mainly cattle for meat as well as for diary production; high inputs and high productvity.
				Boreal		Rangelands: boreal	Found in the northern part of Canada, the Scandinavian countries, Russia and Alaska; extensive system of very low productivity
Forest						Forest	Includes extensive forest based subsistence agriculture and commercial tree crops
Desert						Desert	Very scattered extensive and low productive livestock grazing.
Other land						Other land	
Water						Water	