GAEZ
Global Agro-Ecological Zones

Policy Support for Sustainable Development:
Scarcity, Abundance and Alternative Uses of Land and Water Resources

Water Program, IIASA

Günther Fischer, Eva Hizsnyik, Sylvia Tramberend, Harrij van Velthuizen

Meeting the SDG challenges

Widespread hunger and rising global food demand necessitate better use of the world's water, land, and ecosystems. For a world population of about 9 billion in 2050, agricultural production has to increase by 70 percent globally and to double in developing countries. An enormous effort is required to achieve such growth.

Compounding food insecurity is water scarcity in the locations that need it most. Some 30 countries already face water shortages, and by 2050 this number could increase to over 50 countries, most in the developing world. With the majority of the world's fresh water use going to agriculture, water scarcity is often a very serious obstacle to achieving food security. Agriculture is the largest user of water among human activities. Irrigation water withdrawals account for 70 percent of the total anthropogenic use of renewable water resources. Irrigated crops contribute about 40 percent of total crop output.

An already difficult food security situation is made worse by the overarching effects of climate change. While current research confirms that crops would respond positively to elevated CO_2 in the absence of climate change, higher temperatures, altered precipitation patterns, and increased frequency of extreme events will likely depress agricultural yields and increase food production risks in many of the current food-insecure countries.

The Food and Agriculture Organization of the United Nations (FAO) with the collaboration of IIASA, has developed a system that enables rational land-use planning on the basis of an inventory of land resources and evaluation of biophysical limitations and production potentials of land. This is referred to as the Agro-ecological Zones (AEZ) methodology.

New GAEZ v4 system

New comprehensive global information (GAEZ v4.0) is a milestone for the improvement and dissemination of knowledge about current and future alternatives of land and water resources use.

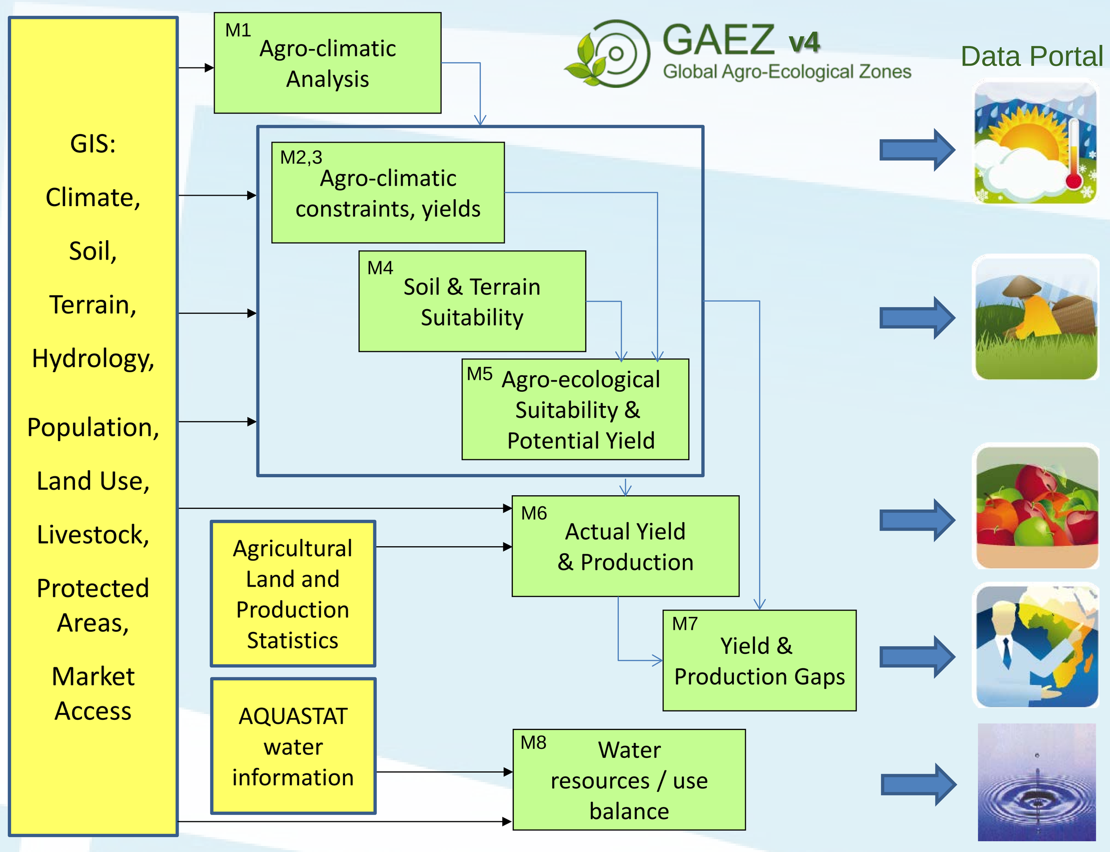

Figure 1: Structure of updated Global Agro-Ecological Zones modelling framework (GAEZ v4)

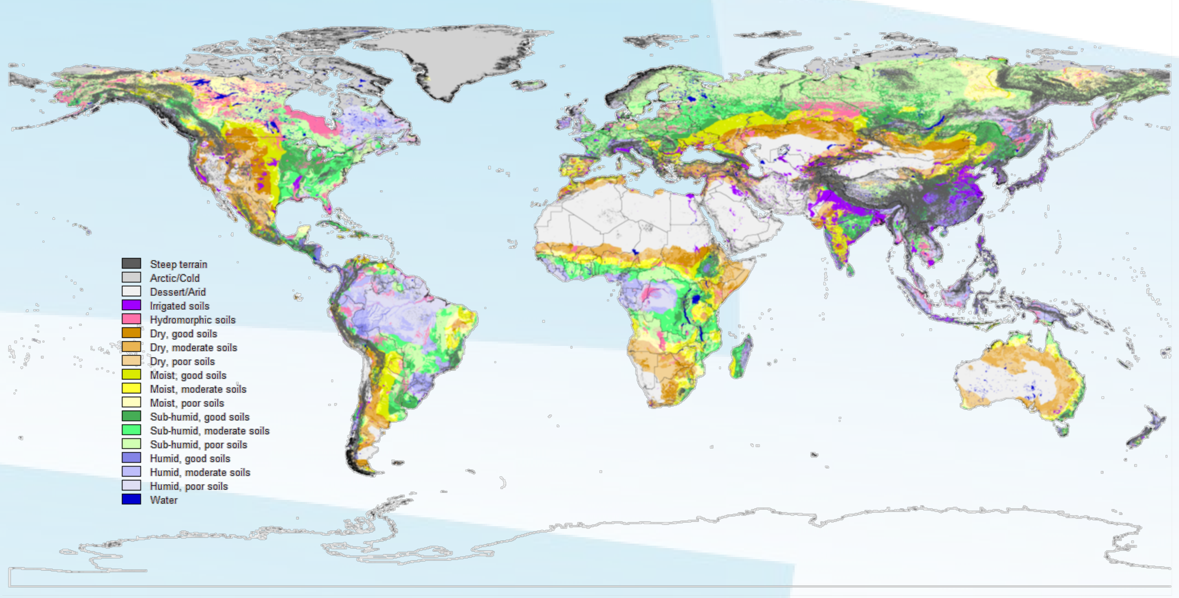

Figure 2: Global agro-ecological zones classification (GAEZ v4)

GAEZ v4 uses national/sub-national statistics and state-of-the art global spatial data layers updated to base year 2010 (including daily climate attributes, soil types and attributes, altitude and terrain slopes, land cover/use, areas equipped for irrigation, hydrology, population and livestock distribution, protected areas, accessibility) to estimate land suitability and productivity of a large number of food, feed and energy crops across a wide range of environmental settings. It computes crop water requirements and irrigation demand and indicates trade-offs among crops and between rain-fed and irrigated uses. GAEZ produces comprehensive resource accounts for current land and water use, indicates resource limitations, reveals apparent yield gaps and helps identify potential hot-spots for land use change and intensification.

GAEZ Products and Results

AEZ information is of critical importance for rational resource management, guiding effective land use changes, making responsible investments in land and water development, and for achieving progress towards sustainable agricultural development, especially with regard to global climate change and the need for adaptation and mitigation in the agricultural sector.

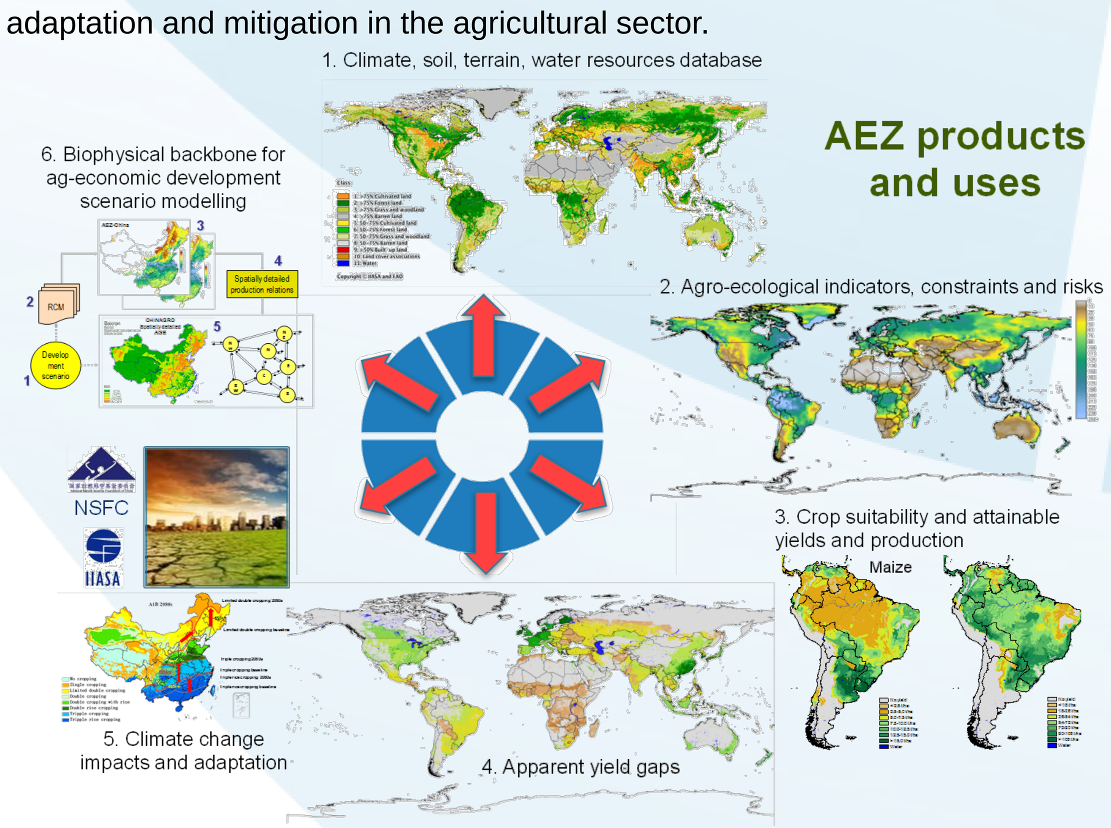

Figure 3: Examples of AEZ products and uses at global to national scales

Global land resources suitable for agricultural production were estimated to comprise 13 Mkm² of prime land (this includes 8 Mkm² of current grassland, woodland and forest land ecosystems), 31 Mkm² of good and moderate land (includes 22 Mkm² grassland, woodland and forest land), and 11 Mkm² of marginal land (of which 8 Mkm² is grassland, woodland and forest land).

Table 1. Global availability and quality of land resources suitable for crop production

Land quality	Cultivated land (Mkm²)	Grass/wood-land (Mkm²)	Forest land (Mkm²)	Other land (Mkm²)	Total (Mkm²)
Prime land	4	4 (3)	5 (4)	0	13 (12)
Good land	8	11 (10)	11 (10)	0	31 (28)
Marginal land	3	5 (5)	3 (3)	0	11 (9)
Not suitable	0	26 (23)	18 (15)	34 (30)	78 (69)
Total	16 (15)	46 (41)	37 (32)	34 (30)	133 (118)

Source: GAEZ v3 simulations of crop suitability for cereals, roots and tubers, sugar crops, pulses, and oil crops. Values in brackets exclude land with protection status.

Very clearly, a large part of the suitable land is already in use or is not available for crop production due to its nature protection status (about 6 Mkm²), its carbon and biodiversity value (some 19 Mkm² of forest assessed as suitable for crops), and because of its current use for feeding a large part of the world's 3.5 billion ruminant livestock.

Prime and good resources for agriculture on a per capita basis are plentiful in only a few regions, foremost Australia, South America, North America, and Eastern Europe & Russia. There is little to very little land per capita available in Northern Africa and Asia and these countries will have to achieve their utmost to overcome resource scarcities with technological improvements and efficiency gains through improved management of land and water resources.

The remaining global land balance, some 78 Mkm², was assessed as not suitable for food crop cultivation due to poor soils, steep slopes and/or areas that are too dry or too cold. Of this, about 34 Mkm² is barren, built-up or water, and 18 Mkm² is forest. Of some 26 Mkm² of grassland/woodland not suitable for crops, about 16 Mkm² is unproductive land (below 0.2 t/ha dry matter) and the remainder, about 10 Mkm², can produce some herbaceous biomass that can support ruminant livestock at an extensive level (yield mostly in the range 0.2-1.0 t/ha dry matter).

The potential for sustainable intensification of agricultural production has been assessed by estimating location specific yield and production gaps between actual achieved and potentially achievable yield and production of cereals, roots and tubers, pulses, sugar crops, oil crops and vegetables. The analysis employs spatially attributed ("downscaled") agricultural statistics of year 2000 and 2010 and compares these with potentials simulated for the baseline climate.

Results of the analysis suggest that on global average the achieved crop yields equate to just over 50% of potentially achievable yields, with large variations across regions. In sub-Saharan Africa yields are lower by a factor 4 compared to potential. Also in Eastern Europe and the countries in Central Asia large yield gaps and underutilization of land prevail. In Northern America, East Asia and Oceania apparent yield gaps are moderate, and yield gaps are smallest in Northern and Western Europe.

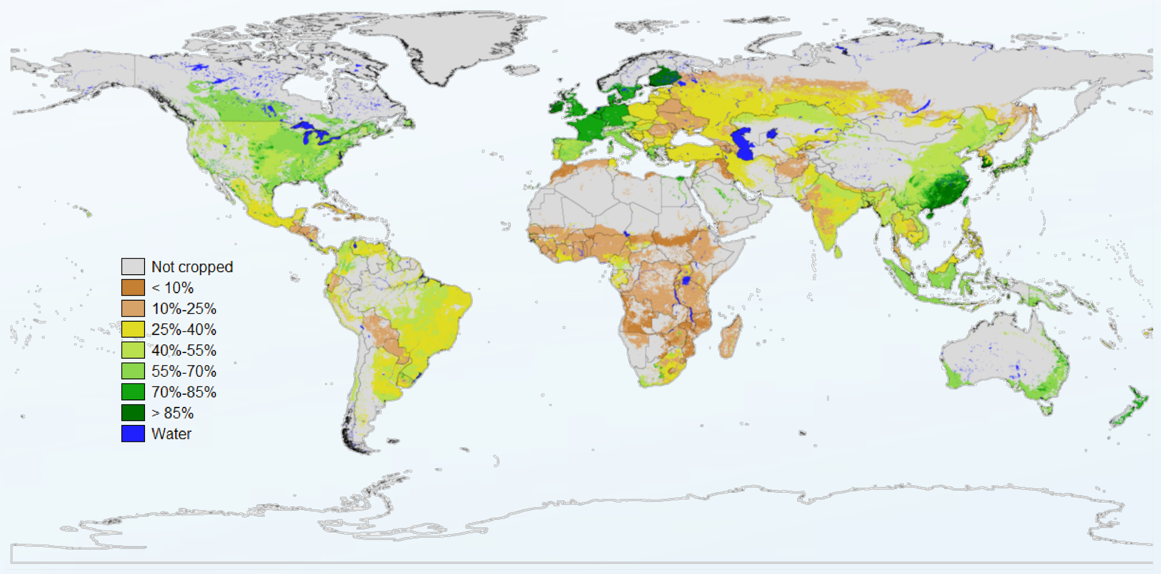

Figure 4. Yield gap ratios (% of potential) comparing actual cereal crop production of year 2000 with potentials achievable in current cultivated land with advanced farming.

Main Messages and Policy Conclusions

- From a resources point of view it is possible to produce enough food for a projected 9 billion population in 2050 at global level; yet, one cannot ignore disparities across and within regions. For countries with a limited resource base and large projected population growth, efforts to develop agriculture need to be supplemented with interventions in other sectors.
- Per capita availability of prime land resources is plentiful in only a few regions. Yield gap reductions, technological improvements and efficiency gains will be needed to allow development. Overall there is much lower productivity of crops in potentially available grass/woodland and forest ecosystems than in current cultivated land.
- To prevent widespread land conversion and reduce the greenhouse gas and environmental effects of deforestation, the required agricultural production increases to 2050 should largely be achieved on current cultivated and pasture land, which means an enormous effort for farmers, agricultural researchers, irrigation development, fertilizer industry and infrastructure for inputs and market accessibility. It is uncertain whether an 1.4% average annual yield growth can indeed be achieved and sustained over 50 years.
- Soil nutrient availability is by far the most prevalent soil limitation in most regions. When combined with low nutrient retention capacity of soils, fertilizers alone may prove less effective for increasing crop yields, notably in tropical regions, requiring also strategies of integrated plant nutrient management.
- Within the context of 'land grabbing', information on the agro-ecological potentials of land (e.g. such as provided in GAEZ v3.0) combined with participatory land use planning is key to the principle of responsible investment strategies for sustainable and mutually beneficial development.
- While the global balance of crop production potential of the current cultivated land is not much affected by climate change in the next decades, there are several regions where climate change poses a significant threat for food production and food security. Scenario results confirm that, with and without CO2 fertilization, the impacts of projected climate change on crop yields and production could become severe in the second half of this century.

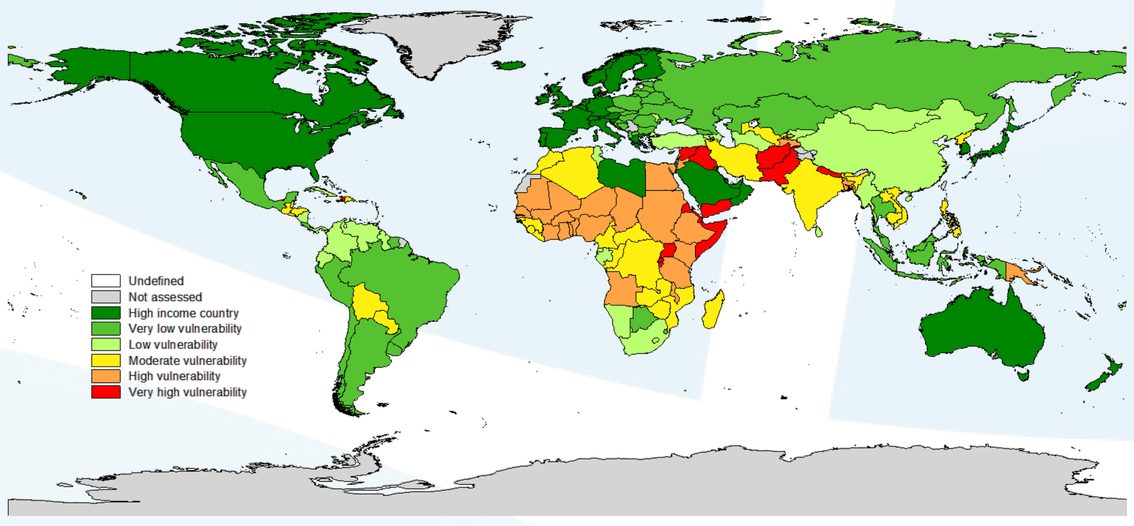

Figure 5. Countries vulnerable to food insecurity (Data compilation by authors using World Bank, FAO, GAEZ v3)

The map identifies the countries that are most vulnerable to food insecurity. A country's vulnerability is estimated according to: (1) projected population growth in 2000 to 2050; (2) wealth expressed in GDP per capita in 2005; (3) land potential for rain-fed cereal production per capita of 2050 population; (4) total renewable water resources per capita in 2050; and (5) impact of climate change on crop production potential in 2050s. High income countries with 2005 GDP per capita exceeding US$ 7500 (in 1990 US$) are assumed not to be vulnerable to food insecurity.

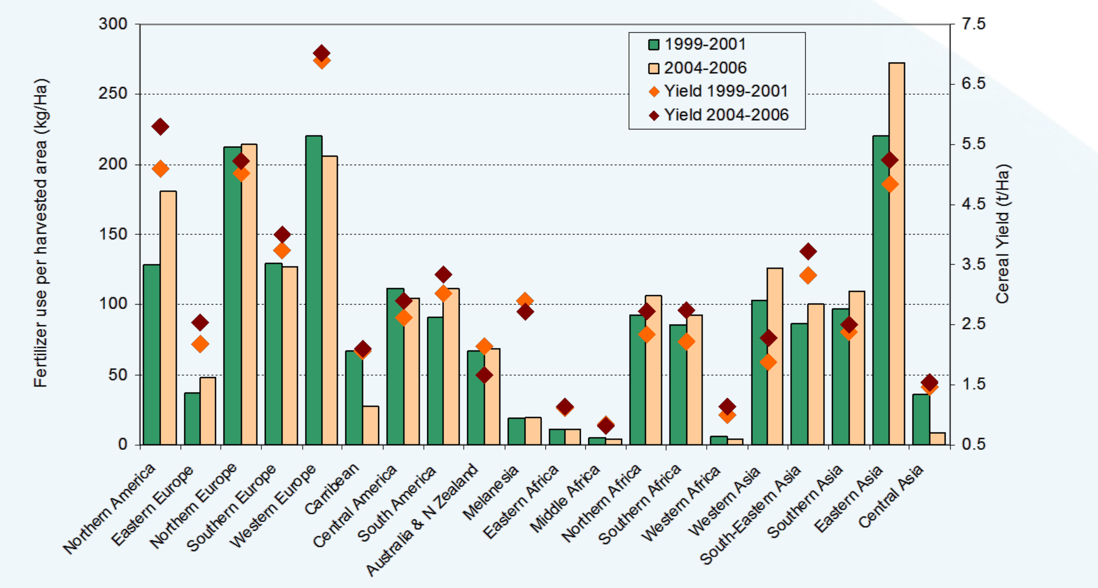

Figure 6. Differences in fertilizer use and cereal yields (Data compilation by authors based on FAOSTAT)

The figure shows average fertilizer application by region and it indicates reported average cereal yields of 2000 and 2005. Yields in the 20 main world regions shown correlate well with respective fertilizer consumption. Creating an enabling and economically attractive environment for improved nutrient management and use therefore appears to be a prerequisite for effective yield gap reduction in these areas.

Ways forward

- Commitment to sustainable agricultural development: Agriculture is the dominant user of the environment and natural resources; it has the greatest impact on the sustainability of ecosystems and their services, and accounts directly and indirectly for a major share of employment and livelihoods in rural areas in developing countries. The reality for many developing countries is that no progress on reducing rural poverty and hunger can be achieved without political and resource commitment to sustainable agricultural development.
- However, trends over the last 30 years show a reduced allocation of national development budgets to agriculture in many developing countries, a setback that has coincided with declining multilateral lending and bilateral aid for the sector due to low priority allotted by national governments and their international partners.
- Providing adequate rights of access to land and other natural resources and secure tenure of those rights are essential to fostering sustainable and progressive agricultural development. Farmers are quite naturally more inclined to invest in improving their land through soil protection measures, planting trees, and improving pastures if they have secure tenure and can benefit from their investments.
- Development of adequate infrastructure for both transport and communication will help farmers to access required inputs such as fertilizers as well as to target production for local markets.
- Land and water uses for food production regularly compete with other ecosystem services. Ignoring such resource use conflicts and tradeoffs can lead to unsustainable exploitation, environmental degradation, and avoidable long-term societal costs. Overcoming this limitation requires better understanding and management of competing uses of land, water, and ecosystem services, including robust expansion of food and bio-energy production, sustaining regulating ecosystem functions, protecting and preserving global gene pools, and enhancing terrestrial carbon pools.