ENERGY and PHOTOSYNTHESIS

- Definition of energy
- Energy Laws (Thermodynamics)
- Solar Radiation
  - Atmospheric
  - Ground level
- Primary Production
- Photosynthesis
- World distribution of primary production
- Food
  - for humans
  - for domestic animals
- Energy partitioning in food webs

Energetics

Energy: ability or capacity to do work
Heterotrophs: food (+fuel)
Autotrophs: solar energy (+wind, rain)

Joule: J
Calorie: cal (or gcal), kcal
BTU
horsepower

Watt=J/s
Kilowatt-hour=1000 watt x 3600 seconds

One gcal= amount of heat to raise the temperature of one gram of water one degree centigrade.

One kcal= amount of heat to raise the temperature of one kilogram of water one degree centigrade.

2000-3000 kcal per day to power human body

Energy laws

Laws of thermodynamics

1st law: energy is transformed from one form into another (e.g. light to food) never created nor destroyed.

2nd law: degradation of energy takes place during transformation from a concentrated form into a dispersed form.

Some of the energy is dispersed into unavailable form (such as dispersed heat).

Energy transfer is not %100 efficient.

You can not finish a real physical process with as much useful energy you start with.

Second law is known as entropy law.
Entropy is a measure of disorder in terms of unavailable energy.
How to define disorder:

entropy : measure of the "multiplicity" associated with the state of the objects.

When "throwing dice",

throwing a seven is more probable than a two

seven : in six different ways

two : only one way

So seven has a higher multiplicity than a two:

a seven represents higher "disorder" or higher entropy.

Glass of ice chips vs glass of water
Which is more ordered?

The ice chips place limits on the number of ways the molecules can be arranged.

The water molecules in the glass of water can be arranged in many more ways; they have greater "multiplicity" and therefore greater entropy.

Because there are so many more possible disordered states than ordered ones, a system will almost always be found either in the state of maximum disorder or moving towards it.

The concept of entropy and the second law of thermodynamics suggest that systems naturally progress from order to disorder.

If so, how do biological systems develop and maintain such a high degree of order? Is this a violation of the second law of thermodynamics?

Order can be produced with an expenditure of energy:

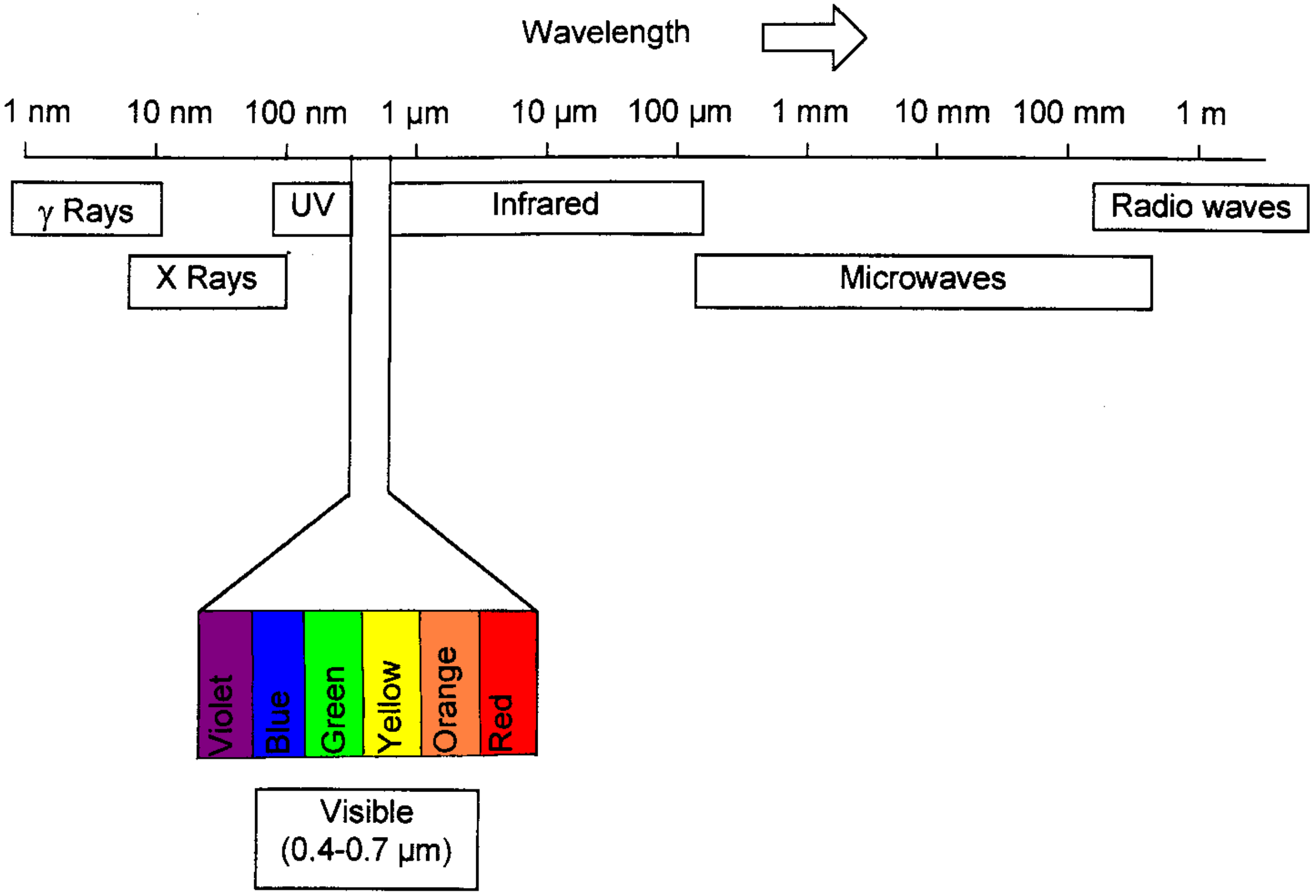
The order associated with life on the earth is produced with the aid of energy from the sun.

Organisms and ecosystems maintain their highly organized, low entrophy (low disorder) state by transforming energy from high to low utility states.

Respiration in a forest is the dissipative part of the energy use. That part of the energy must be adequately supplied, otherwise order will disintegrate.

Solar radiation

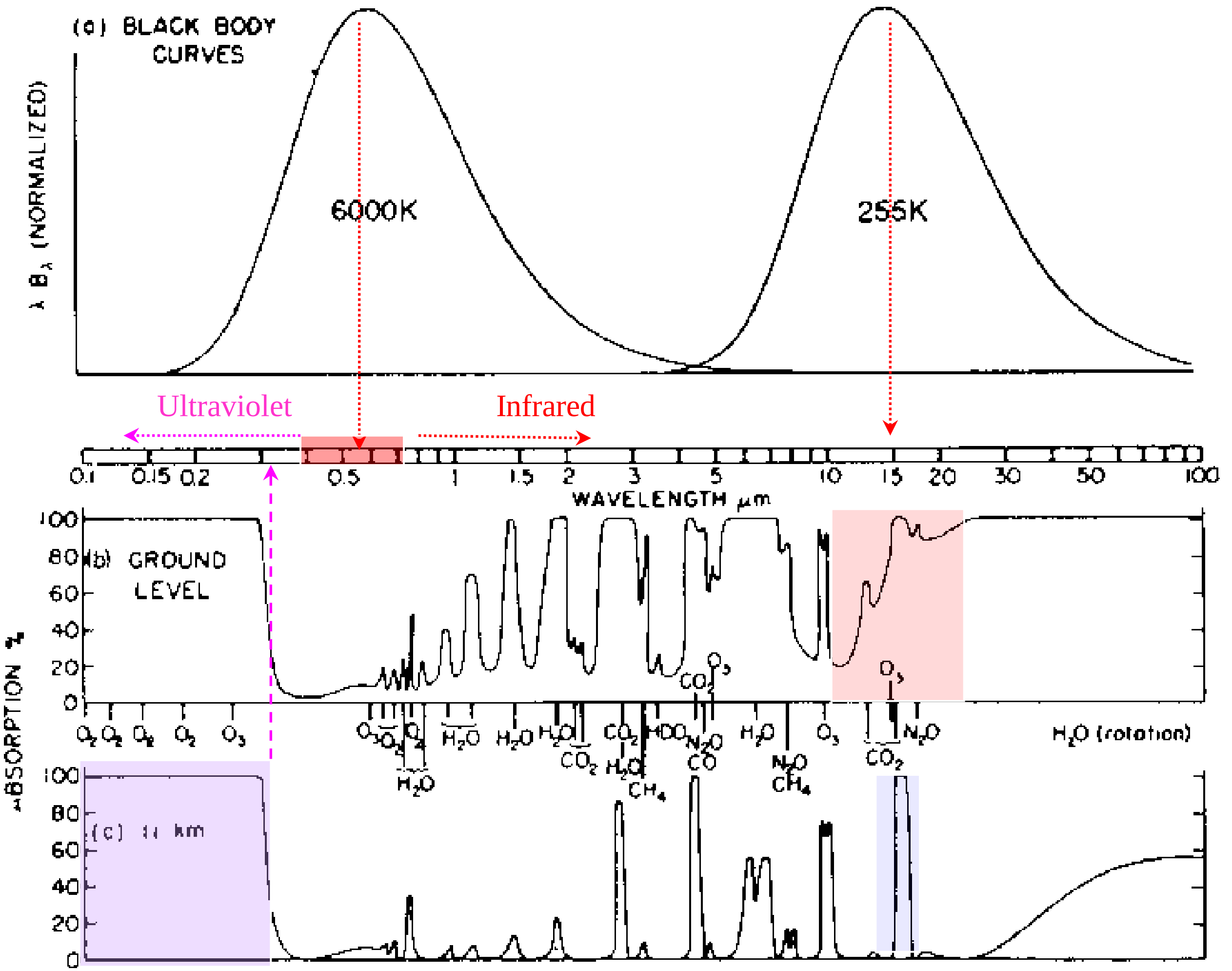
Radiation



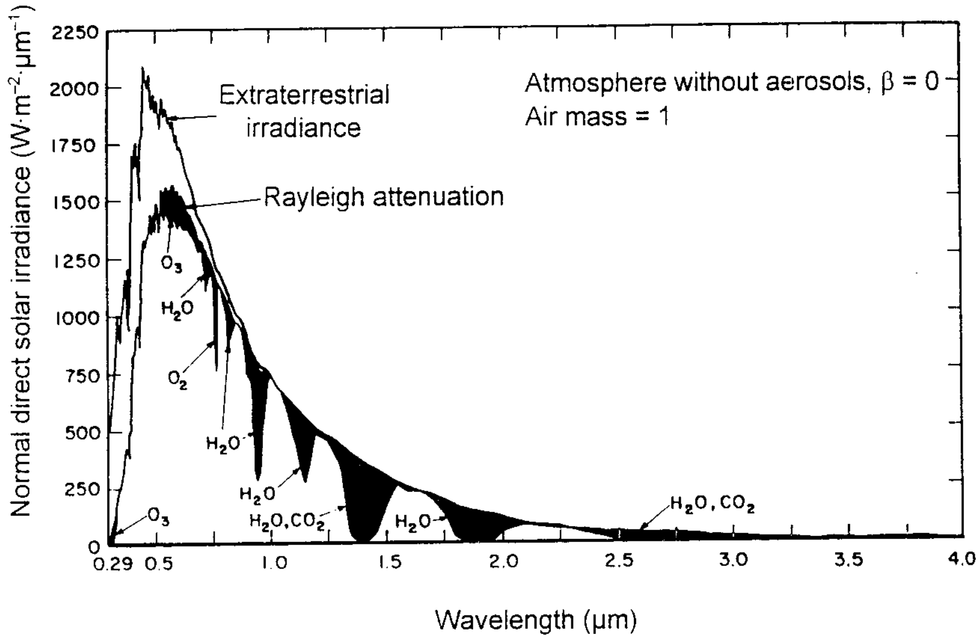
The electromagnetic spectrum.

Ground Level

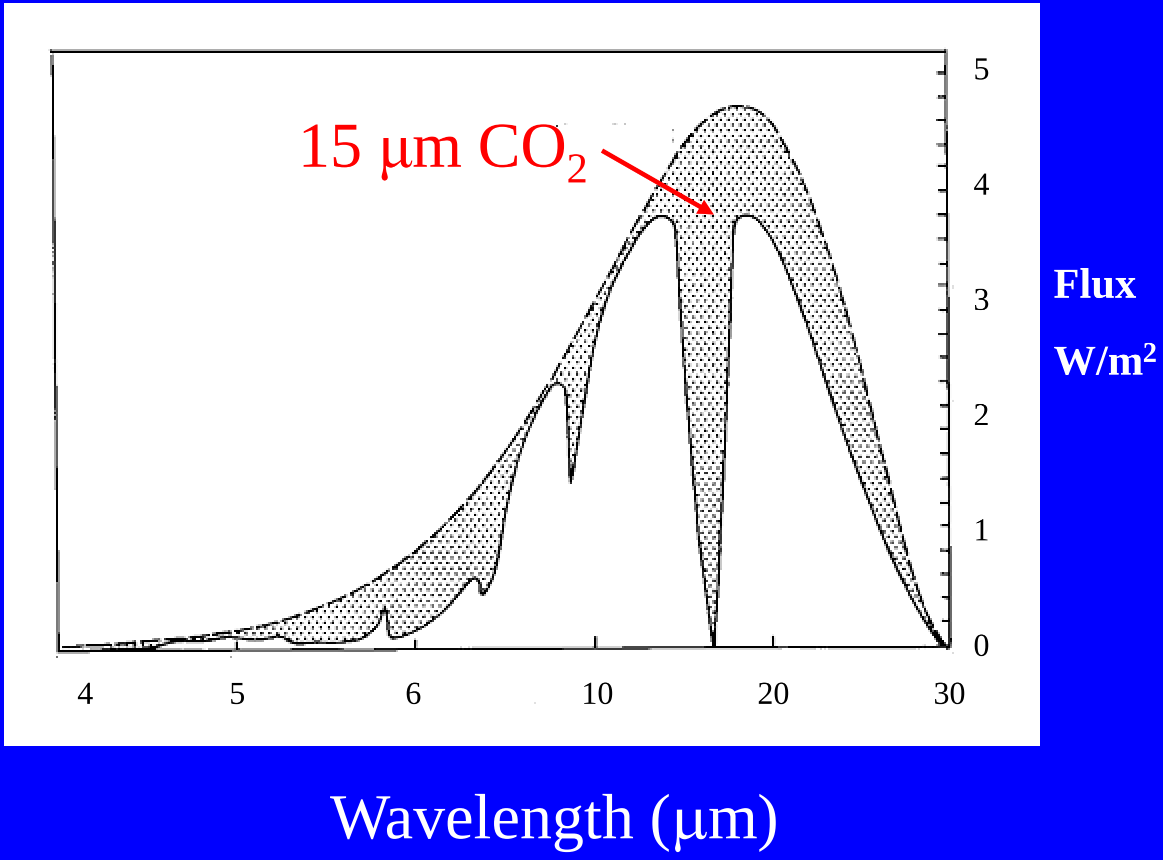
From top to trapopause



The normalized blackbody emission spectra for the sun (6000 K) and Earth (255 K) as a function of wavelength (top). The fraction of radiation absorbed while passing from the surface to the top of the atmosphere as a function of wavelength (middle). The fraction of radiation absorbed from the tropopause to the top of the atmosphere as a function of wavelength (bottom). The atmospheric molecules contributing the important absorption features at each frequency are indicated. [Taken from Goody and Yung (1989). Reprinted with permission from Oxford University Press.]

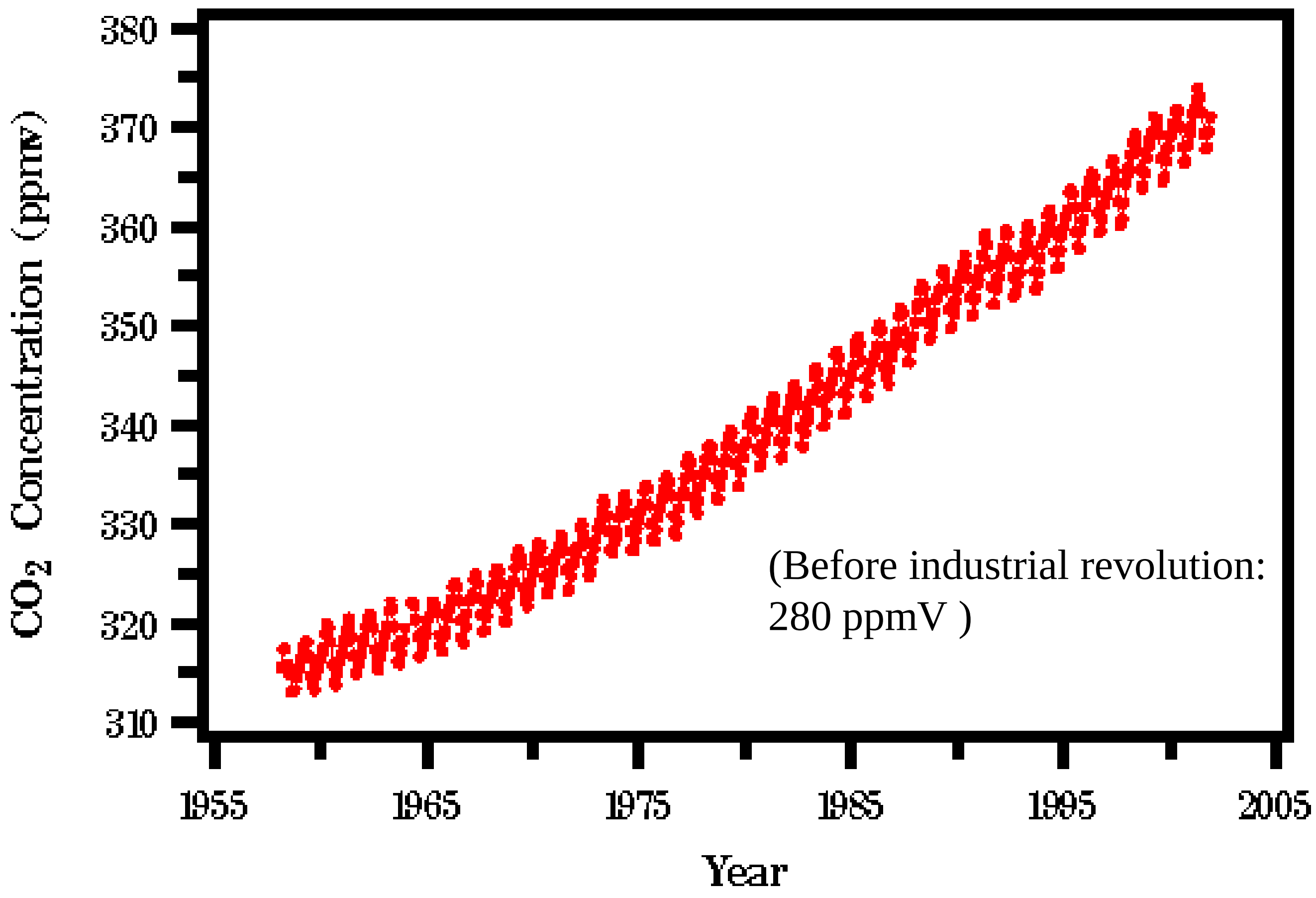


Solar radiation spectra at the limit of the atmosphere and at sea level. The shaded parts correspond to gaseous absorption (adapted from Iqbal, 1983).

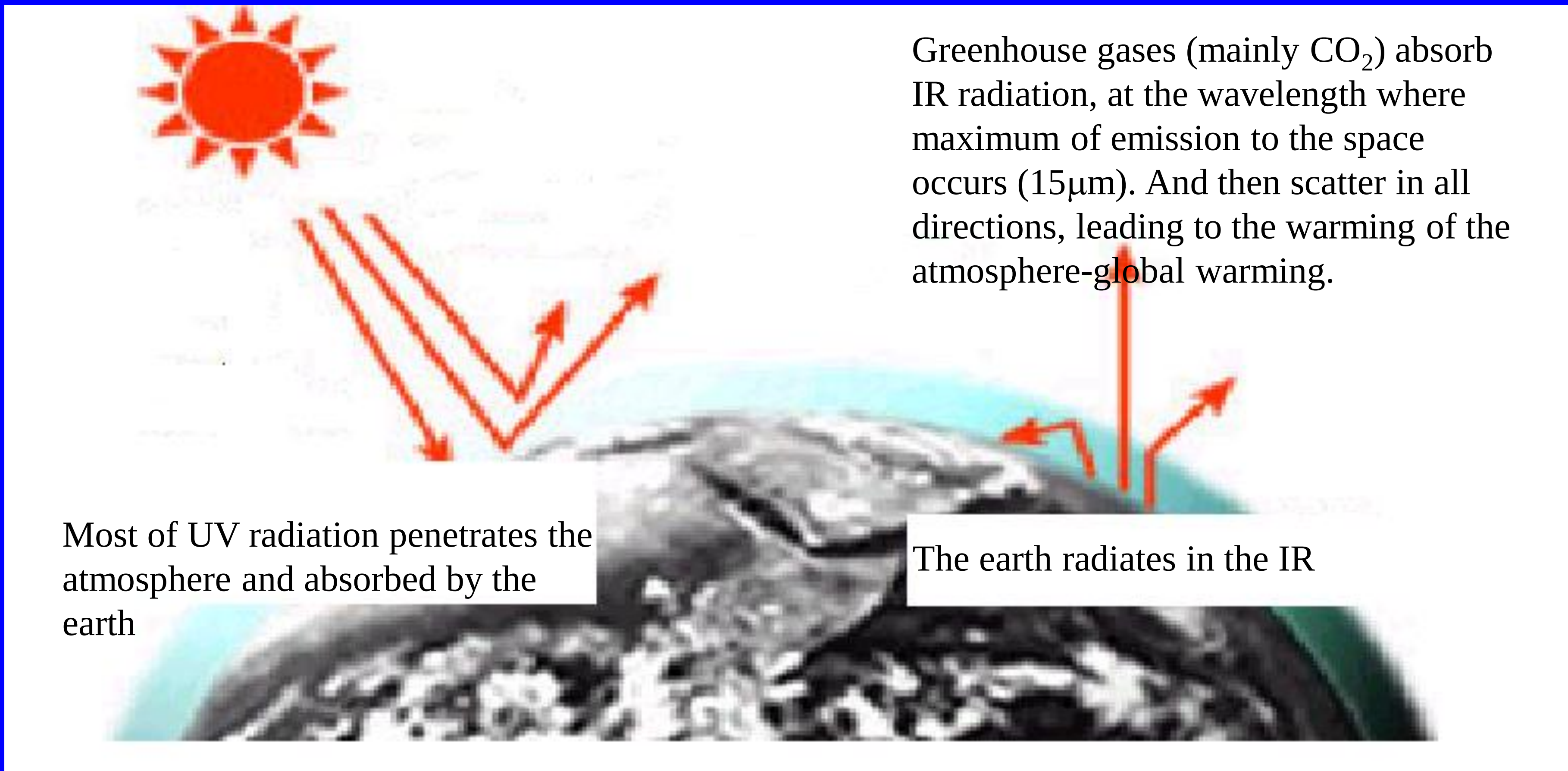


15 µm CO_2
5
4
3
2
1
0
4
5
6
10
20
30
Flux
W/m²
Wavelength (µm)

Carbon dioxide concentration as measured at Mauna Loa, Hawaii. These measurements represent the globally mixed concentration.



Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)


Greenhouse gases (mainly CO_2) absorb IR radiation, at the wavelength where maximum of emission to the space occurs (15µm). And then scatter in all directions, leading to the warming of the atmosphere-global warming.
Most of UV radiation penetrates the atmosphere and absorbed by the earth
The earth radiates in the IR

Energy flow through the biosphere

TABLE 1 Energy Dissipation of Solar Radiation as Percentage of Annual Input into the Biosphere

Energy Dissipation	Percent
Reflected	30
Direct conversion to heat	46
Evaporation, precipitation (drives hydrological cycle)	23
Wind, waves, and currents	0.2
Photosynthesis	0.8
Total	100

1 to 5 percent is used for photosynthesis

A large part of the solar energy is dissipated into unavailable heat which

warms the biosphere to a life sustaining level

drives the hydrological cycle

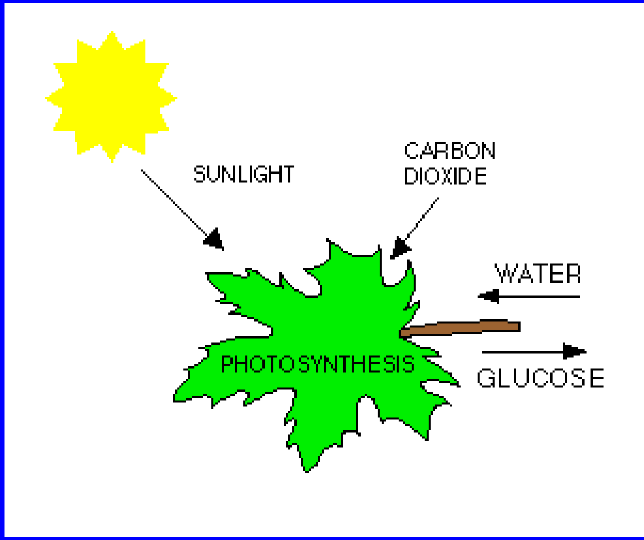
powers the weather system

Flow of energy drives the cycles of materials

As energy quantity decreases its quality increases.

Photosynthesis

A small portion of solar energy → High quality organic matter



Carbon dioxide + water + light energy =Carbohydrate +water+oxygen

Oxidation – reduction process
Water is oxidized
Carbon dioxide is reduced

The xylem (colored **blue**) transport water & minerals from the roots, through the stem, & into the leaves

Phloem (colored **orange**) are tubes that transport "food" through the plant. This "food" is basically sugary water. The sugars are synthesized during photosynthesis

The little round flat shaped things are called *thylakoids*. A stack of them is called a *granum*. Two or more stacks are called *grana*.
There can be from 2 to around 100 thylakoids in one granum. The little tube like strands connecting thylakoids from granum to granum are called *stroma lamellae* .

Ribosomes – make proteins -

Starch granules- storage of carbohydrate in plants –

Stroma – dark reaction happens here

SOLAR COLLECTERS

The outer surfaces of the thylakoids and the lamellae connecting the thylakoids are also called the photosynthetic membrane.

This membrane contains the pigment molecules of chlorophyll and carotenoid. These solar collector pigments act like antennae to capture the solar energy and start the carbohydrate making process we call photosynthesis.

They are spread around the chloroplast to provide a lot of solar collecting surface area.

Light dependent stage

Chrolorophyll molecules in granna absorb light energy and synthesise ATP (adenosine triphosphate)

Also photolysis takes place

H_2O + light energy $\longrightarrow$ 2H + O

Oxygen diffuses through stomata out of the leaf

H ions are used in the light independent stage.

Light independent stage

occurs in stroma of the choloroplast
ATP and H ions produced in the light dependent stage and CO_2 which diffuses through stroma are used to form carbohydrates.

The following nutrients are used to form different parts of the plants

Which nutrients does a plant need and why?

Element	Form absorbed by plant	Used for
calcium	Ca^{2+}	cell walls
magnesium	Mg^{2+}	making chlorophyll and proteins
phosphorus	$H_2PO_4^-$	proteins, DNA, ATP
potassium	K^+	stomatal movement
nitrogen	NO_3^- or NH_4^+	making proteins
sulphur	SO_4^{2-}	enzyme activity
boron	H_3BO_3	regulates metabolism
iron	Fe^{2+} or Fe^{3+}	enzyme activity
copper	Cu^+ or Cu^{2+}	leaf growth
zinc	Zn^{2+}	root/stem growth
molybdenum	MoO_4^{2-}	nitrogen fixation
nickel	Ni^{2+}	enzyme activity
manganese	Mn^{2+}	enzyme activity
chlorine	Cl^-	regulates water potential

In most plants CO_2 fixation start with the formation of three C compounds, but some plants reduce CO_2 starting with 4 carbon carboxylic acids.

named C3 and C4 plants.

C3 plants: wheat, rice, patatoes
C4 plants: corn, sugar, millet, sorghum

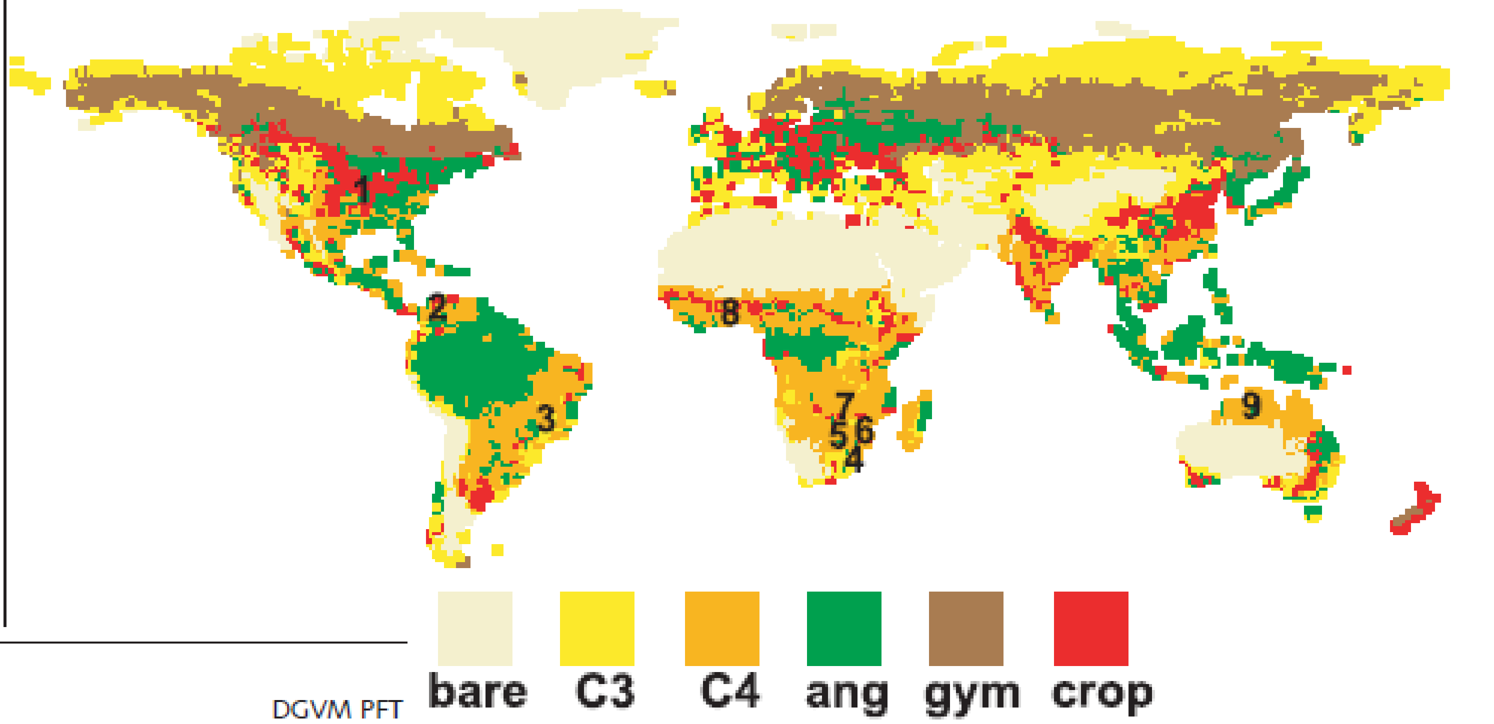
C4 plants have different arrangement of choloroplasts in their leaves. They are much more efficient at capturing CO_2 than C3 plants . They function very efficiently at low CO_2 concentrations and high light intensities and high temperatures- suitable for tropics and arid regions.

CAM plants fix CO_2 at night

Desert plants (cacti)
Crassulacean acid metobolism (CAM)

•CAM plants fix CO_2 at night, and synthesize glucose during the day.

allowing the plant to keep its stomata closed during the day. (Why?)



ISLSCP number	Land cover type	DGVM PFT
1	Broadleaf evergreen forest	Angio
2	Broadleaf deciduous forest and woodland	Angio
3	Mix of 2 and coniferous forest	Angio
4	Coniferous forest and woodland	Gymno
5	High latitude, deciduous forest and woodland	Gymno
6	Wooded C_4 grassland	C_4
7	C_4 grassland	C_4
9	Shrubs and bare ground	Bare
10	Tundra	C_3
11	Desert, bare ground	Bare
12	Cultivation	Cultivation
13	Ice	Bare
14	C_3 wooded grassland, shrublands	C_3
15	C_3 grassland	C_3

Seeds:

Gymnosperms: like a pine cone

Angiosperms: like apple

Source:
ftp://daac.gsfc.nasa.gov/data/inter_disc/biosphere/land_cover

The global distribution of ecosystems in a world without fire
W. J. Bond F. I. Woodwardand G. F. Midgley

Primary production : *amount of organic matter fixed per*
and primary productivity *day or year*

Gross primary production: *total amount including its own needs*

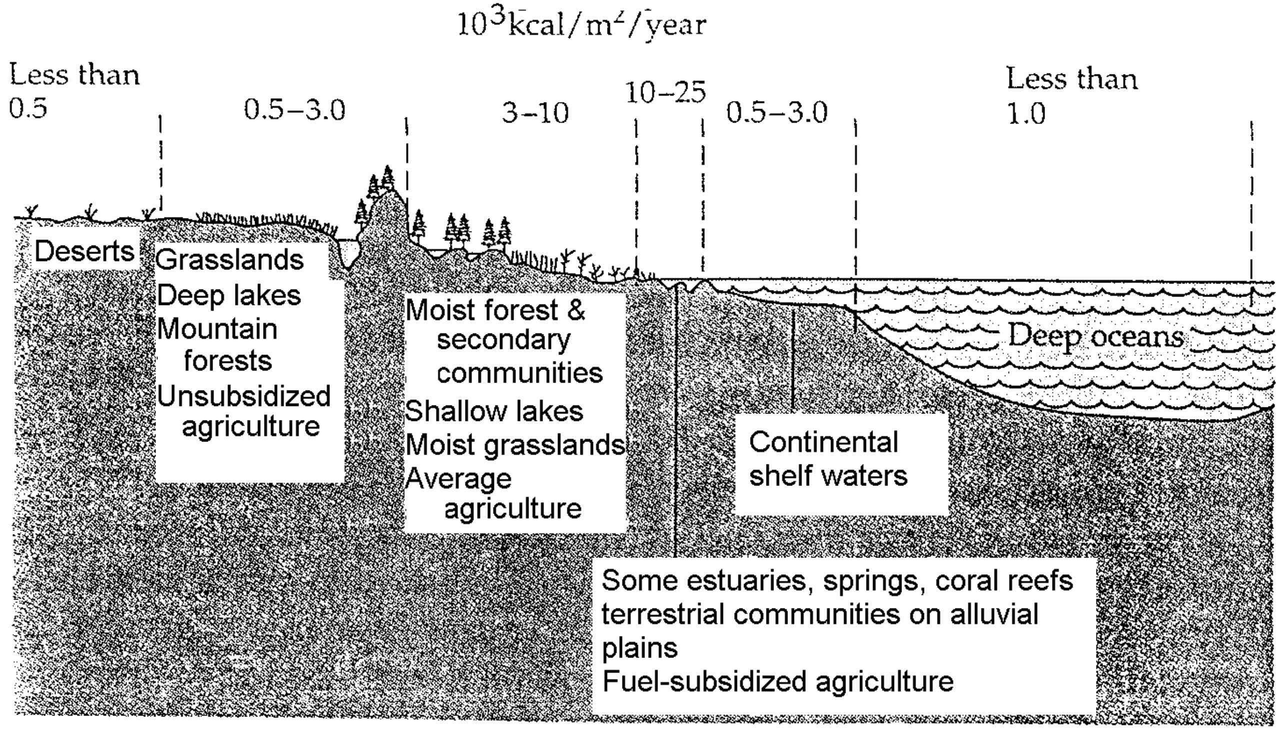
Net primary production: *excess of its respiratory needs*

Net community production: *the amount left after biotic community autotrops and heterotrops consumption*

Secondary production: *energy storage at consumer level*

Source sink energetics: *excess organic production by one system (a source) is exported to another, less productive system (sink)*

World distribution of primary production



World distribution of primary production.

Ecology, Eugene P. Odum, Sinauer Associates, Inc., Rev. Ed. of 2nd Ed. 1993

In terms of area ¾ of the biosphere is ocean and desert
Only 10% is naturally very fertile.
Because of *the large area* total productivity of less fertile regions is *very large*.

Net annual primary production and plant biomass for the earth dry weight

Ecosystem type	Area / 10^6 km^2	Net Primary Productivity per unit area / g m^{-2} or t km^{-2}		World Net Primary Production / 10^9t	Biomass per unit area / kg m^{-2}	
		Normal range	Mean		Normal range	Mean
tropical rainforest	17.0	1000–3500	2200	37.4	6–80	45
temperate deciduous forest	7.0	600–2500	1200	8.4	6–60	30
boreal forest	12.0	400–2000	800	9.6	6–40	20
tundra and alpine	8.0	10–400	140	1.1	0.1–3	0.6
desert and semi-desert shrub	18.0	10–250	90	1.6	0.1–4	0.7
cultivated land	14.0	100–3500	650	9.1	0.4–12	1
swamp and marsh	2.0	800–3500	2000	4.0	3–50	15
total continental		**149**		**773**	**115**	**112.3**
open ocean	332.0	2–400	125	41.5	0–0.005	0.003
upwelling zones	0.4	400–1000	500	0.2	0.005–0.1	0.02
continental shelf	26.6	200–600	360	9.6	0.001–0.04	0.01
algal beds and reefs	0.6	500–4000	2500	1.6	0.04–4	2
estuaries	1.4	200–3500	1500	2.1	0.01–6	1
total marine		**361**		**152**	**55.0**	**3.033**

Food for humans

Worldwide application of

mechanization

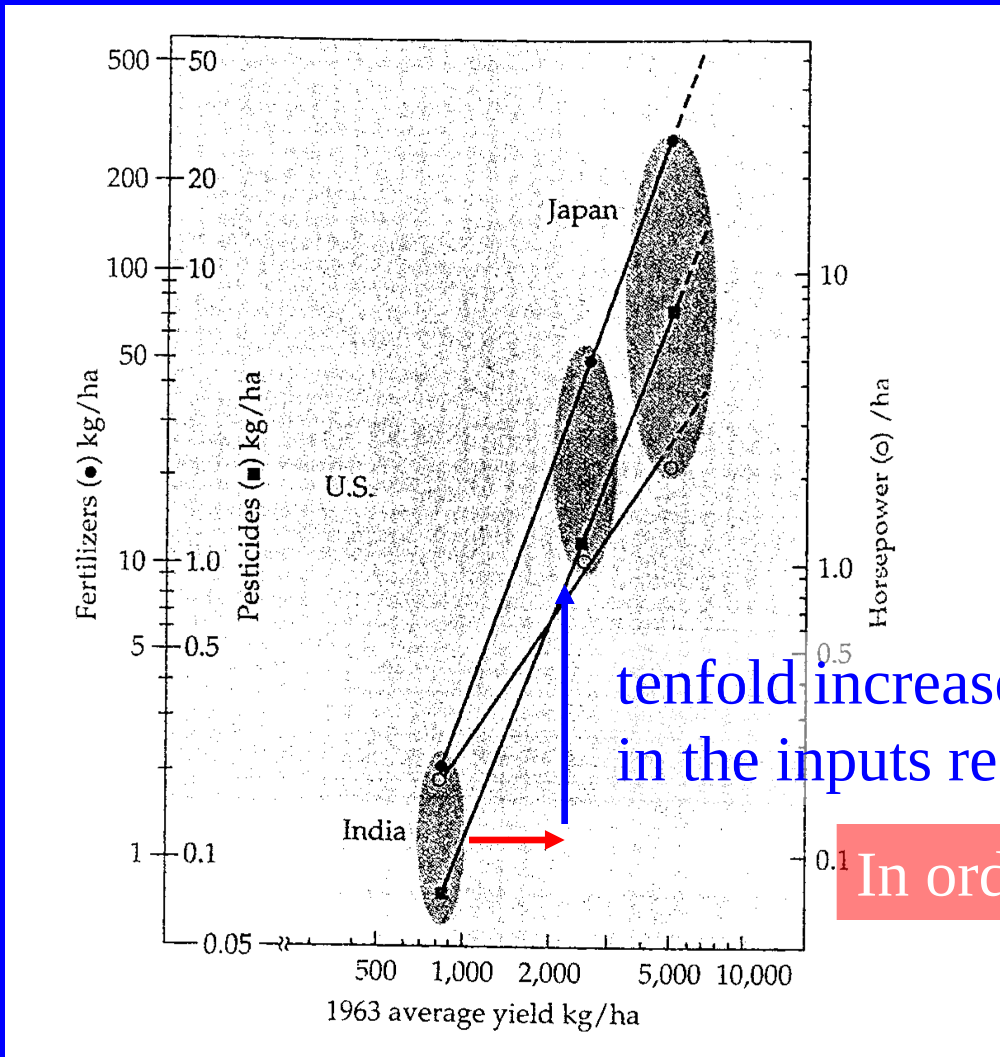
fertilizers

irrigation

pesticides

} additional energy inputs

has increased food production.



tenfold increase
in the inputs required

In order to double the yield

Increased efficiency can reduce the cost

Harvest ratio = edible part/ non edible part

Example:
Miracle rice %80 grain
h.r.= 4 to 1

No energy left for self protection

Chemical subsidies are required to nourish it and to keep the bugs off. } pollution

TABLE 2 Annual Yield of Edible Portion of Major Food Crops at Four Levels of Protein Content and Three Levels of Subsidy

Crops	Harvest Weight (Kilograms/Hectare)					
	Developed Country (with fuel-subsidized agriculture 1990)		Undeveloped Country (with little energy subsidy)		World Average	
					1990	1970
Sugar[a] (from sugarcane —less than 1% protein)	U.S.A.	7680	Pakistan	4150	6133	3000
Rice (10% protein)	Japan	6325	Bangladesh	2630	3550	2200
Wheat (12% protein)	Netherlands	7700	Argentina	1850	2550	1200
Soybeans (30% protein)	Canada	2650	India	1000	1900	1200

Figures are rounded-off averages from the *FAO Production Yearbook*, 1990. Yields of basic food crops have leveled off with very little increase since 1990, and the difference between rich and poor countries remains wide.

[a]Sugar is estimated as 10 percent of the harvest weight of the cane, as reported in the *Yearbook*

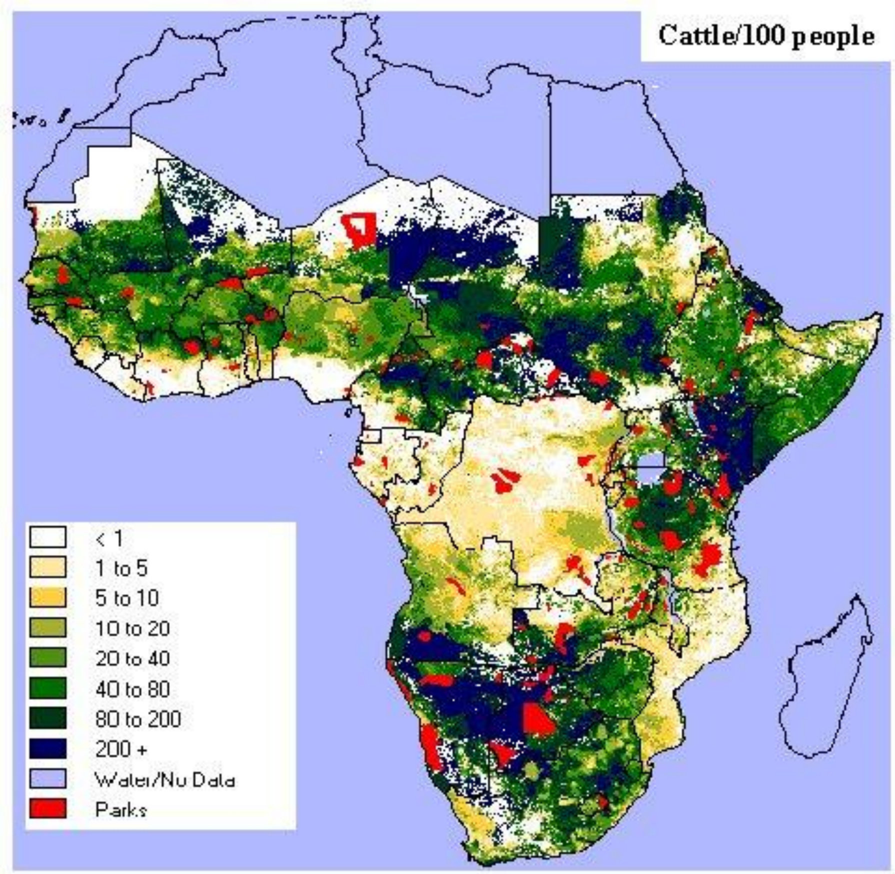
Crop	Country	Yield		Share of the Country in world production %	World average		
		Year					
		1998	**1999**		1999	1990	1970
wheat	France	7603	7235	6	2711	2550	1200
	England	7558	8051	2.5			
	Egypt	5990	6347	1			
	USA	2907	2872	11			
	China	3667	3969	19.4			
	India	2578	2583	11.5			
	Turkey	**2234**	**2081**	**3.2**			
	Syria	2299	1922	0.5			
	Russia	1029	1347	5.7			
	world average	2624	2711				

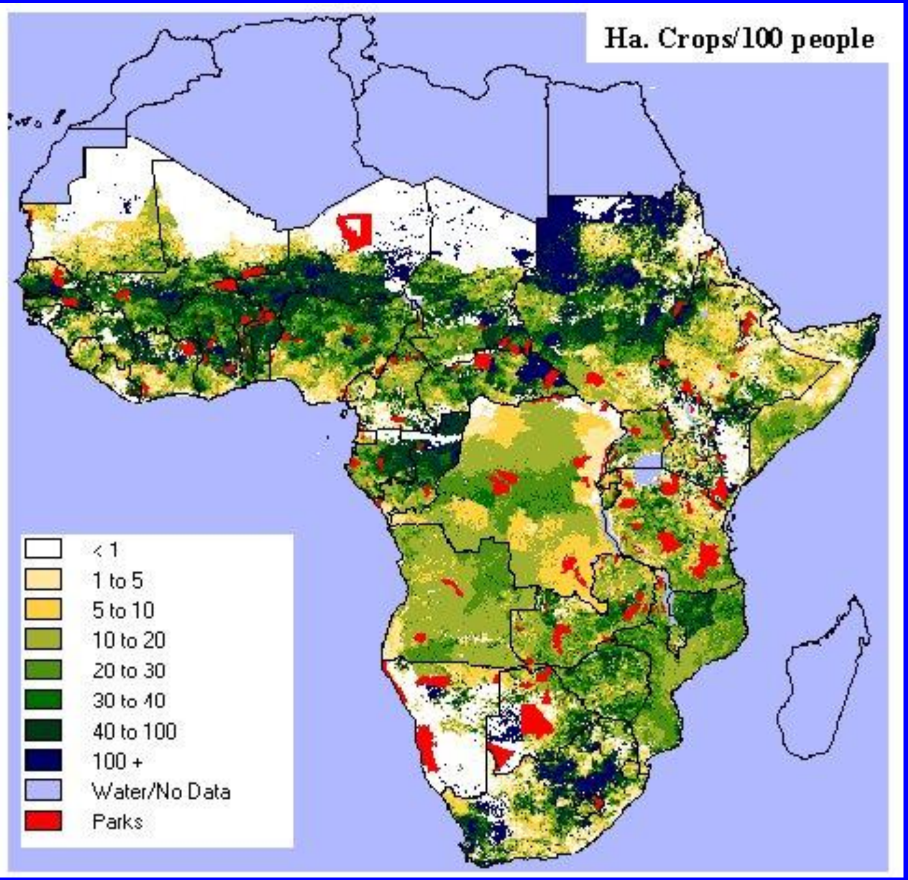
Food for domestic animals

Domestic animals consume a large amount of world’s net primary production (more than humans do)

The ratio of livestock to people (in biomass equivalent units)

New Zealand	43:1	(sheep)
Japan	0.6:1	(fish)





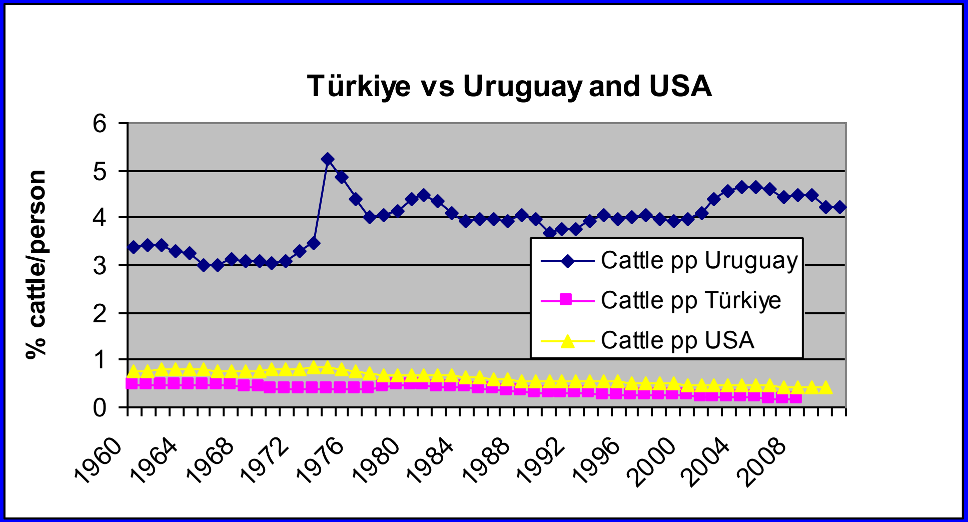
http://ergodd.zoo.ox.ac.uk/livatl2/index.htm
http://www.fao.org/

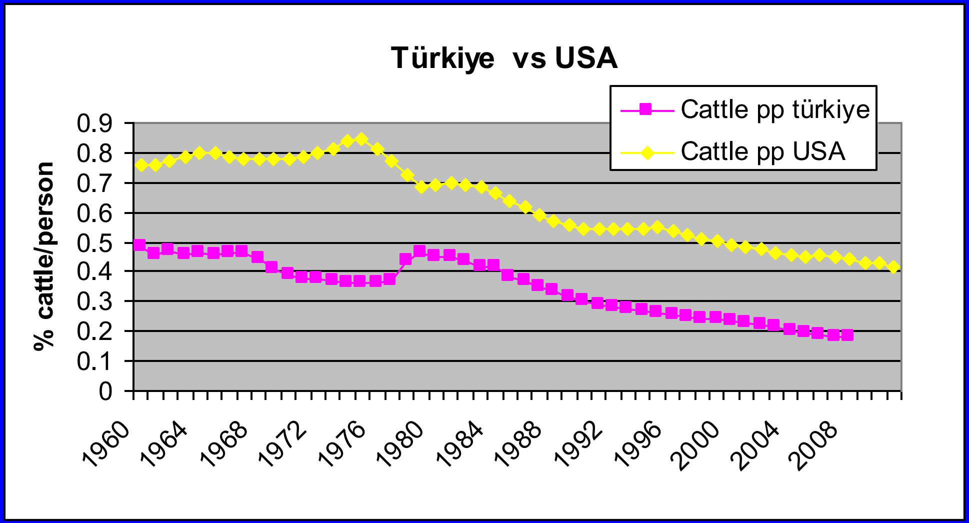
MercoPress. South Atlantic News Agency

Montevideo, December 5th 2011 - 12:47 UTC

Uruguay has 3.8 cattle per capita, highest in the world

Uruguay currently has a cattle herd of 12 million head with beef becoming the main export commodity of the country, over a billion US dollars last year. Based on this it can be said that Uruguay is the country with the highest number of cattle per capita, 3.8.





http://www.census.gov/population/international/data/idb/informationGateway.php

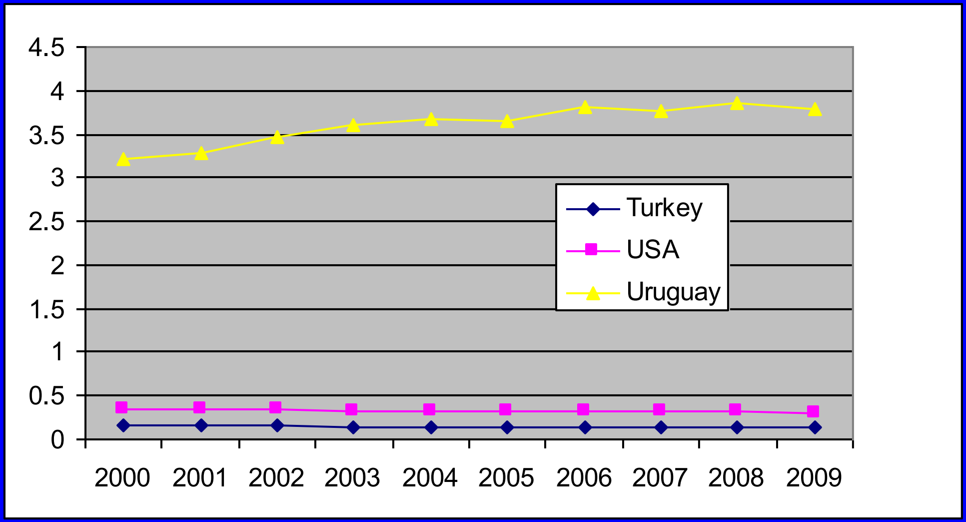
http://www.indexmundi.com/agriculture/?country=tr&commodity=cattle&graph=total-distribution

TOP 10 BEEF PRODUCING COUNTRIES

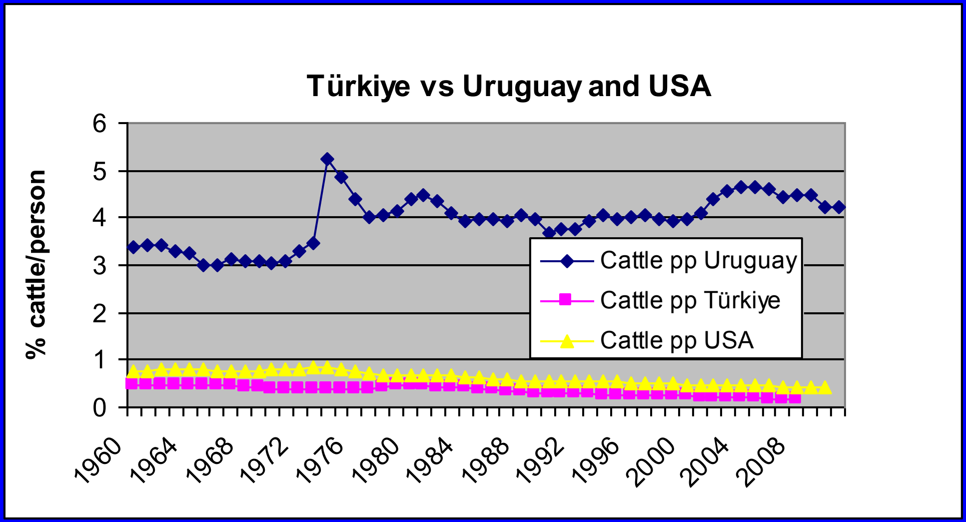
United States
25%
Brazil
20%
EU-27
17%
China
12%
Argentina
6%
India
6%
Australia
4%
Mexico
4%
Pakistan
3%
Russia
3%

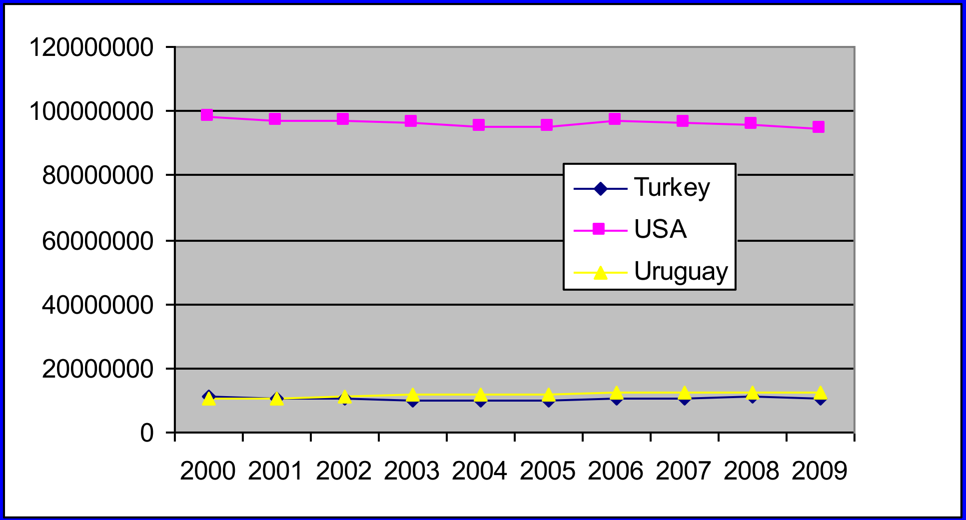
TOP 10 PORK PRODUCING COUNTRIES

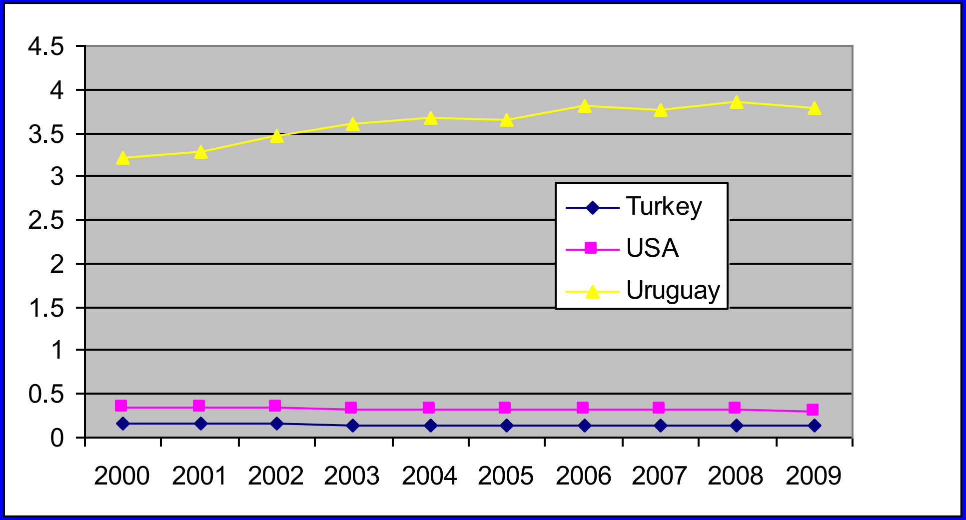
China
54%
EU-27
23%
United States
11%
Vietnam
2%
Canada
2%
Japan
1%
Russia
2%
Brazil
3%
Mexico
1%
Philippines
1%

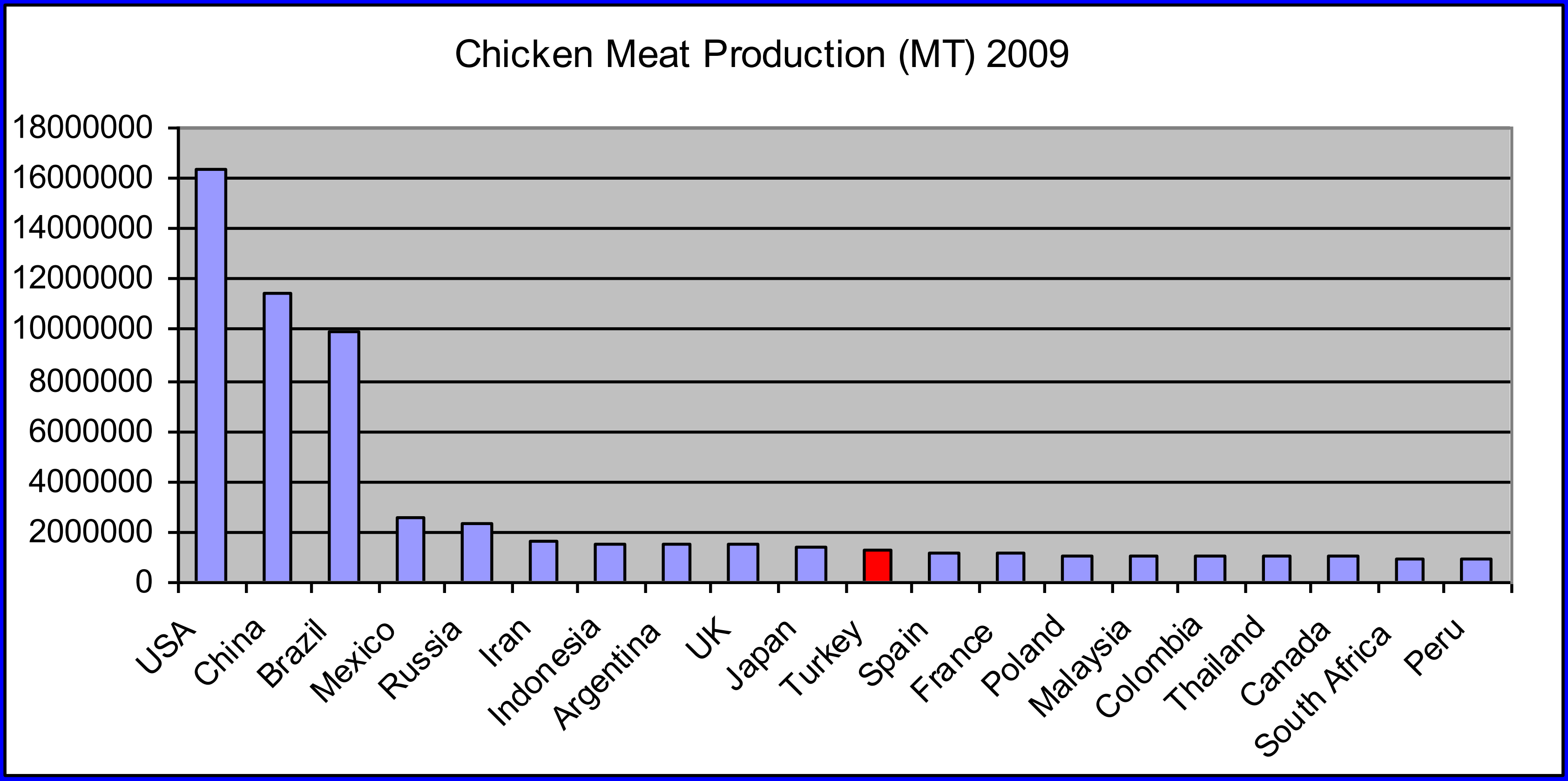


http://faostat.fao.org/site/573/DesktopDefault.aspx?PageID=573

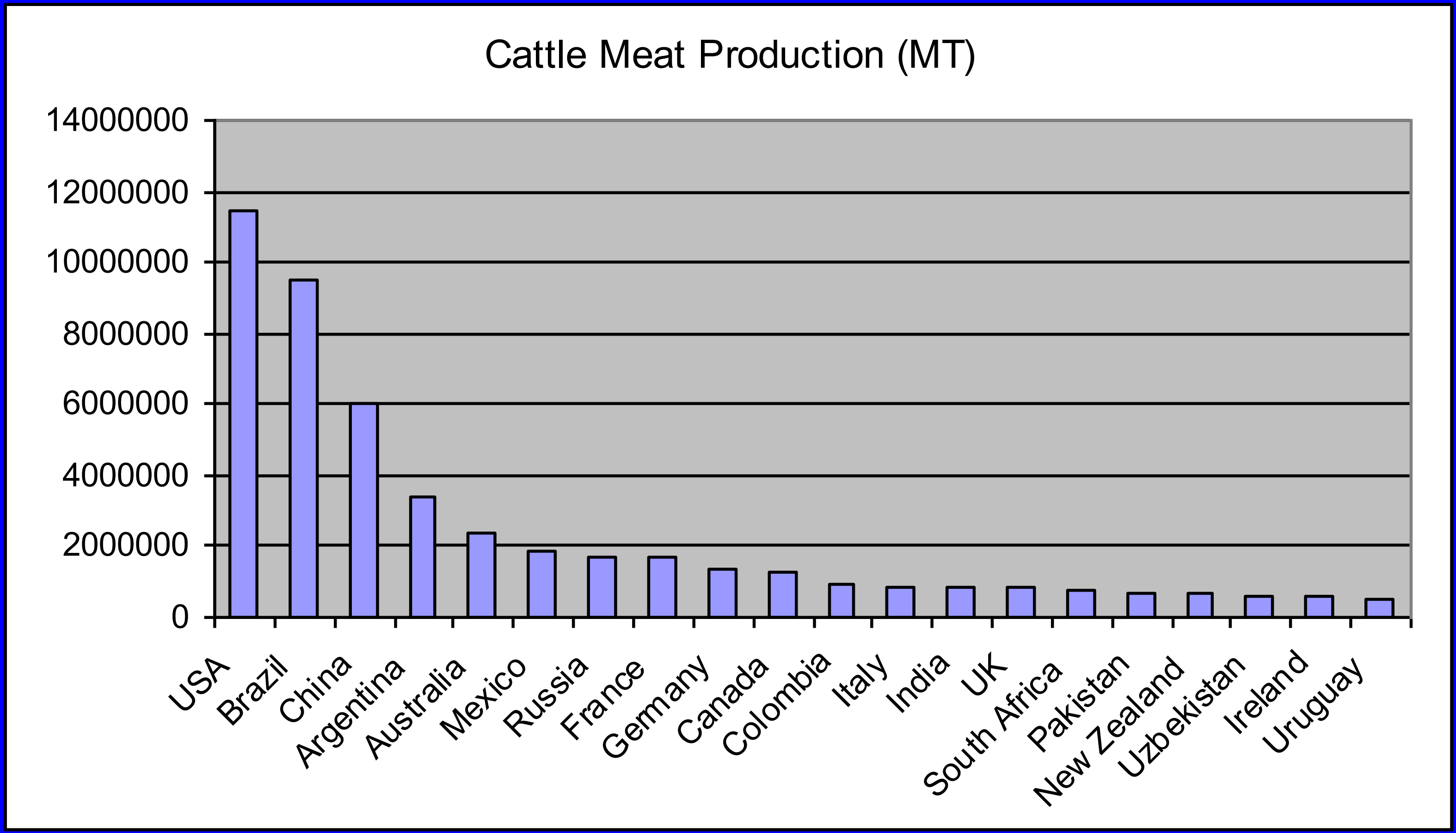


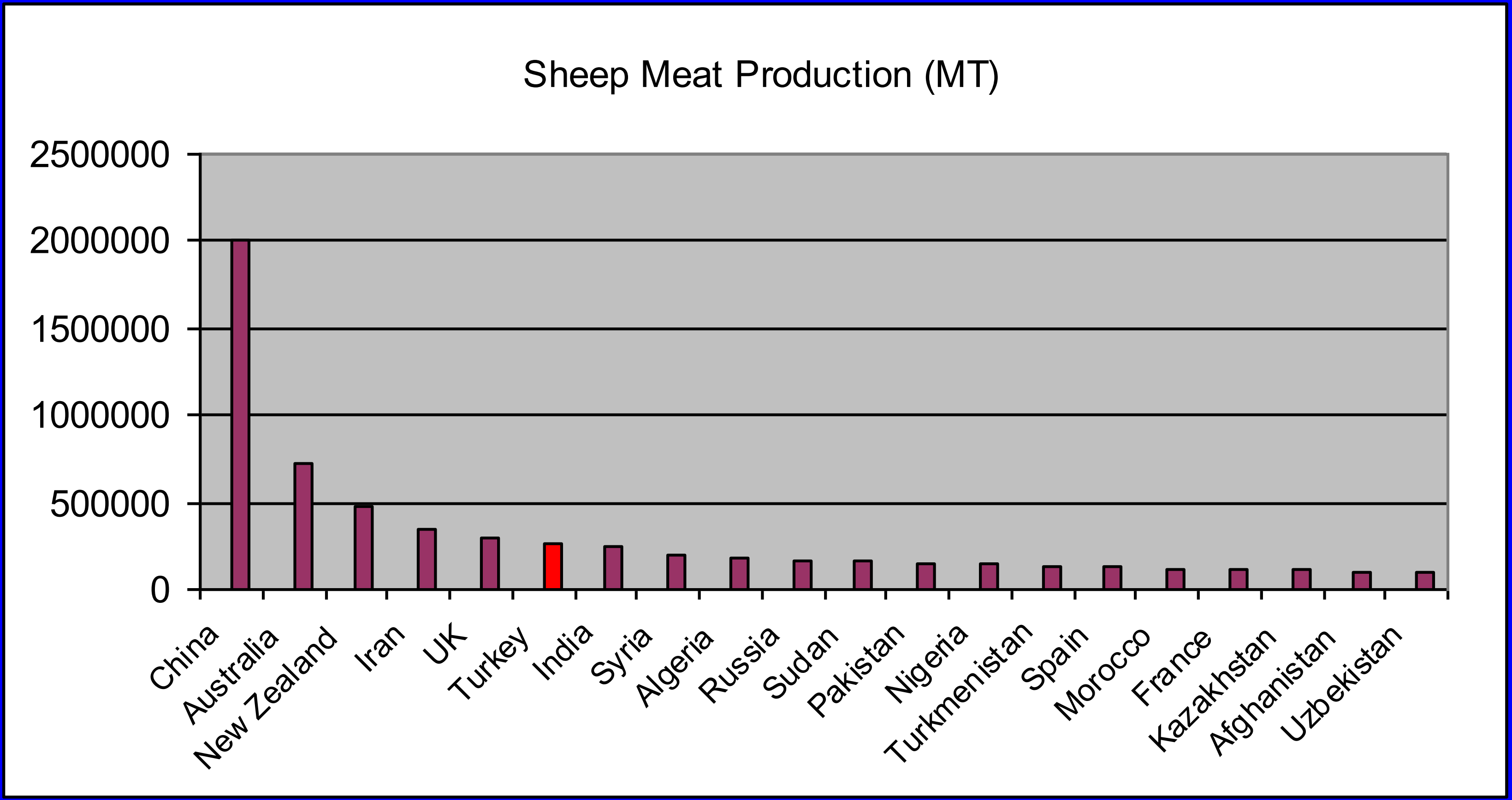

120000000
100000000
80000000
60000000
40000000
20000000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Turkey
USA
Uruguay


4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Turkey
USA
Uruguay

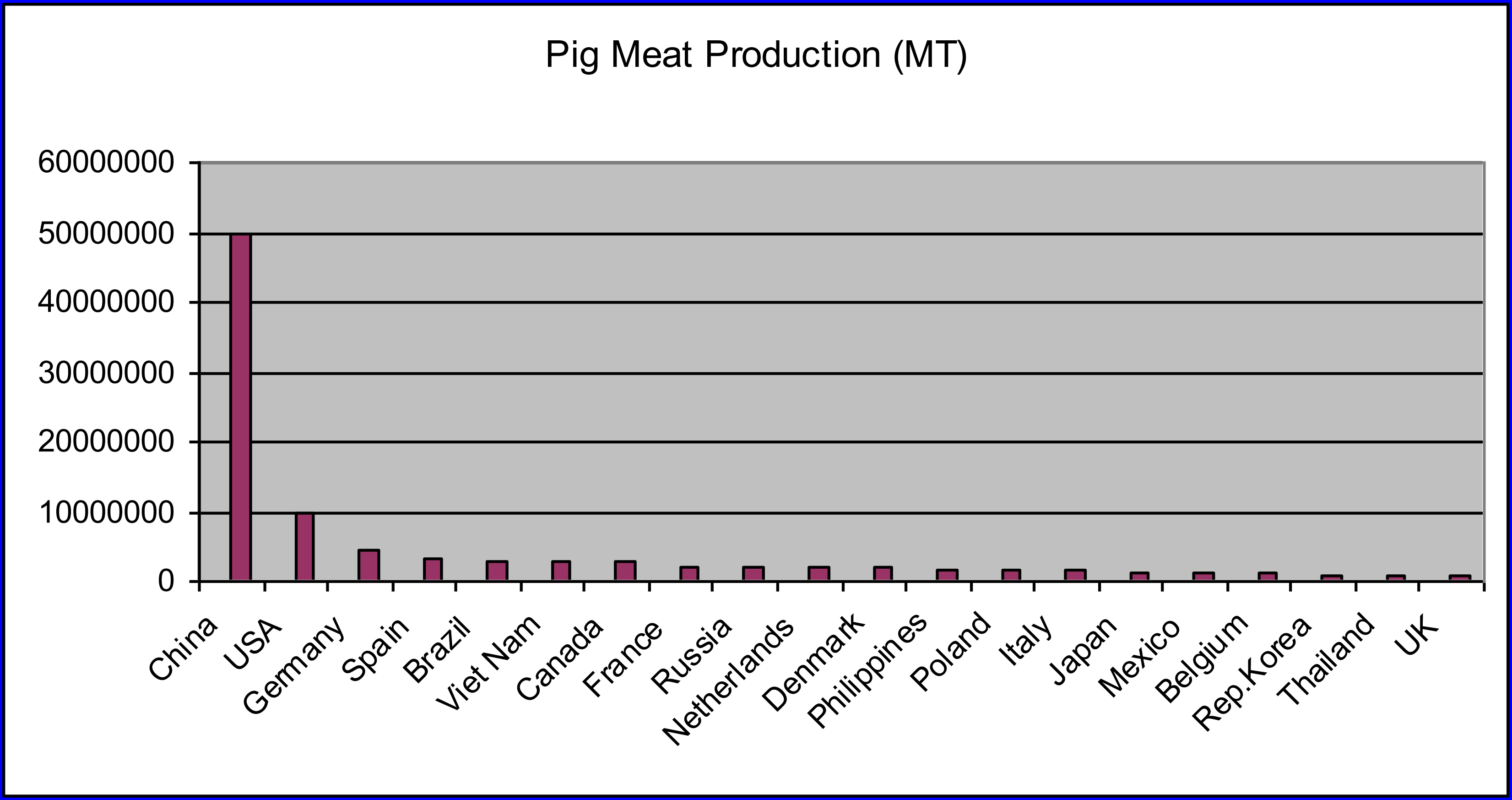


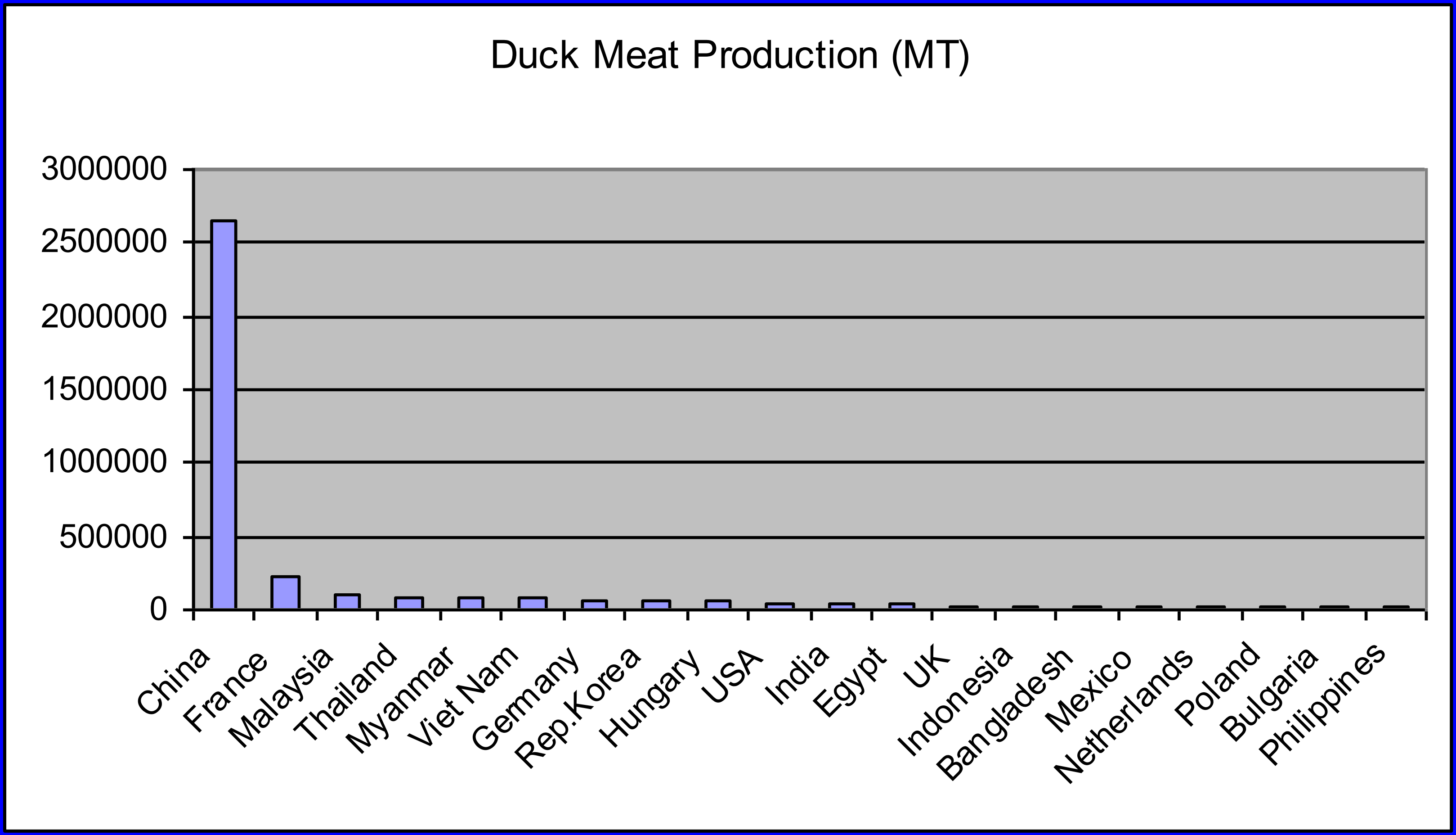
Chicken Meat Production (MT) 2009
18000000
16000000
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
USA
China
Brazil
Mexico
Russia
Iran
Indonesia
Argentina
UK
Japan
Turkey
Spain
France
Poland
Malaysia
Colombia
Thailand
Canada
South Africa
Peru


Cattle Meat Production (MT)
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
USA
Brazil
China
Argentina
Australia
Mexico
Russia
France
Germany
Canada
Colombia
Italy
India
UK
South Africa
Pakistan
New Zealand
Uzbekistan
Ireland
Uruguay



Sheep Meat Production (MT)
2500000
2000000
1500000
1000000
500000
0
China
Australia
New Zealand
Iran
UK
Turkey
India
Syria
Algeria
Russia
Sudan
Pakistan
Nigeria
Turkmenistan
Spain
Morocco
France
Kazakhstan
Afghanistan
Uzbekistan


Pig Meat Production (MT)
60000000
50000000
40000000
30000000
20000000
10000000
0
China
USA
Germany
Spain
Brazil
Viet Nam
Canada
France
Russia
Netherlands
Denmark
Philippines
Poland
Italy
Japan
Mexico
Belgium
Rep.Korea
Thailand
UK


Duck Meat Production (MT)
3000000
2500000
2000000
1500000
1000000
500000
0
China
France
Malaysia
Thailand
Myanmar
Viet Nam
Germany
Rep.Korea
Hungary
USA
India
Egypt
UK
Indonesia
Bangladesh
Mexico
Netherlands
Poland
Bulgaria
Philippines

Food from the Sea

Less than 5% is coming from the sea

Aquaculture is getting important

1/7 of the world's production is from cultured fish

Adding minerals and high protein fish chow
can increase the efficiency.

Cold temperatures
Suitable area
pollution

Fuel and fiber production

Primary production:

Food, also:

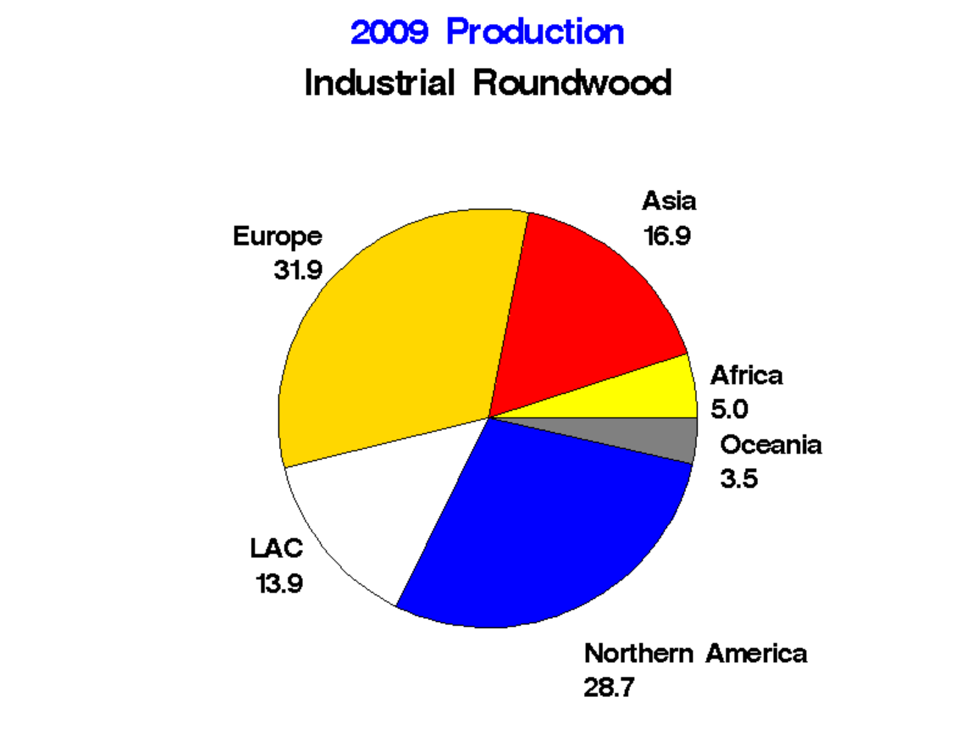
Fiber (e.g. cotton and paper)

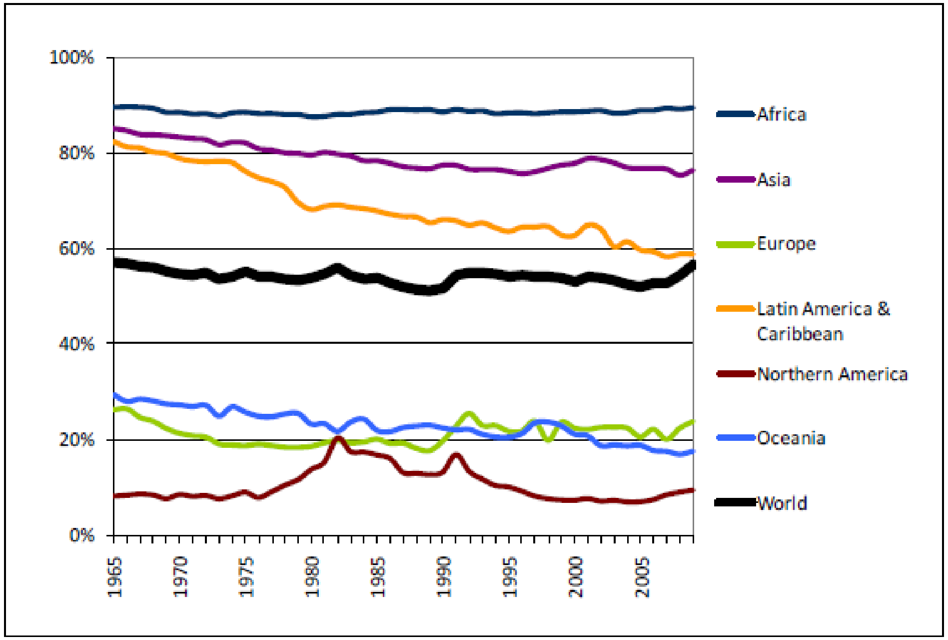
Fuel

Wood: both used as fuel and raw material to make paper

Worldwide, half of the wood consumption is for fuel ("fuel wood"), but in developing countries this figure rises to 80 percent. For almost 3 billion people, wood is the main energy source for heating and cooking.

Developed countries: wood is consumed as building material, in paper and packaging industry ("industrial roundwood").


2009 Production
Industrial Roundwood
Asia
16.9
Europe
31.9
Africa
5.0
Oceania
3.5
LAC
13.9
Northern America
28.7



Share of wood fuel in total roundwood production (%)

The world's leading per-capita consumers of timber (all using more than three times the global average) include nations at all levels of economic development: Liberia and Zambia; Malaysia and Costa Rica; Sweden and the United States of America.

By continent, Africa is the second largest per-capita consumer of wood, after North America.

There is no sharp divide in total wood consumption between under-developed and developed countries, largely because under-developed countries have a large demand for wood as fuel.

collection of wood for fuel is generally a less important cause of worldwide deforestation :

(forest clearance for farming is number one)

- **it is a prime cause of the loss of African tropical forests, particularly in the hinterland of cities, which still rely on wood for their energy requirements.**
- **Many countries, particularly in Asia, face a growing domestic shortage of wood for this basic purpose, notably Bangladesh, Nepal and Pakistan .**

In North America and other regions with large standing stocks of vegitation, there is interest in *using biomass from both forest and agricultural land as fuel.* Options:

Planting fast growing trees
Complete tree harvest (to use all parts of the tree).
Recycling paper
Obtaining methane and alcohol from the <u>waste</u>
Growing crops for alcohol production to be used in car engines.

Energy partitioning in food webs

4% used by humans and domestic animals
34% non-edible production or destroyed by human activities
50% available for other creatures

Why does biomass decrease at each trophic level?

Because transfer of energy from one level to the other one is inefficient.

100 kg of grass → 10 kg of rabbit → 1 kg of fox

Roots left behind

Can not digest everything + Maintanance energy

Bones and fure left behind

Energy partitioning in the individuals

energy ⟶ Maintanance or
Existance
+
Growth, reproduction,
Stored
+
Excretions

Warm blooded animals respire more than cold blooded animals
Predators expend larger assimilated energy than herbivores.

Energy based classification of ecosystems

Developed	fuel powered
Cultivated	subsidized solar powered
Natural	solar powered