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AGRICULTURAL RESEARCH IN 21ST CENTURY: CHALLENGES FACING THE FOOD SECURITY UNDER THE IMPACTS OF CLIMATE CHANGE

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Abstract

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During the recent decades, global climate change recognized as one of the most serious challenges facing the world – its people, the environment and its economies. Agriculture will face significant challenges in the 21st century, largely due to the need to increase global food supply under the declining availability of soil and water resources and increasing threats from climate change. Nonetheless, these challenges also offer opportunities to develop and promote food and livelihood systems that have greater environmental, economic and social resilience to risk. It is clear that success in meeting these challenges will require both the application of current multidisciplinary knowledge, and the development of a range of technical and institutional innovations. The changing climate is also a major challenge for agriculture and agricultural policy-making. Agriculture needs to address the double challenge of reducing its greenhouse gases emissions (GHGs) while at the same time adapting to projected impacts of climate change. In 2003, Nobel Laureate Richard E. Smalley outlined Humanity's Top Ten Problems for the next 50 years, in a talk given for the MIT Enterprise Forum. According to Professor Smalley, the biggest problems facing humanity are: Energy, Water, Food, Environment, Poverty, Terrorism and War, Disease, Education, Democracy and Population. The goal of the present study is to summarize main findings regarding some of these problems focusing on changes in climate conditions and to provide an overview of major challenges facing the global food and agricultural system in the 21st century and the impacts of the climate change. In the future, the review studies will focus on expanding the research for some specific challenges of climate change (Drought, cold, salinity) and its impact on agriculture.

Key words: Abiotic stresses, Agriculture, Biotechnology, Climate change, Food security, Drought, Cold, Salinity

How does the future look, why look to 2050, facts or idle speculation?

Wiebe Keith (2009) asks this fundamental question for any serious discussion concerns the humanity future "Why look to 2050?" and he formulates the next answer:

- Food prices and the economic crisis have increased the number of hungry to 1.02 billion in 2009, but the number has exceeded 800 million for decades
- Sustainable reduction in poverty and food insecurity remain long-term challenges
- Long-standing pressures will continue (e.g. population, income growth, urbanization)
- Some new pressures are likely to remain or return in the long run (e.g. biofuels)
- Some short-run shocks are likely to become more frequent in the long run (e.g. due to climate change)
- The structure of agriculture is changing
- Challenges are long-term and wide-ranging, but policy responses are needed now

The debate over what should be done about the biggest problems facing humanity raged in the new century.

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What are the facts?

Are we facing population overload?

In 1900, there were 1.6 billion of us; by 2000, the global population had shot up to 6.1 billion. Last year, we passed the seven billion mark. This century the world will come face to face with the results of the biggest population explosion in human history (Figure 1a). Population is still growing, but more slowly, nearly all-future population growth will be in the World's less developed countries (Figure1b). Developed countries as a whole will experience little or no population growth in this century, and much of that growth will be from immigration from less developed countries. The world's poorest countries will see the growth. In 1950, 1.7 billion people lived in less developed countries—about two-thirds of the world total; by 2050, the population of less developed countries will number over 8 billion, or 86 percent of world population. In 1950, only about 200 million of the population of the less developed countries resided in countries now defined as "least developed" by the United Nations, but that population is projected to rise to nearly 2 billion by 2050. Those countries have especially low incomes, high economic vulnerability, and poor human development indicators (Population Reference Bureau, 2012).

World Urbanization Prospects

Urbanization is one of the key drivers of change in the world today. The world's urban population currently stands at around 3.5 billion. It will almost double to more than 6 billion by 2050. This is a challenge not only for urban areas but also for rural areas, because many people, especially the young, will migrate from rural areas to urban areas over this period. When addressing urbanization challenges, we are also addressing, directly or indirectly, rural and territorial development. What do we have to do to ensure people's access to good nutrition in cities? What do we have to do to produce enough food for urban dwellers? What infrastructures are needed and what kind of food production is possible in cities? How can cities preserve the services of the surrounding ecosystems? A very wide range of important issues links urbanization and food security (FAO, 2011).The urbanization is changing dietary preferences, but also sources of income and vulnerability. The structural transition is also happening within rural areas. Income growth (Figure 2) is still uneven across and within countries (Wiebe, 2009).The expectation is strong growth in the world economy until 2050 (Figure 3), with real GDP growth at PPP exchange rates of 4.6% per annum until 2030 and 3.8% for the period 2030-2050. This would cause global real GDP at PPP exchange rates to rise from $73 trillion in 2010 to about $377 trillion in 2050 (Buiter and Rahbari, 2011).

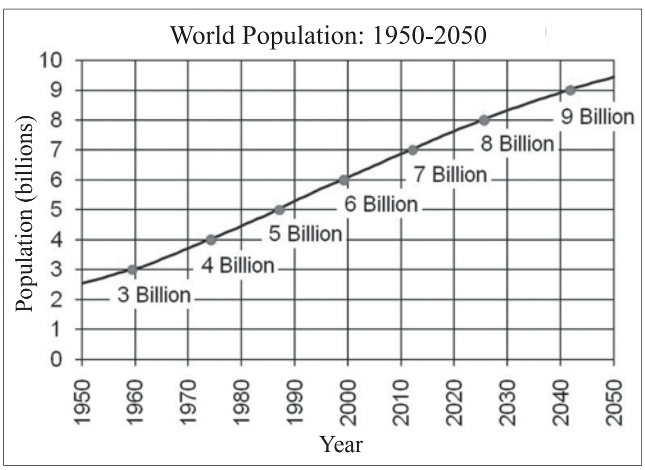

Fig. 1a. Population growth (World Population: 1950–2050)
Source: U.S. Census Bureau, International Data Base, June 2011 update

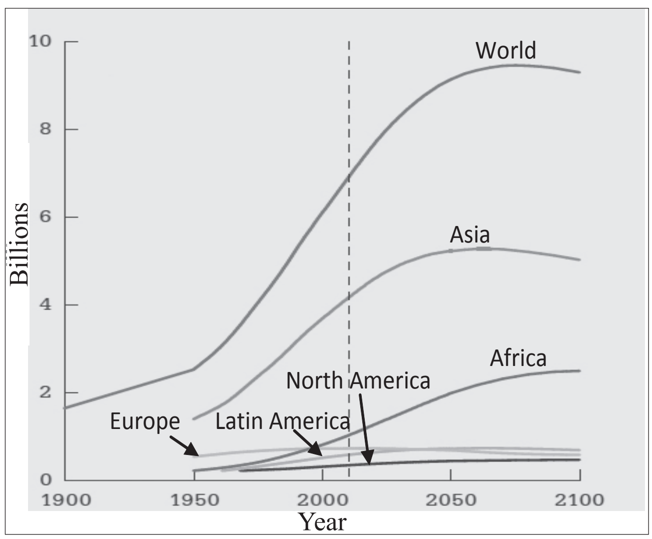

Fig. 1b. Population growth (World Population distribution: 1950 - 2100)
Source: Population: One Planet, Too Many People? Edited by Nabil Abumhadi 2012

World Hunger and Poverty Facts and Statistics

The reason why 850 million people go hungry each day - the vast majority being rural dwellers in the developing world - probably has less to do with food production than poverty - the rich never starve, the poor often do. However, there is a fear now that food shortages may themselves lead to instability, famine and mass migration.

According to FAO's most recent estimate, the number of people suffering from chronic hunger has increased from under 800 million in 1996 to over a billion. Most of the world's hungry are in South Asia and sub-Saharan Africa. These regions have large rural populations, widespread poverty and extensive areas of low agricultural productivity due to steadily degrading resource bases, weak markets and high climatic risks (Vermeulen et al., 2012).

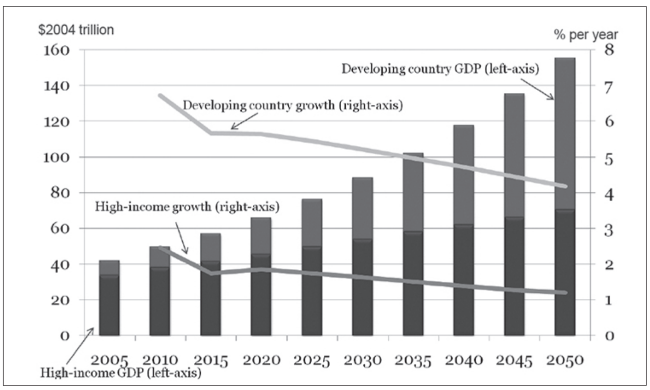

Fig. 2. Income growth
Source: Wiebe K.- FAO, 2009

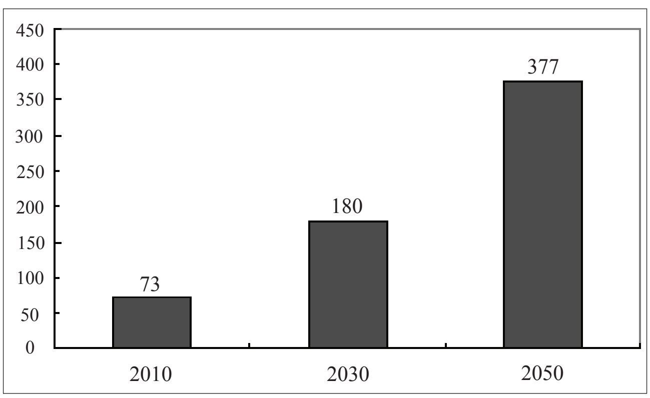

Fig. 3. World real GDP growth 2010-2050 (2010 USD Trillions)
Source: Buiter and Rahbari, 2011

Of the world's 1.1 billion extremely poor people, about 74 % (810 M) live in marginal areas and rely on small-scale agriculture. While the world currently produces enough food to feed everyone, at least one billion people remain food insecure.8 Although the incidence of hunger dropped from a ratio of one in three in 1960 to affecting roughly one in seven people by the 1990s, the trend reversed in the 1990s and the absolute number of people blighted by hunger continues to grow (Figure 4). In 2009, for the first time in history the population considered to be malnourished exceeded one billion people (Giovannucci et al., 2012).

Per capita food production and consumption has been falling for some years in sub-Saharan Africa, along with life expectancy. In addition, it is in poor African countries such as Malawi, Niger and Ethiopia that population is growing fastest, where the fertility of the land is falling most rapidly, and where the ability to absorb newcomers in the cities is most weak.

World hunger, according to the 2012 Global Hunger Index (GHI), has declined somewhat since 1990 but remains "serious." The global average masks dramatic differences among regions and countries. Regionally, the highest GHI scores are in South Asia and Sub-Saharan Africa. South Asia reduced its GHI score significantly between 1990 and 1996 - mainly by reducing the share of underweight children - but could not maintain this rapid progress. Though Sub-Saharan Africa made less progress than South Asia in the 1990s, it has caught up since the turn of the millennium, with its

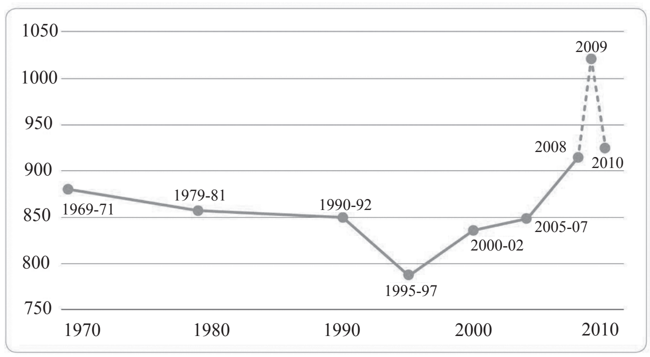

Fig. 4. Trend of undernourished people(millions) 1970–2010
Source: FAO. 2011. Rural Poverty Report. Rome – using other FAO publications sources: "State of Food Insecurity in the World" and "Global Hunger Declining but Still Unacceptably High".

2012 GHI score falling below that of South Asia (Grebmer et al., 2012).

World production and use, major products

To meet the world's increasing demand for food, an anticipated 70-percent boost in global food production will be necessary by 2050 (Table 1). To protect the environment, most of the growth in food production will need to come from increased yields and productivity rather than from the use of additional land – a challenge met in prior years. For the food system to become more productive, sustainable and reliable, agricultural raw materials will need to be grown where resources provide the greatest production efficiency and can be renewed so that production can continue for many years.

The evolution of food production systems over the last decades has been characterized by an increased integration between agriculture, fishery and forestry and other economic activities.

The projected growth rate of total world consumption of all agricultural products is 1.1 percent p.a. from 2005/07-2050. Since at the world level (but not for individual countries or regions) consumption equals production, this means global production in 2050 should be 60 percent higher than that of 2005/07 (Alexandratos and Bruinsma, 2012).

Concerning the main product groups, percentage increases shown by growth rates may be small compared with those of the past, but the absolute volumes involved are nonetheless substantial (Figure 5). For example, world cereals production is projected to grow at 0.9 percent per year from 2005/07 to 2050, down from the 1.9 percent per year of 1961-2007. However, world production, which increased by 1,225 million tones between 1961/63 and 2005/07, is projected to increase by another 940 million tones in the next 44 years, to reach 3 billion tones by 2050 (Alexandratos and Bruinsma, 2012).

Achieving such production increases will not be easier than in the past; rather, the contrary often holds for a number of reasons. Land and water resources are now much more stressed than in the past and are becoming scarcer, both in quantitative terms (per capita) and qualitative ones, following soil degradation, saliniza-

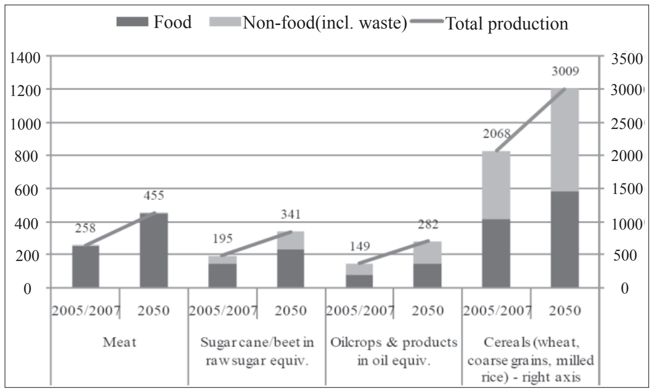

Fig. 5. World production and use, major products (million tonnes)

Source: Alexandratos, N. and J. Bruinsma (2012)

Table 1
World: Offer and estimated demand for food (in million tons)

Product	Production (2005)	Estimated demand (2025)	Necessary additional product	Increase of the production
Cereal	2 219.40	3 140.40	921.00	41.5
Oil seeds	595.01	750.97	155.96	26.2
Perennials	242.81	321.99	79.18	32.6
Annual	352.20	437.98	85.78	24.4
Meat [1]	264.70	376.49	111.79	42.2
Poultry	80.00	113.70	33.70	42.1
Pork	103.40	146.80	43.40	42.0
Bovine	63.50	90.40	26.90	42.4
Coffee	7.72	9.40	1.68	21.8
Fiber	28.50	36.37	7.87	27.6
Wood	3 401.90	4 148.40	746.50	21.9

Source: FAO (2003) Elaboration: AGE-MAPA [1] all of consumed meats tion of irrigated areas and competition from uses other than for food production (Alexandratos and Bruinsma, 2012). Growth of crop yields has slowed down considerably, and fears are expressed that the trend may not reverse. The issue is not whether yields would grow at the past high rates, as they probably would not, apart from the individual countries and crops. Rather, the issue is whether the lower growth potential, together with modest increases in cultivated land, is sufficient to meet the increased requirements. Climate change, furthermore, looms large as a risk that would negatively affect the production potentials of agricultural resources in many areas of the world (Alexandratos and Bruinsma, 2012).

In general, the sustainability of the food production system is being questioned. Doubts are cast on the possibility to continue doing more of the same that is, using high levels of input in production, increasing the share of livestock in total output, expanding cultivated land and irrigation, and transporting products over long distances. Many advocate the need for "sustainable intensification" of production (Society, 2009; Godfray et al., 2010; Nature, 2010). Will it be possible to achieve the projected quantities of production? We shall show what we consider are possible combinations of land and water use and yield growth that could underlie the production projections.

According to the International Food Policy Research Institute, the annual growth in cereal yields is projected to fall to about one per cent during the next two decades. However, the Food and Agricultural Organization estimates that total food production of all sorts will grow annually at about 1.5 per cent over the next 30 years, keeping ahead of population growth, now running at 1.3 per cent a year (Diouf, 2012).

Food prices

Global food prices rose twice as fast as inflation in the last decade (Figure 6), impoverishing millions at a time when poverty relief captured the world's attention. Huge price swings for wheat; maize; soybeans and rice - staple crops for much of the world - made matters worse, disrupting markets and harming both producers and consumers. The food riots that swept more than two dozen countries in 2008 and 2011 were the most visible effect of these trends, but they also point to a deeper and more lasting concern: chronic food insecurity (von Grebmer et al., 2012).

On average, food prices are expected to rise moderately in line with moderate increases of temperature until 2050; some studies even foresee a mild decline in real prices until 2050. Second, after 2050 and with further increases in temperatures, prices are expected to increase more substantially (Tubiello et al., 2008). Local food prices in developing countries increased 8.9 percent in 2011, reflecting drought conditions in several developing regions the year before (notably in Europe and Central Asia and the Horn of Africa) and a sharp 24 percent rise increase in the dollar price of international food commodities. Food prices in 2012 are expected to average 3 percent lower than in 2011, assuming a normal crop year (Table 2). Despite the welcome normalization of domestic food price inflation, domestic food prices in developing countries remain 25 percent higher relative to non-food consumer prices than they were at the beginning of 2005. While incomes in developing countries have continued to rise, the sharp increase in food prices will have limited gains for many households, such as the urban poor, where food often represents more-than one-half of their total expenditures (The World Bank, 2012).

Climate Change

Terminology

The most general definition of *climate change* is a change in the statistical properties of the climate system when considered over long periods of time, regardless of cause (NSIDC, 2012). Accordingly, fluctuations

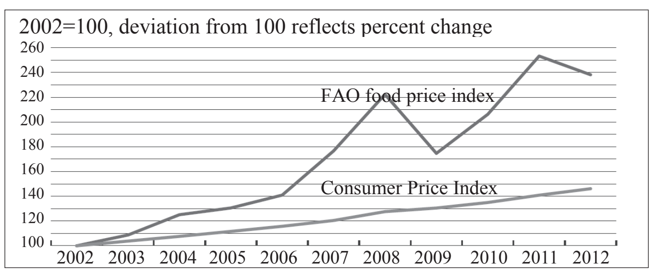

Fig. 6. Rise of global food prices vs inflation
Source: Economist Intelligence Unit and Food and Agriculture Organization. Edited by Nabil Abumhadi 2012

over periods shorter than a few decades, such as El Niño, do not represent climate change.

The term sometimes is used to refer specifically to climate change caused by human activity, as opposed to changes in climate that may have resulted as part of Earth's natural processes (The United Nations Framework Convention on Climate Change. http://unfccc.int/essential_background/convention/background/items/1349.php, 1994). In this sense, especially in the context of environmental policy, the term climate change has become synonymous with anthropogenic global warming. Within scientific journals, global warming refers to surface temperature increases while climate change includes global warming and everything else that increasing greenhouse gas levels will affect (NASA, 2008).

Causes

On the broadest scale, the rate at which energy is received from the sun and the rate at which it is lost to space determine the equilibrium temperature and climate of Earth. This energy is distributed around the globe by winds, ocean currents, and other mechanisms to affect the climates of different regions.

Factors that can shape climate are called climate forcing or "forcing mechanisms" (EPA U.). These include processes such as variations in solar radiation, variations in the Earth's orbit, mountain building and continental drift and changes in greenhouse gas concentrations. There are varieties of climate change feedbacks that can either amplify or diminish the initial forcing. Some parts of the climate system, such as the oceans and ice caps, respond slowly in reaction to climate forcing, while others respond more quickly.

Forcing mechanisms can be either "internal" or "external". Internal forcing mechanisms are natural processes within the climate system itself (e.g., the thermohaline circulation). External forcing mechanisms can be either natural (e.g., changes in solar output) or anthropogenic (e.g., increased emissions of greenhouse gases).

Whether the initial forcing mechanism is internal or external, the response of the climate system might be fast (e.g., a sudden cooling due to airborne volcanic ash reflecting sunlight), slow (e.g. thermal expansion of warming ocean water), or a combination (e.g., sudden loss of albedo in the arctic ocean as sea ice melts, followed by more gradual thermal expansion of the water). Therefore, the climate system can respond abruptly, but the full response to forcing mechanisms might not be fully developed for centuries or even longer.

Internal forcing mechanisms

Natural changes in the components of Earth's climate system and their interactions are the cause of internal climate variability, or "internal forcings." Scientists generally define the five components of earth's climate system to include atmosphere, hydrosphere,

Table 2
Nominal price indices—actual and forecasts (2005 = 100)

	Actual						Forecast		Change	
	2006	2007	2008	2009	2010	2011	2012	2013	2011/12	2012/13
Energy	118	130	183	115	145	188	191	185	1.3	-3.0
Non-Energy	125	151	182	142	174	210	192	188	-8.5	-2.2
Agriculture	112	135	171	149	170	209	193	184	-7.8	-4.4
Food	111	139	186	156	170	210	204	193	-2.7	-5.7
Beverages	107	124	152	157	182	208	168	163	-19.3	-2.7
Raw materials	118	129	143	129	166	207	177	174	-14.3	-1.9
Fertilizers	104	149	399	204	187	267	268	245	0.4	-8.5
Metals	154	186	180	120	180	205	182	189	-11.2	3.7
Memorandum items										
Crude oil, $/bbl	64	71	97	62	79	104	107	103	2.5	-3.4
Gold, $/toz	604	697	872	973	1 225	1 658	1 675	1 600	6.8	-4.5

Source: World Bank

cryosphere, lithosphere (restricted to the surface soils, rocks, and sediments), and biosphere (NASA Earth Observatory, 2011).

Cost of climate change

Understanding the climate change impacts on the world economy is, obviously, of paramount importance for both climate change mitigation and adaptation policies. Modeling climate impacts, however, is a quite hard enterprise, for two main reasons (Roson and Mensbrugghe, 2010).

First, climate change is a systemic phenomenon, both in terms of natural and human systems. In the so-called "Earth System", physical elements like the oceans, winds, the stratosphere, etc., interact in the determination of global climate conditions. In terms of socio-economic consequences, market linkages and trade propagate the effects of no economic factors throughout the globalize economy. As climate change is an intrinsically systemic phenomenon, it is inherently affected by complexity and uncertainty.

Second, socio-economic impacts of climate change have different dimensions (e.g., sea level rise, human health, etc.), each one with different mechanisms and implications. To achieve a realistic assessment of the impacts, there is a need to separately and adequately address each dimension.

The world is set to pay a heavy price if it fails to tackle climate change. As per a report commissioned by 20 governments, more than 100 million people will die and global economic growth will be cut by 3.2 percent of gross domestic product (GDP) by 2030 if steps are not taken to arrest climate change (Zeenews Bureau, 2012). Roson and Mensbrugghe (2010) described how the climate change impacts on the world economy have been modeled and how parameters have been estimated. Seven types of impacts are considered in the work: agriculture productivity, sea level rise, water availability, tourism, energy demand, human health and labor productivity. Catastrophic events and extreme weather are not taken into account (Roson and Mensbrugghe, 2010).

The report by humanitarian organisation DARA says that as global average temperatures rise due to greenhouse gas emissions, the effects on the planet, such as melting ice caps, extreme weather, drought and rising sea levels, will threaten populations and livelihoods (ZEENEWS BUREAU, 2012). It calculated that five million deaths occur each year from air pollution, hunger and disease as a result of climate change and carbon-intensive economies, and that toll would likely rise to six million a year by 2030 if current patterns of fossil fuel use continue. As per the report, more than 90 percent of those deaths will occur in developing countries, said the report that calculated the human and economic impact of climate change on 184 countries in 2010 and 2030. The Climate Vulnerable Forum, a partnership of 20 developing countries threatened by climate change, commissioned it. "A combined climate-carbon crisis is estimated to claim 100 million lives between now and the end of the next decade," the report said. It said the effects of climate change had lowered global output by 1.6 percent of world GDP, or by about $1.2 trillion, a year and losses could double to 3.2 percent of global GDP by 2030 if global temperatures are allowed to rise, surpassing 10 percent before 2100.

It estimated the cost of moving the world to a low-carbon economy at about 0.5 percent of GDP this decade (Zeenews Bureau, 2012).

In the following, we briefly describe how the climate change influences Food Security and agriculture.

Agriculture and Food Security under Climate Change

Agriculture in the 21st century faces multiple challenges: it has to produce more food and fibre to feed a growing population with a smaller rural labour force, more feed stocks for a potentially huge bioenergy market, contribute to overall development in the many agriculture-dependent developing countries, adopt more efficient and sustainable production methods and adapt to climate change (Bruinsma, 2009).

In the study done by the International Food Policy Research Institute (IFPRI), titled 'Climate change: Impact on agriculture and costs of adaptation', highlighted some of the anticipated costs of climate change:

□□25 million more children will be malnourished in 2050 due to climate change without serious mitigation efforts or adaptation expenditures.

□□Irrigated wheat yields in 2050 will be reduced by around 30% and irrigated rice yields by 15% in developing countries.

□□Climate change will increase prices in 2050 by 90% for wheat, 12% for rice and 35% for maize, on top of already higher prices.

□□At least US$7 billion a year are necessary to improve agricultural productivity to prevent adverse effects on children.

It is generally accepted that climate change is the result of human activity including industrial output, car exhaust, and deforestation. These types of activities increase the concentrations of carbon dioxide, methane, nitrous oxide and other greenhouse gases (GHGs) in the atmosphere. If the current trend in carbon emissions continues, temperatures will rise by about 1 degree C by the year 2030 and by 2 degree C by the next century. This increase, however, will probably have different impacts in different regions. Agricultural impacts, for example, will be more adverse in tropical areas than in temperate areas. Developed countries will largely benefit since cereal productivity is projected to rise in Canada, northern Europe and parts of Russia. In contrast, many of today's poorest developing countries are likely to be negatively affected in the next 50 – 100 years, with a reduction in the extent and potential productivity of cropland. Most severely affected will be sub-Saharan Africa due to its inability to adequately adapt through necessary resources or through greater food imports (FAO, 2003).

According to the Intergovernmental Panel on Climate Change (IPCC), in 2004 agriculture directly contributed 13.5 per cent of global greenhouse gas emissions (GHGs). In addition, deforestation, mainly to convert land to agricultural uses, contributed a further 17 per cent (Figure 7). Taken together, agriculture contributes about one third of global GHG emissions (Huang et al., 2010).

Like most other sectors, this carbon footprint is increasing, since farming is set to expand to produce more food for a growing world population. That means more land-use change, more cultivation of crops, many more livestock, more demands for water and more use of fossil fuels. In addition, that has to be seen in the light of more competition for the land for bioenergy

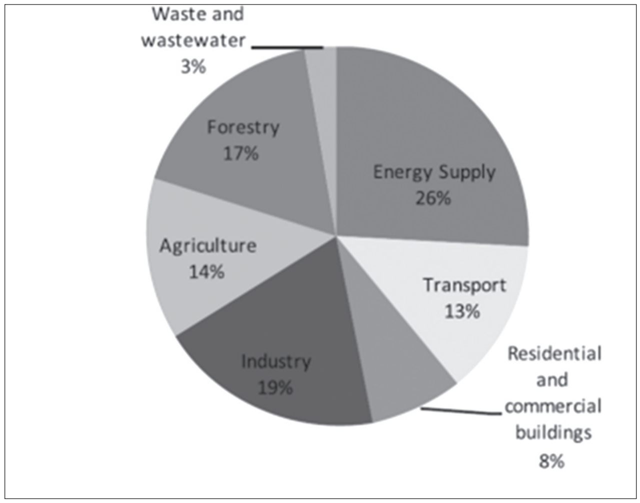

Fig. 7. Global GHG emissions by sector, in CO_2 equivalents

production as well as for urban and environmental uses. As well as being a source of GHGs contributing to climate change, agriculture is itself affected by shifts in climate. Projections to 2050 suggest an increase in both global mean temperatures and weather variability, including precipitation (IPCC, 2007).This will clearly affect the type and location of agricultural production worldwide, with implications for trade and for livelihoods (Huang et al., 2010).

"Agriculture is the sector most affected by changes in climate patterns and will be increasingly vulnerable in the future," said FAO in a press statement. "Especially at risk are developing countries, which are highly dependent on agriculture and have fewer resources and options to combat damage from climate change." Farming is most dependent on stable climate. "The most serious threats will not be occasional severe drought or heat wave but subtle temperature shifts during key periods in the crop's life cycle, as these are most disruptive to plants bred for optimal climatic conditions," wrote Danielle Nierenberg and Brian Halweil in a Worldwatch report (Diouf, 2012). Some of the impacts of climate change on food production which are already visible and seem to be advancing at a higher rate than previously anticipated include:

- The response of agricultural, pastoral and forest systems to simultaneous changes in atmospheric and climatic parameters:

- carbon dioxide - are there saturation effects, if so at what concentration level
- mean temperature and its variability (day-night and summer-winter ratios)
- mean precipitation and its variability
- other factors, including tropospheric ozone, UV-B and acid deposition
- The impact of changes in climate and atmospheric composition on: disturbance regimes, including fires and pest and disease outbreaks, Adaptation options (planting times, crop selection, irrigation, fertilization)
- new cultivars - the role of biotechnology, including transgenic crops (temperature, drought, pest and salinity tolerance)

Depending on the actual outcome for future climate change, the expected impacts on agriculture in temperate zones – which include OECD countries – and assuming no measures are taken to adapt, are summarised in (Table 3) (Huang et al., 2010).

Understanding the problem, targeting the solutions

The first step is to understand the problem; but this in itself is a major challenge. While climate scientists are working to understand what is going to happen to the climate, there is currently much uncertainty in their projections. Predicting how these uncertain changes will affect agricultural and food systems is thus extremely difficult. What we can do, however, is look at the vulnerability of systems, in the light of possible changes to the climate. Vulnerability depends on both sensitivity of the system to the climate, and the adaptive capacity of the population (Moorhead, 2009).

Table 3
Impacts of climate change on OECD (The Organization for Economic Co-operation and Development) agriculture

Temp. Change	Impact
+1° to +2°	Some increase in yield Cold limitatin alleviated Yield reduction on some latitudes (without adaption) Seasonal increase in heat-stress for livestock
+2° to +3°	Potential increase in yield due to CO_2 fertilisation (but likely offset by other factors) Moderate production losses of pigs and confined cattle Increased heat stress Yields of all crops fall in low latitudes (without adaptation)
+3° to +5°	Maize and wheat yields fall regardless of adaptation in low latitudes High production losses of pigs and confined cattle Increased heat stress and mortality in livestock

Source: Adapted from IPCC Working Group II Report, *Impacts, Adaptation and Vulnerability.*

Climate change on food security

Climate change is expected to impact food security in a number of different ways. The chart (Figure 8) opposite lists the important effects of global warming and climate change on agricultural food production, both positive and negative. For food security, we must focus on the negative aspects (http://www.climatechange-foodsecurity.org/many_impacts.html).

The negative adverse effects predominate in number and overall effect. The higher the global temperature increase the more the negative effects predominate. Increasing the CO_2 in the air potentially has a beneficial fertilizer effect on crops. However this only applies to some crops and for those global warming may have a modest and brief benefit (IPCC, 2007).There is no question at some level of warming from heat damage alone any CO_2 benefit will be negated. Troposphere (or ground level ozone) is increased with increasing temperatures and is toxic to green plants. This makes for double damage to crops from global warming. A red cross indicates the very many Impacts that are not included or poorly represented in the climate crop computer models (according to the IPCC). The absolute limit of crop tolerance in all regions is a global average temperature increase of 3.0C (see Met Office NRC and IPCC). However this relies on vary inadequate climate crop models, that do not capture many adverse impacts and so that should not be relied on for food security under climate change.

Atmospheric greenhouse gas pollution causes the following that all impact adversely of food productivity and food security.

They are global warming, global climate change, climate variation, heavier precipitation, more floods, more severe storm, more cyclones, more heat waves

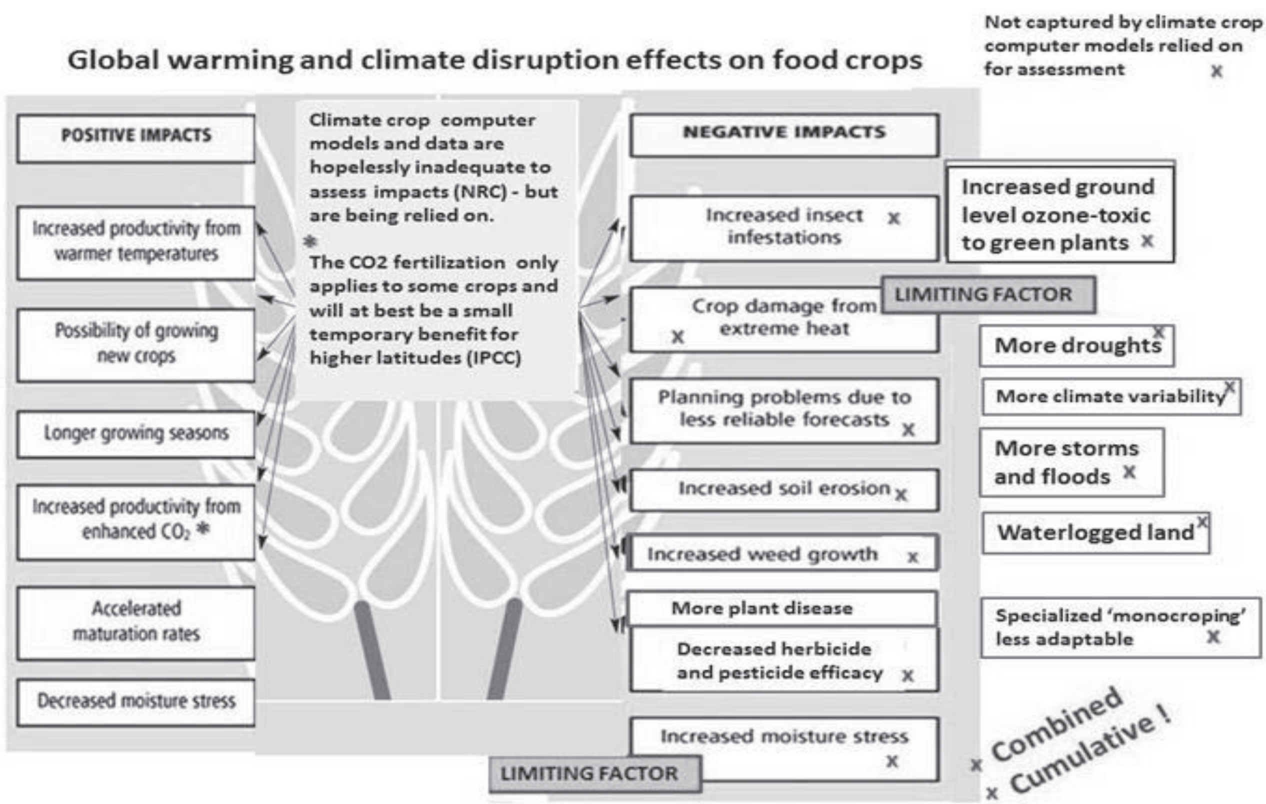

Fig. 8. The important effects of global warming and climate change on agricultural
Source: http://www.climatechange-foodsecurity.org/index.html

and sudden temperature spikes, increased troposphere ozone, ocean acidification (with ocean warming) and sea level rise, more weeds, more insect pests (+ more pesticide resistance), more plant diseases.

In responding to the future challenges for agriculture of addressing climate change and meeting growing food demand, it is important to develop a coherent policy approach that (Huang et al., 2010):

- ensures a stable policy environment that sends clear signals to consumers and producers about the costs and benefits of GHG mitigating/sequestering activities;
- implements policies that provide a real or implicit price of carbon to create incentives for producers and consumers to invest in low-GHG products, technologies and processes;
- designs policies that foster the application of existing technologies and invest in research and development for new technologies to reduce GHG emissions and increase productivity;
- builds capacity to better understand and measure the GHG impact of agricultural activities – essential for monitoring progress relative to national and international climate change goals;
- implements or enhances existing policies that facilitate adaptation by increasing producer resilience to climate change, and that compensate the most vulnerable groups, in particular in developing countries; and
- encourages more research on understanding and linking agronomy, ecology and economics, in particular taking into account

These days, seasons are changing, temperature is rising of both earth and seawater and there is no end to it. Hence, it is high time that globe as a whole must come forward to formulate a collective strategy for meeting or facing the biggest challenge of 21st century. Both developed and developing nations are sailing in the same boat. Both must take lesson from Japanese disaster. Hence, it is high time that globe as a whole must come forward to formulate a collective strategy for meeting or facing the biggest challenge of 21st century (Iqbal and Ghauri, 2011).

Adapting agriculture to climate change

Agriculture is itself responsible for about a third of greenhouse-gas emissions. Activities such as ploughing land and shifting ('slash and burn') cultivation for agricultural expansion release CO_2 into the air. Much of the 40% of human caused methane comes from the decomposition of organic matter in flooded rice paddies. About 25% of world methane emissions come from livestock. In addition, agriculture is responsible for 80 percent of the human-made nitrous-oxide emissions through breakdown of fertilizer and that of manure and urine from livestock. However, agriculture's GHG emissions can be largely reduced, and much can be done to lessen their effect on production and on the livelihoods of farmers, especially in developing countries (FAO, 2003).

Adapting Agriculture to Climate Change is a fundamental resource for primary industry professionals, land managers, policy makers, researchers and students involved in preparing the world for the challenges and opportunities of climate change.

The term ''adaptation'' include the actions of adjusting practices, processes, and capital in response to the actuality or threat of climate change, as well as responses in the decision environment, such as changes in social and institutional structures or altered technical options that can affect the potential or capacity for these actions to be realized (IPCC, 2007).

Howden et al. (2007) emphasize the importance of greater focus on the adaptation of agriculture to climate change and they summarized several considerations:

1. Past emissions of greenhouse gases have already committed the globe to further warming of 0.1°C per decade for several decades, making some level of impact, and necessary adaptation responses, already unavoidable.

2. The emissions of the major greenhouse gases are continuing to increase, with the resultant changes in atmospheric CO_2 concentration, global temperature, and sea level observed today already at the high end of those implied by the scenarios considered by the Intergovernmental Panel on Climate Change (IPCC). Furthermore, some climate change impacts are happening faster than previously considered likely. If these trends continue, then more proactive and rapid adaptation will be needed.

3. There is currently a lack of progress in developing global emission-reduction agreements beyond the Kyoto Protocol, leading to concerns about the level of future emissions and hence climate changes and associated impacts.

4. The high end of the scenario range for climate change has increased over time, and these potentially higher global temperatures may have nonlinear and increasingly negative impacts on existing agricultural activities.

5. Climate changes may also provide opportunities for agricultural investment, rewarding early action taken to capitalize on these options.

There is an immense diversity of agricultural practices because of the range of climate and other environmental variables; cultural, institutional, and economic factors; and their interactions. This means there is a correspondingly large array of possible adaptation options (Howden et al., 2007). Adapting agriculture to climate change does not require reinventing agricultural practices. Instead, it requires adapting good agricultural practices to meet changing and often more difficult environmental conditions. To make sure the appropriate information is shared and put into practice, FAO works with its member countries to build capacities at the national, local and community levels, to raise awareness and prepare for the potential effects of climate change. At the government level, the goal is to mainstream climate change issues by ensuring inclusion of appropriate adaptation practices in agricultural policies and programmes. At the grassroots level, FAO provides local communities with site-specific analyses of potential impacts of climate change and possible solutions for adapting their livelihoods more effectively to a changing environment.

Adaptation measures are either planned or taking place in the context of natural hazard prevention, environmental protection and sustainable resource management, which are also beneficial for adapting to climatic change. These measures are generally aimed more at reducing vulnerability to current climate variability, than at preventing the potentially more extreme weather conditions projected to take place in the future.

Farmers can adopt coping mechanisms that withstand climate variability through activities such as the use of drought-resistant or salt-resistant crop varieties, the more efficient use of water resources, and improved pest management. Changes in cultivation patterns can include the reduction of fertilizer use, the better management of rice production, the improvement of livestock diets and the better management of their manure. In addition, national governments have an important role to play in enforcing land use policies which discourage slash and burn expansion and extensive (rather than *intensive)* livestock rearing, as well as raising the opportunities for rural employment (FAO, 2003).

New Challenges for Agricultural Research

On 7 and 8 April 2008 the Management Committee of the Co-operative Research Programme: Biological Resource Management of Sustainable Agricultural Systems (CRP), upon the request of the Governing Body, met in Budapest to consider a “Vision for the Future” for the CRP programme, with a view to contributing to the preparation of the CRP’s mandate for 2010-2014(OECD, 2010).

This report first reflects on the multiple roles of agriculture in the provision of public goods and services (OECD, 2010).The report then reflects on the CRP’s present themes and suggests some specific priority research areas for future work. The report then considers the governance structure of the CRP and in particular the respective roles of the GB and the MC and the links between the CRP and the Committee for Agriculture. The Reflection Group finally found it appropriate also to include some suggestions for a communications strategy that might help in adding visibility to the Programme.

Specific priority areas of agriculture and fisheries research in discussing a range of issues that would be of particular relevance and priority to consider, the Reflection Group focused on the 12 areas of work described below (OECD, 2010). This is not exhaustive and as the CRP develops over 2010-2014, guidance from the Committee for Agriculture will periodically be sought with a view to prioritizing the work and ensure the continued policy relevance of the Programme.

Landscape

Landscape is a useful conceptual principle, which captures the integration of ecological processes and agricultural productivity at relevant spatial scales. Healthy functioning landscapes, with their links to the urban environment, have multiple roles and deliver a range of services to society some of which are non-economic and intangible in nature. This includes, but is not limited to, leisure, health, tourism and biodiversity conservation. Key services provided by landscapes include the stabilization of water resources, significant buffering of climate through carbon sequestration of soil and the role of vegetation cover. Agriculture plays a key role in maintaining landscapes that deliver such services to society.

Spatial policy

Management of space and therefore ecosystems may be an important future challenge with implications for agriculture roles. Scale of impact, different uses of space, competitive claims from different user groups, and prices all affect the way agriculture is positioned in the policy mix being applied to terrestrial space. There are major competitive forces with respect to the agricultural *versus* non-agricultural uses of space. This includes urban and coastal encroachment. Mapping of different uses of space is an important component in the policy makers’ toolkits for addressing conflicting user claims and societal needs.

Invasive species and bio-security

With increasing global interactions across countries and continents, invasive species are increasingly a challenge and the importance of biosecurity preparedness and risk assessment is growing. Invasive pests and diseases threaten both agricultural productivity and biodiversity. From a human perspective, the emerging issues of pathogens transmitted from animals to humans (zoonotic diseases like SARS, avian “flu”), or directly to humans, animals and crops, can have devastating effects across the globe within a short time span. Understanding the spread of these pests and diseases, early detection and assessment to develop appropriate policy responses are crucial for modern societies. In addition, risk assessment is needed to gauge the importance of these challenges.

Water

Agriculture is a major user of water and in some regions and for some crops may be the primary user. Falling water tables means that water is increasingly being mined, and not replenished. Agriculture is a key driver in the water dynamics of catchments and its total water use may be seriously depleting water availability and influencing quality.

This nexus is becoming a widely recognized problem that needs to be underpinned with appropriate agriculture and food policy research.

Animal production

Growing demand for animal protein due to increasing living standards across the world has put pressure on the animal production systems. This has possible negative consequences for the environment with impacts on the use of feed and feed compounds, and water. In addition, there is competition for alternative uses of the same resources.

There is an urgent need to reconsider present production systems with a view to reducing the externalities of animal husbandry including the identification of new and improved protein sources, animal production practices and animal movement. It is recalled that animal production is an important source of greenhouse gases, notably methane. The role of aquaculture to provide alternative sources of protein and more generally the use of the oceans have a potential to help reduce the stress on the terrestrial food production systems.

Forests

Forests, when sustainably managed, provide an important carbon sequestration service to society over and above social amenities, water retention, biodiversity and the environmental protection of land. Nevertheless, the continued deforestation and certain forest practices make this a key research area, most notably in countries not members of the OECD. In this respect, deforestation in the developing countries is major policy coherence for development issue.

Bio-products and bio-processes

There is a growing demand for bio-products produced with biologically sound farming practices. While still relatively small in the overall food market, this has become a non-negligible part of the consumers' demand schedule. Further, there is a growing interest in bio-products and bioprocesses on an industrial scale from the private sector.

The interaction between these developments and traditional farming practices (e.g. food versus energy, pharmaceuticals, and novel non-food uses for agricultural products) is prone to conflicts of interest and will take a growing space in the policy debate. Nevertheless, the science underpinning the possible externality effects of such production systems is underdeveloped and represents a significant opportunity.

Biodiversity

Biodiversity issues are increasingly coming to the forefront of the agriculture, forestry and fisheries policy debate. Modern management practices coupled with climate change and other human activities (*e.g.* urbanization) consistently put pressures on biodiversity.

The resultant loss of biodiversity not only threatens the functioning of terrestrial and marine ecosystems, but also the capacity of society to adapt to certain challenges (*e.g.* diseases). It is therefore important that management practices take into consideration the protection and enhancement of biodiversity and those policies are being brought to bear to define the limits of tolerable impacts. Two particular areas of concern with respect to biodiversity are "subsidies" for biodiversity and how to deal with property rights for genetic resources.

Waste (and by-products)

The policy and research challenges are to realize the potential and value of what might be regarded as waste. Recycling is an important objective for food production systems with a view to capturing the externalities. Animal husbandry is chief among the agriculture practices with major waste effects with impacts on the environment. Research in this area seeks to understand the potential of waste for alternative uses, improve the use of waste, for example, in energy production, including better sources of fertilizer and conditioners of soil.

Food security

Global food demand is undergoing major change in quantity and structure and will dramatically increase along with demographic changes. Globalization of food production systems may add an additional food security risk. Both are likely to increase the uncertainty and vulnerability of the food production system. Research in this area can contribute to better identifying risks in food production chains through vulnerability, disease, outbreaks (biological and physical crises) and identify best practices among member countries in addressing such risks. The costs of inaction in this respect may add political risks and undermine the stability of societies.

Aquaculture and marine ecosystems

The marine ecosystem can also be an important provider of food and bio-energy products. Given pressures on terrestrial ecosystems, it would be advisable to increasingly focus on the ability of the oceans to reduce the stress on the productive capacity of the terrestrial ecosystem, while recognizing that some marine ecosystems are already under pressure. Research in this area could include better aquaculture practices and the use of algae in bio-energy production.

Energy use in food production

Food production systems are also responsible for adding to climate change through the energy needed to grow crops and raise animals, transport, processing and distribution Research in this area on life cycle analysis could contribute to identifying food production systems with greater energy efficiency.

Governance

From other hand, the European Communities (2009) based on the "SCAR-WG assessment and tentative conclusions" on the second foresight report, the following recommendations in relation to research and innovation can be proposed (in no particular order):

- to further explore the full range of possibilities to reduce GHG emissions and to mitigate climate change effects associated with "the agricultural sector"
- to understand not only the functioning of ecosystems but also their criticality. The resilience of the combined bio- and socio/economic systems is at the heart of our ability to be able to address the challenges that we face. This has strong implications for the knowledge that needs to be generated to address issues that impact on "agriculture" but which have a much wider base than this specific sector. Therefore, the systems approaches needed have to be highlighted
- to further develop low external input concepts which are more diversified and "greener" (the next generation of agricultural research) paving the way for alternative models that will include low input concepts, increased diversification, and a reconsideration of the way we produce, process, retail and purchase food, making sustainable development.
- to quickly improve the capacities of the agricultural knowledge system so that it can address the new and severe challenges in the required timescales.

The Role of Biotechnology in Agriculture and Food Security

Biotechnology is a broad discipline that studies the potential use of natural and modified organisms and systems in agriculture, medicine, environment and many other fields. It uses a wide range of techniques, from relatively simple breeding to highly sophisticated molecular and cellular manipulations to produce specific desired traits in plants, animals or microorganisms, often requiring extensive knowledge of the genetics of the target organisms (Aravindaram and Yang, 2011). The evolution of plant breeding is a classic example of how improved biological understanding has been adapted to provide more effective methods of meeting the demands of a changing world. Plant biotechnology offers significant improvements in virtually every area of crop production and utilization, with potential benefits to farmers, the food industry, consumers and the environment.

Biotechnology is not a separate science, but rather a mix of disciplines, such as biochemistry and physiology, microbiology, genetics, molecular biology, and cell biology. Biotechnology consists of a gradient of technologies, ranging from the long-established and widely used techniques of traditional biotechnology (for example, food fermentation and biogas production), through to novel and continuously evolving techniques, such as genetic engineering and genomics. Biotechnology could also be seen as an integration of new techniques emerging from modern biotechnology with the well-established approaches of traditional biotechnology, such as crop and livestock breeding, food production, fermentation products and processes, and the production of pharmaceuticals. The diversity of techniques that constitute modern biotechnology offers much promise to serve the pressing needs of sustainable development in the agriculture, industrial and health sector. For developing countries the challenge will be to develop biotechnology based innovation systems that are able to adapt relevant knowledge and technologies that can contribute to economic growth and also improve environment, health and livelihoods. Agricultural biotechnology is becoming a progressively more important factor in shaping agricultural production systems worldwide, including developing countries (FAO, 2005). According to the opinions of the authors of "Plants for the Future", biotechnology and genomics are the most promising tools for addressing new agricultural challenges. The ultimate vision of the plan is a sustainable, resource-conserving, and highly innovative "bio-based economy" (European Commission, 2005). Plants for the future" (European Commission, 2005) centers around four essential principles:

- The production of safe, high-quality food and feed in sufficient quantities
- Sustainable agriculture
- The development of plants for the production of renewable resources and energy
- Increasing competitiveness while maintaining the freedom of choice for consumers

However, Farmers and pastoralists have manipulated the genetic make-up of plants and animals since agriculture began more than 10 000 years ago. Farmers managed the process of domestication over millennia, through many cycles of selection of the best-adapted individuals.

This exploitation of the natural variation in biological organisms has given us the crops, plantation trees, farm animals and farmed fish of today, which often differ radically from their early ancestors.

Adoption of modern practices of agriculture, starting from the use of superior germplasm for improvement in plant characteristics by modern biotechnological methods and traditional plant breeding technologies, coupled to innovative farm practices, have influenced food production. Research in plant biotechnology has previously focused primarily on agronomic characteristics to improve resistance or tolerance to biotic and abiotic stresses in particular crop plants. While this effort has been relatively successful, new products that can meet the demands for increased yield and quality are limited, although recent efforts are showing some promise. These include improvement of the nutritional quality of food for human and livestock health, and the development of ingredients with superior properties for food manufacturing and processing. Systematic efforts to improve the quality and quantity of carbohydrates, proteins, lipid, vitamins and minerals in staple cereal or vegetable crops have made encouraging progress and led to the development of new approaches (Aravindaram and Yang, 2011).

Major Challenges for Plant Biotechnology

Using advanced biotechnology tools, genetic resources can be more precisely characterized, efficiently improved and tailored to specific needs. The technologies can be used to support the development of sustainable production systems for food, feed and crops for industrial purposes, such as biofuel. Novel agro processing techniques using biotechnology can add downstream value to crops and their byproducts. Modern agricultural biotechnology, which includes disciplines such as genetic engineering, bioinformatics, structural and functional genomics, and synthetic genomics, is a comparatively young field of science. Thus, we have so far only seen the beginning of what promises to be a very exciting and maybe also revolutionary technology (Chikaire et al., 2012).

Agricultural biotechnology is however not a solution or a means in itself and largely depends on the existence of effective breeding programmes. Thus, agricultural biotechnology can never replace conventional breeding, but can be a vitally important tool in supporting sustainable agricultural production and breeding systems to be highly adaptive and effective in serving local needs (Chikaire et al., 2012). The Grand Challenge in Plant Biotechnology therefore lies foremost in increasing crop productivity at orders of magnitude, which has never been achieved so far, but not much less in improving plant quality to be optimal for its traditional uses, e.g., food and feed, but also to provide tailor-made biomaterials for a vast range of industrial applications including the provision of energy for a range of purposes, which can only be achieved if the enabling technologies are also further developed allowing advancements in plant breeding at unprecedented speed (Kossmann, 2012). This will lead to address new challenges for Plant Biotechnology (Kossmann, 2012):

- Increase crop productivity especially in adverse environments
- Management of herbicide tolerance
- Management of resistance to pests
- Management of resistance to diseases
- Improvement of genetic engineering technologies to enhance public perception
- Improvement of harvest index
- Improvement of nutrient cycling in agricultural ecosystems

To meet the challenges a broad interdisciplinary approach needs to be taken next to the scientific and technological prerequisites that have to be met. Multidisciplinary is not only needed to transfer knowledge generated with model plants into crops, or even highly environmentally specialized varieties, but also to stimulate public acceptance and thus decreasing regulatory restraints. Technologically we will need to be able to generally simplify genetic manipulation of any plant species, and be able to precisely engineer genomes beyond simply inserting transgenes introducing also a range of traits simultaneously, next to taking maximal advantage of the knowledge generated in any sub-discipline of Plant Science (Kossmann, 2012).

Humanity future facing 2050!

The world's population is expected to hit seven billion in the next few weeks. After growing very slowly for most of human history, the number of people on Earth has more than doubled in the last 50 years.

In 1900, there were 1.6 billion of us; by 2000, the global population had shot up to 6.1 billion. Last year, we passed the seven billion mark, and best estimates have us reaching the nine billion mark before 2050 (Gaia Vince, 2012).

The sheer number of people has profoundly changed the global landscape, as we convert vast tracts of wild vegetation to agricultural or grazing areas, for example. Fishing on an industrial scale to provide for billions has dramatically altered marine diversity. Individual farmers breeding livestock or keeping chickens, when multiplied by millions, have caused biodiversity changes in which more than 90% of the weight of all terrestrial vertebrates is now made up of humans and the animals we have domesticated. The quest for resources to supply us all with materials and the trappings of life has depleted the forests, polluted rivers and soils and even carved the tops of mountains. And the fuels used by each of us for energy have produced combined emissions that are already altering the planet's climate (Gaia Vince, 2012).

By 2050, it is estimated that we could triple our resource consumption to a whopping 140 billion tones of minerals, ores, fossil fuels and biomass per year. Our food requirement alone is expected to double by then.

Is our ever-increasing human population propelling us to our doom? Is there a limit to how many people can be sustained on a finite planet – and, if so, have we already passed it? (Gaia Vince, 2012). "Agriculture is still considered a sideshow in the climate arena and a decision has been lacking over several years of U.N. climate negotiations.

World agriculture in the 21st century will face three major challenges: how to feed a growing world population, how to contribute to reducing the still–high prevalence of rural poverty in the world, and how to respond to increased concerns about managing the natural resource base. Bruce Campbell, head of the CGIAR Climate Change, Agriculture and Food Security (CCAFS) research program said: "Agriculture will be massively impacted by climate change, both the increase in extreme conditions and the rising temperatures. We need global action to ensure food security under climate change".

References

Alarcon, D., G. Deoudes, T. F. Joehnk, K. Jordan, S. Kim, V. Lai, P. Minkovski and R. Powell, 2012. Global Food Security Index. FAO.

Alexandratos, N. and J. Bruinsma, 2012. World agriculture towards 2030/2050: the 2012 revision. *ESA Working paper No. 1212-03. Rome,* FAO, (12).

Aravindaram, K. and N.Yang, 2011. Applications of Agricultural and medicinal biotechnology in Functional Foods. Chapter 11, Pp. 257–274. In: *Sustainable Agriculture and New Biotechnologies.* DOI: 10.1201/b10977-12.

Bruinsma, J., 2009. The resource outlook to 2050 By how much do land, water use and crop yields need to increase by 2050. *FAO- Expert Meeting on How to Feed the World in 2050*, (June): 24–26.

Buiter, W. and E. Rahbari, 2011. Global growth generators Moving beyond merging markets and BRICs vox. vox. http://www.voxeu.org/article/global-growth-generators-moving-beyond-emerging-markets-and-brics.

Chikaire, J., F. Nnadi, N. Ejiogu-Okereke and J. Echetama, 2012. Participatory Technology Development: Current Approach to Sustainable Agricultural Biotechnology Development. *Continental J. Sustainable Development,* **3** (1): 1–18.

Diouf, J., 2012. Content Feeding a world of 9 billion. *People & the Planet (2000 - 2010), 2012.* http://www.peopleandplanet.net/?lid=26107&section=34&topic=44.

EPA U. Glossary of Climate Change Terms Climate Change US EPA.

European Commission, 2005. Plants for the Future: A European Vision for Plant Genomics and Biotechnology Towards 2025. www.europabio.org/.

FAO, 2003. Impact of climate change on food security and implications for sustainable food production.

FAO, 2005. Status of research and application of crop biotechnologies in developing countries. ISBN 92-5-105290-5, http://www.fao.org/docrep/008/y5800e/y5800e00.htm

FAO, 2011. Food, Agriculture and Cities. www.fao.org/fcit.

Gaia Vince, 2012. BBC - Future - Science & Environment - Are we facing population overload. http://www.bbc.com/future/story/20120725-population-overload.

Giovannucci, D., S. Scherr, D. Nierenberg, C. Hebebrand, J. Shapiro, J. Milder and K. Wheeler, 2012. Food and Agriculture: the future of sustainability. A strategic input to the Sustainable Development in the 21st Century (SD21) project. *New York: United Nations Department of Economic and Social Affairs, Division for Sustainable Development*.

Godfray, H. C. J., J. R. Beddington, I. R. Crute, L. Haddad, D. Lawrence, J. F. Muir, J. Pretty, S. Robinson, S. M. Thomas, C. Toulmin, 2010. Food security: the challenge of feeding 9 billion people. *Science* **327**, 812 (2010); DOI:10.1126/science.1185383

Grebmer, K., C. Ringler, M. W. Rosegrant, T. Olofinbiyi, H. Fritschel, M. Torero, Y. Yohannes, J. Thompson and J. Rahall, 2012. Global HunGer Index. The challenge of hunger: Ensuring sustainable food security under land, water, and energy stresses. International Food Policy Research Institute, http://dx.doi.org/10.2499/9780896299429.

Howden, S. M., J.-F. Soussana, F. N. Tubiello, N. Chhetri, M. Dunlop and H. Meinke, 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America*, **104** (50): 19691–6.

Huang, H., W. Legg, and A. Cattaneo, 2010. Climate Change and Agriculture: The Policy Challenge for the 21. *EuroChoices*, **9** (3): 9–15.

IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: *M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, Eds., Cambridge University Press, Cambridge,* UK, 976 pp.

Iqbal, B. A. and F. N.Ghauri, 2011. Climate change: The biggest challenge in 21ST century. *African Society for Scientific Research (ASSR). Proceedings of the 1st International Technology, Education and Environment Conference,* (c), pp. 497–508.

Kossmann, J., 2012. Grand challenges in plant biotechnology. *Frontiers in plant science*, 3(April): 61.

Moorhead, A., 2009. Climate, agriculture and food security: a strategy for change. *Alliance of the CGIAR Centers,*www.ccafs.cgiar.

NASA Earth Observatory, 2011. Glossary. http://earthobservatory.nasa.gov/Glossary/index.php?mode=alpha&seg=b&se gend=d

NASA, 2008. What's in a Name Global Warming vs Climate Change. http://www.nasa.gov/topics/earth/features/climate_by_any_other_name.html.

Nature, 2010. How to feed a hungry world. *Nature*, 466(7306): 531–2.

NSIDC, 2012. Climate Change (glossary definition). http://nsidc.org/arcticmet/glossary/climate_change.html.

OECD, 2010. Challenges for global agricultural research. *OECD Publishing.* http://dx.doi.org/10.1787/9789264090101-en.

Population Reference Bureau, 2012. *World population data sheet,* 1–20.

Roson, R. and D. van der Mensbrugghe, 2010. Climate Change and Economic Growth: Impacts and Interactions. *Working Papers Department of Economics of the Ca' Foscari University of Venice.* No. 0 7 /WP/2010, (07).

Society, R., 2009. Reaping the benefits. *RS Policy document 11/09, Royal Society, London*, (October).

The United Nations Framework Convention on Climate Change. http://unfccc.int/essential_background/convention/background/items/1349.php. 1994. "Climate change means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

THE WORLD BANK, 2012. Global Economic Prospects. *The International Bank forReconstruction and Development/ The World Bank 1818 H Street NW Washington DC 20433.* www.worldbank.org, 5(June).

Tubiello, F., J. Schmidhuber, M. Howden, P. Neofotis, S. Park and E. Fernandes, 2008. Climate change response strategies for agriculture: challenges and opportunities for the 21st Century Agriculture and development discussion paper. No42. *The World Bank*.

Vermeulen, S. J., P. K. Aggarwal, A. Ainslie, C. Angelone, B. M. Campbell, A. J. Challinor, J. W. Hansen, J. S. I. Ingram, A. Jarvis, P. Kristjanson, C. Lau, G. C. Nelson, P. K. Thornton and E. Wollenberg, 2012. Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, **15** (1): 136–144.

Wiebe, K., 2009. How to Feed the World in 2050. *OECD Global Forum on Agriculture*, (June): 24–26.

ZEENEWS BUREAU, 2012. Cost of climate change 100 mn people will die by 2030. http://zeenews.india.com/news/eco-news/cost-of-climate-change-100-mn-people-will-die-by-2030_801923.html.