# Climate Change and Global Food Crisis
# - With emphasis on Taiwan

Yuan Shen

Department of Soil and Environmental Sciences

National Chung Hsing University

Global food prices increased on average more than 50% in 2008 comparing to that of early 2000s and a record number of countries faced food crises requiring emergency assistance, according to Food and Agriculture Organization (FAO), UN. Recent Pakistan's floods have washed away significant amounts of the grain, sugarcane and rice harvests, which also led flood victims living in very difficult conditions. Rising food prices and extreme weather disasters contributed to a significant increase in food insecurity worldwide, particularly among poorer populations. The food insecurity ignited street riots, caused social unrest and even destabilized several governments, such as Haiti and Liberia. "A hungry world is a dangerous world," said Josette Sheeran of the World Food Program (WFP), UN. "Without food, people have only three options: they riot, they emigrate or they die."

Approximately 1 billion people, about one seventh of the world's population, subsist on less than one US dollar per day. At the household level, increasing food prices have the greatest effect on poor and food-insecure populations, who spend half or more of their income on food, reported by International Food Policy Research Institute (IFPRI). Overall, increased food prices particularly affect developing countries, and the poorest people within those countries.

According to the official United Nations population estimates and projections, world population is projected to reach 7 billion in late 2011, up from the current 6.8 billion, and surpass 9 billion people by 2050. Most of those additional 2.3 billion people will enlarge the population of developing countries, which is projected to rise from 5.6 billion in 2009 to 7.9 billion in 2050. In contrast, the population of the more developed regions is expected to change minimally, passing from 1.23 billion to 1.28 billion, including projected immigrants from developing countries of 2.4 million persons annually from 2009 to 2050. World population increase rate would reduce gradually from current 1.3% per year to 0.4% or 0.9% per year during 2040s, depends on the projected fertility rates. Rising population in various parts of the developing world combined with strong economic growth have increased demand for both food and feed grains. As a result, the growth of world consumption of cereals is expected to be in the range of 1.0-1.5% per year till 2050.

Statistics of FAO indicated that wheat plantation reached maximum in 1980s, but the planted hectarage of rice and maize is still increasing at gradually smaller rates. However, food crisis in 2007/08 has led to a rapid hectarage expansion of all these three crops. Better varieties, more use of fertilizers, herbicides and insecticides, and improved irrigation facilities contributed to the yield increases of these main staple crops. But, the yield increasing rates were all in decreasing trends according to law of diminishing marginal returns. World productions of wheat, rice and maize have shown significant yearly increase and are thus still able to meet the demands for 85% of the world's population. The production increasing rates of wheat, rice, and maize are now approaching a stable rate of about 1%, 2% and 3% per year, respectively, combined results of increasing yield and/or plantation hectarage.

Historical records indicated that the cereal production tended to match with the utilization. However, major cereal prices have fluctuated sharply in recent years. Many factors can contribute to the fluctuation of market price. For example, factors contributed to the rapid rises of global food prices during 2007/08 including extreme weather events, low cereal stocks, competition for cropland from the growth in biofuels, high oil prices, and speculation in food markets. A significant increase in world cereal production in 2008 led to improved global cereal stocks and an associated reduction in the international prices of most cereals. However, food prices remain high in most developing countries. According to FAO, food emergencies, resulting from the combined effects of chronic food insecurity and high food price levels, persist in 31 countries, including 20 African nations. Therefore, it is expected that future cereal production may be able to meet world majority needs if extreme weather events are not wide-spread, and when farming is profitable for farmers of cereal exporting countries.

World major wheat exporting countries are USA, Canada, France, Australia, and Russian Federation. These five countries accounted for over 60% of the global wheat exportation at 105.5 million tones (Mt). The major maize exporters are USA, Argentina, France, China, and Brazil, which accounted for nearly 80% of the global maize exportation (74.2 Mt). The five leading rice exporting countries are Thailand, India, Viet Nam, USA, and Pakistan, which accounted for more than 75% of the global rice exportation (23.3 Mt). USA plays a very important role in meeting the world food demand as she ranks first among world wheat and maize exporters, the fourth in rice, and the second in meat. While a handful of nations dominate cereals exports, stability of world cereal trades and prices are easily affected by adverse weather events, societal stability, and even political decisions occurred in or made by these major exporters. For example, in 2007 and 2008, India and Vietnam blocked the export of rice to guarantee that domestic supplies remain affordable and had nearly tripled the price of world rice market. The recent Russian export ban on wheat has also led to a sharp upward adjustment of wheat prices in international markets between July and August.

In photosynthesis, carbon dioxide ($CO_2$) from the air and water ($H_2O$) from the soil are used by chlorophyll in green plant cells in the presence of light energy to produce glucose ($C_6H_{12}O_6$) and release oxygen ($O_2$). Plant then uses the glucose in combination with nutrients uptake from the soil for growth and development. Therefore, a crop’s yield potential depends on the sufficiency of light, water, and nutrients. If any one factor, or combination of factors, is in limited supply, plant growth will be adversely affected according to principle of limiting factors. Weeds will reduce light by shading or using up soil moisture and nutrients that would otherwise be available to the crop. Insects and diseases will reduce the quantity and quality of the harvests. Generally, factors such as moisture, temperature, soil fertility, soil texture, soil structure, weeds, insects and diseases are responsible for a crop's inability to reach potential yield. But, a disaster weather event, such as typhoon, heavy rainfall, drought, heat wave, or frost, can destroy a very good crop production were it not happened.

Global warming is projected to have significant impacts on conditions affecting agriculture, including $CO_2$, temperature, and water availability. Increasing atmospheric $CO_2$ is beneficiary to crop yield through improving the photosynthetic efficiency. Temperature increase may impose heat stress to crops in lower latitudes, but is favorable to crop production in higher latitudes by extending the growth period. Increasing temperature will also shorten the duration of growth stages, which implicates that a good crop production must have enough sunshine and adequate supply of nutrients and water provided in shorter time periods.

The impacts of climate change on global crop production are geographically unevenly distributed. Results of an agro-climatic assessment using climate projections of Global Circulation Models, by International Institute for Applied Systems Analysis (IIASA), indicated a northward shift in world cereal production due to global warming. The countries at high latitudes will see a considerable potential for expansion of suitable land and increased production potential for cereals, where increases of 6 to 9% are possible. In contrast, countries at low latitude regions will suffer a loss in cereal productivity. The most significant negative changes will occur in Asian developing countries, where production declines in all scenarios, ranging from about 4% to 10%.

Natural disasters can be classified as either “slow onset” (e.g. drought and prolonged dry spells) or “sudden onset” (e.g. typhoons and floods). Sudden-onset disasters leave much less time for response than slow-onset ones. FAO Global

Information and Early Warning System (FAO/GIEWS) data indicate that sudden-onset disasters, especially floods, have increased from 14% of all natural disasters in the 1980s to 20% in the 1990s and 27% since 2000. Human induced crises can be divided into war or conflict-related ones and disasters induced mostly by socioeconomic shocks. The latter can in turn stem from internal factors (such as poor economic or social policies, conflicts over landownership or a deteriorating public health situation) or from external factors (such as a loss of export earnings or a sharp increase in the price of imported food commodities). The relative share of food crises caused by socioeconomic factors has risen in the past three decades from about 2% in the 1980s to 11% in the 1990s and 27% since 2000. Natural disasters were the primary cause of food insecurity until the early 1990s. However, human-induced crises were becoming more prominent in the past decade.

Climate change will result in more extreme variations in weather. Frequency of heavy precipitation and heat waves, area affected by droughts and intense of tropical cyclone (typhoon) are all expected to increase due to global warming, according to Intergovernmental Panel on Climate Change (IPCC). These natural disasters alone, or compounded with human-induced disasters, may aggravated the already fluctuated world cereal markets and ushering in complex and long-lasting food crises.

Adapting plants to climate change is a challenge to world's plant breeders. Advances in molecular and cellular biology now allow scientists to introduce desirable traits into crop plants. The ability to transfer genes between species is a leap beyond crop improvement through previous plant breeding techniques, and genetic modified (GM) crops are believed can play an important role in mitigating food crisis. Statistics of International Service for the Acquisition of Agri-Biotech Applications (ISAAA) indicated that the global hectarage of biotech crops reached 125 million hectares (Mha), and the number of countries planting biotech crops soared to 25 in 2008. The top eight countries each grew more than 1 Mha were USA (62.5 Mha), Argentina (21.0 Mha), Brazil (15.8 Mha), India (7.6 Mha), Canada (7.6Mha), China (3.8 Mha), Paraguay (2.7 Mha), and South Africa (1.8 Mha). Two thirds (17) of the 25-biotech countries planted biotech maize, 10 countries planted biotech soybean, and 10 countries planted biotech cotton. Biotech soybean occupied 65.8 Mha or 53% of global biotech area, followed by biotech maize (37.3 Mha at 30%) and biotech cotton (15.5 Mha at 12%). Herbicide tolerance (63%) and insect resistant (15%) are the dominant traits in current biotech varieties, but varieties with stacked traits are increasingly.

Breeding programs for flood-, drought- and heat-tolerant crops have been initiated from early 1990s. For example, International Rice Research Institute (IRRI) has modified several popular rice varieties by introducing a submergence tolerant gene (*SUB1*) to help survival under flooding conditions. IRRI's Drought Frontier Project (DFP) will develop new genotypes that can potentially double rice yield under drought stress in rainfed environments. Change the biophysical structure of plants, making them a much more efficient user of energy from the sun is another approach to meet world's food demand. For example, rice has what is known as a $C_3$ photosynthetic pathway, less efficient than that of maize which has a $C_4$ pathway. IRRI's $C_4$ Rice Project intends to convert rice from $C_3$ to $C_4$ plant, which would involve rearrangement of cellular structures within the leaves and more efficient expression of various enzymes related to the photosynthetic process.

However, excessive reliance on a single technology combined with a lack of diverse farming practices could undermine the economic and environmental gains from these GM crops. The development and commercialization of GM crops should also meet human and environmental safety standards and regulations.

Water is the basic ingredients of the photosynthetic reaction. Therefore, adequate water is still required even for those drought-tolerant GM varieties. Climate change is expected to alter hydrologic regimes and freshwater availability, which has significant impacts on both rainfed and irrigated agriculture. A report by United Nations World Water Assessment Program (UN WWAP) indicates reduction of precipitation in semi-arid areas with greater variability in rainfall distribution and greater frequency of extreme events. It is thus anticipated that large areas of croplands, particularly in semi-arid zones, will need to adapt to new conditions with lower precipitation. Severe reductions in river flow and aquifer recharge are expected in the Mediterranean basin and in the semi-arid areas of Southern Africa, Australia and the Americas. The production risks will be amplified in alluvial plains dependent on glacier melt (e.g. northern China, Punjab, and Ganges-Brahmaputra) and lowland deltas dependent on upstream development (e.g., Nile River, Yellow River, and Mekong River). While dam constructions may be necessary from economical development and agricultural irrigation standpoints, they can be very detrimental to downstream river ecosystems and may sometimes ignite international conflicts.

Fertilizers increase crop production by replenishing essential nutrients, particularly the nitrogen, phosphorus and potassium, used by a previous crop or by boosting the abundance of the elements. Statistics of International Fertilizer Industry Association (IFA) indicated that global fertilizer consumption was about 168.5 Mt in 2007/08, which comprised of 101.2 Mt N, 38.4Mt $P_2O_5$, and 28.9Mt $K_2O$. World demand for fertilizers is projected to be 188.3 Mt in 2014/15. The bulk of the increase in demand would come from Asia and, to a lesser extent, from the Americas. East Asia and South Asia together would account for 59% of total growth. If Latin America and North America are added, the four regions together would account for

82% of the projected increase in demand.

Over 90% of nitrogenous fertilizers contain ammonia or are derived from ammonia (e.g., ammonium nitrate, ammonium sulfate, ammonium phosphates, sodium nitrate, calcium nitrate, and urea). The Haber-Bosch process allows economical mass synthesis of ammonia from nitrogen (from air) and hydrogen (mainly from natural gas, some from coals). Phosphorus is mined from rock phosphate deposits. Known phosphate reserves are unevenly distributed around the world. Over 90% worldwide reserves located in five countries: China (39%), Morocco/Western Sahara (34%), South Africa (9%), USA (6%) and Jordan (5%). Potassium bearing minerals are mined from underground ore deposits, salt lakes and brines. Potassium chloride accounts for most of the potassium fertilizers and are produced in 12 countries, of which seven account for 90% of the world production. The largest production is in Canada (36%), followed by Germany (14%), Russia (14%), Belarus (13%), Israel (6%), USA (5%) and Jordan (4%).

Fertilizers are associated with high energy consumption. Most fertilizer energy use is attributable to the production of nitrogen fertilizers. Therefore, energy price hike in the future may affect nitrogen fertilizer supply. Besides, government policies relative to resources and exports controls and environmental concerns on atmospheric emissions from manufacturing of nitrogen products, on soil and water pollution from phosphate and potash mining, and on the disposal of production wastes would all affect the availability of phosphorus and potassium fertilizers.

A major problem with the use of fertilizers occurs when they are washed off by rainwater from agricultural fields into rivers, lakes, and eventually into oceans. The increase of nitrate or phosphate in water bodies encourages algae growth, also known as “Eutrophication”. Although these algae produce oxygen in the daytime via photosynthesis, they continue to undergo respiration during nighttime and can therefore deplete oxygen dissolved in water. When dissolved oxygen in water is further used up due to bacterial decomposition of the dead algal cells, the lake and costal waters may be left completely lifeless.

To reduce runoff of fertilizers from fields, new technologies that ensure correct nutrients are applied at right time, right location and in amount needed by crops are required. Precision agriculture (also known as site-specific nutrient management), a farming system based on site-specific information and tactics to capture spatial and temporal field variability, can improve the efficiency and efficacy of fertilization and thus reduce the pollution from overdose application of fertilizers. It requires the use of technologies, such as global positioning system, satellite or aerial images, and geographic information management tools to assess and understand the variations, and variable rate application technologies to dispense the fertilizers.

Taiwan has an area of 36,000 $km^2$ and is home of 23 million people. The island is consisting by mountains running from north to south in the eastern two-thirds of the island, and the flat to gently rolling plains in the west. The entire island experiences hot, humid weather from June through September. The northern part has a rainy season that lasts from October through late March due to northeast monsoon. The middle and southern parts of the island have a dry season during winter months. Precipitation from Meiyu in May and June and typhoons during summer months generally cover the entire island. Annual precipitation of Taiwan is 2.6 times of the world average, exceeding 2500mm. However, water available per capita is less than one seventh of the world average. Water scarcity problem is due to the steep land slope, uneven time and space distribution of rainfall, and high population density. According to statistics of Water Resource Agency (WRA), the annual water consumption is about 18 billion cubic meters, 23.7% from about 80 dams, 44.8% from rivers, and 31.5% from ground water. During dry seasons, part of the irrigation water has sometimes used to support household and industrial water demands.

The birth rate in Taiwan has dropped far below the replacement level of 2.1‰ during the past two decades, 1.03‰ in 2009. The projection made by Council of Economical Planning and Development (CEPD) indicated that Taiwan's population is expected to reach maximum between 2018 and 2025, then starts to decrease. Although many serious social problems may emerge, the population reduction and aging will decrease the food consumption demand in Taiwan.

The rapid economic growth from late 1970s has significantly changed the dietary pattern in Taiwan by decreasing consumption of rice and increasing consumption of meat and wheat. The increasing consumption of meat promoted local livestock industry and thus created a huge demand for maize. Though domestic rice production can meet the demand, rice only accounts for 54% of the daily consumption of cereals. Wheat and maize are imported because of the high local production costs. Statistics of Council of Agriculture (COA) indicated that the food self-sufficiency ratio weighted by energy has decreased from over 60% before 1980 to about 32% in 2009. The expenditure on importing agricultural products increased rapidly since 1980s, primarily due to increased importation of cereals. Therefore, Taiwan’s food supply is very vulnerable even not considering the effects of climate change. The future food security depends on how world cereal markets are affected by climate change, the buying power compared with competitors in international cereal markets, and to what extend the deficiency in wheat and maize can be compensated by domestic production.

The ensemble projection of island-wide average temperature will increase by approximately 2.3 $^{o}C$ in 2080-2099 compared to the 1980-1999 values. Higher increases are expected over the western lowland region, as compared to the mountainous and eastern coastal regions. Annual rainfall increase of 5.2-5.6% is expected, with major increases over the eastern and northern regions but decreases over the central and southern regions. The number of rainless days in dry season will increase in the central and southern regions, and the number of heavy rain days in wet season is expected to increase at most regions. These forecasts implicate large instability of domestic crop production in the future.

Current annual water consumption in Taiwan is about 17.9 billion cubic meters, in which agricultural water use stands at 12.8 billion (71.4%); household use 3.5 billion (19.6%); and industrial use 1.6 billion (9.0%) cubic meters. According to projections by WRA, Taiwan's total annual water demand will rise to 20 billion cubic meters by 2021. The projected supply of water from conventional sources, however, will provide at most 19.2 billion cubic meters per year. When considering the difficulties to build new dams and to reduce river pollution, the shortage from projected demands is expected to be much larger. The changing weather caused by global climate change will further make the already limited supply of water less dependable. The water appropriated for irrigation will most likely be reallocated to prevent the damage of water shortage to living standards and economic development.

The changes of diet structure in Taiwan resulted excessive production of rice and rapid decrease of paddy fields. Due to lower average yield and production is easily affected by typhoon, hectarage of rice planted in the second crop season decreased faster than that in the first crop season. Starting from 2002, the hectarage of paddy fields paid to set aside, in order to meet the domestic subsidy regulation of World Trade Organization (WTO), has increased rapidly. Currently, the hectarage of rice planted and set-aside fields nearly equals. Those set-aside fields are potential targets for many non-agriculture development projects. Losses of arable lands due to those non-agricultural uses are far greater than that due to sea level rise induced by global warming. Faster organic matter decomposition in warmer environment, soil acidification due to more fertilizers applied and more soil pollution will degrade soil quality of arable lands and thus affect crop yields.

From above discussions, several major conclusions may be reached.

1. Global food crisis can significantly affect a nation’s social stability and economic developments, particularly those poor nations and nations in lower latitudes.
2. World as a whole, food production should be able to meet the majority’s demands if no wide-spread adverse weather events and when farming is profitable for those major cereal exporters.
3. Climate change will increase the frequency of extreme weather events, which in turn will increase the fluctuation of international cereal markets and chances of

global food crisis.

4. A sustainable agriculture must meet the food demand of the present generation but not sacrificing the needs/benefits of future generations.
5. Taiwan's food security is already very vulnerable even not considering the effects of climate change.
6. Taiwan needs to increase food self-sufficiency ratio in order to regain flexibility and maneuverability in mitigating the impacts of climate change on food insecurity.
7. Improved arable land rehabilitation and preservation, greater water conservation and better water management, and development and application of new technologies are key issues in achieving sustainable agriculture.