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Review

Agriculture, pesticides, food security and food safety

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ABSTRACT

Decades ago, agrochemicals were introduced aiming at enhancing crop yields and at protecting crops from pests. Due to adaptation and resistance developed by pests to chemicals, every year higher amounts and new chemical compounds are used to protect crops, causing undesired side effects and raising the costs of food production. Eventually, new techniques, including genetically modified organisms (GMOs) resistant to pests, could halt the massive spread of agrochemicals in agriculture fields. Biological chemical-free agriculture is gaining also more and more support but it is still not able to respond to the need for producing massive amounts of food. The use of agrochemicals, including pesticides, remains a common practice especially in tropical regions and South countries. Cheap compounds, such as DDT, HCH and lindane, that are environmentally persistent, are today banned from agriculture use in developed countries, but remain popular in developing countries. As a consequence, persistent residues of these chemicals contaminate food and disperse in the environment. Coordinated efforts are needed to increase the production of food but with a view to enhanced food quality and safety as well as to controlling residues of persistent pesticides in the environment.

1. World population and food production

The world population grew from 2.5 billion in 1950 to 6.1 billion in the year 2000. By the year 2050 the world population is estimated to reach 9.1 billion (between 7.7 and 10.6 billion, depending on estimates). This means that the population of Earth more than doubled in the past 50 years, from 1950 to 2000, and will probably grow only slightly less in the 50 years from 2000 to 2050 (Fig. 1).

Currently, world population is growing with an annual rate of 1.2%, i.e. 77 millions people per year. Six countries account for half of this annual increment: India, China, Pakistan, Nigeria, Bangladesh and Indonesia. According to the United Nations (UN) estimates, the population of the more developed regions (1.2 billion) will change little during the next 50 years, because fertility levels will remain low, even below replacement level. In contrast, the population of less developed regions is foreseen to rise from 4.9 billion in the year 2000, to 8.2 billion in the year 2050, assuming that some degree of decline in fertility will occur. Therefore, despite the projected decline of population growth rate, occurring both in developed and developing countries, probably 95% of the global population increase will take place in the developing countries (UN, 2001, 2005; Cohen, 2005). Regions with very modest gross domestic products (GDPs) such as sub-Saharan Africa, will register the highest growth rate of population (UN, 2001).

Life span is also increasing. In the period 1995–2000, life expectancy at birth in more developed regions has been estimated at 75 years and in the less developed regions at 63 years. Globally, the number of older persons, 60 years old or

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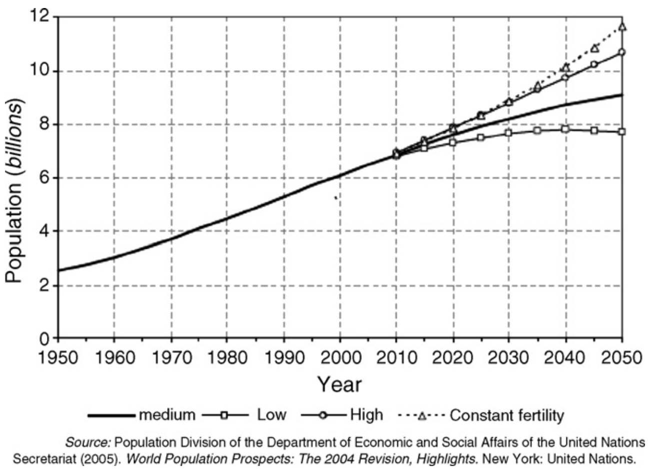

Fig. 1 – Estimates of the world population growth with projections till the year 2050 (*Source*: UN, 2005).

over, will more than triple from now to the year 2050, i.e. will grow from 806 million to 2 billion (UN, 2001).

An adult person needs on average 2900 kcal/day in order to work productively. In developed countries the daily average consumption of food provides about 3500 kcal, whereas in poor countries people may not obtain even 2000 kcal/day, and thus suffer of under nourishment. Undernourished in all developing regions were about 800 millions and 840 millions all over the world in 1998–2000, according to the Food and Agriculture Organization (FAO). This represents an increase in the number of undernourished compared with the figures for the previous decade (UN, 2001).

Throughout the world, people get their daily supply of calories from different diets. In Europe and North America this supply is largely obtained from livestock products, while in many other regions the calories supply is primarily obtained form cereal grains. Overall, 80% of the poor in developing countries live in rural areas and derive their livelihood directly from agriculture with diets that are deficient in micronutrients (minerals, vitamins, etc.) and amino acids (FAO, 2002). These populations have a diet deficient in amino acids from animal protein. Daily consumption of animal protein *per capita* in 1999 varied from 3 g in Burundi to 76 g in France (FAOSTAT, 2001). Frequently, 40 g of animal protein per day are taken as a reference target value, corresponding to 740 kcal/day of livestock products, i.e. about 25% of the calories in a balanced diet that should include also another 2160 kcal/day from plant origin (Srinivasam et al., 2006). Theoretically, and if statistics and calculations are right, current world food production could provide in average around 2800 kcal/day *per capita*, nearly sufficient to feed the world population (Gilland, 2002).

It should be realized that about 75% of the world cereal production is used to feed livestock. Taking into account that there is a limit for the world cereal grain production, the smaller the human population the greater the fraction of grain that can be used as livestock feed and the greater will be the supply of animal protein (Alexandratos, 1999; Gilland, 2002).

At the global level, significant progress has been made since 1960 towards improved nutrition and food security. Since then, world gross agricultural production has grown more rapidly than the world population, with an average positive production increase of food *per capita* (Klassen, 1995). Nevertheless, progress achieved has been very different between regions. While food security improved significantly in East Asia, it became very unsatisfactory in sub-Saharan Africa and South Asia where the number of people suffering with hunger dramatically increased (FAO, 2002). There are several causes for this such as regional conflicts, political instability and wars, droughts and shortage of water supply, abandonment of agriculture by migrant populations and increased desertification (Fig. 2). These causes will likely remain present in the near future. At the same time, more developed regions produce high quantities of food and generate a surplus of food commodities. In spite of this, under nourishment exists in developed countries also (FAO, 2002, 2004). As stated by FAO, literally millions of people, including 6 million children under the age of five, die each year as a result of hunger. ‘‘Of these millions, relatively few are the victims of famines that attract headlines ... and emergency aid. Far more die unnoticed, killed by the effects of chronic hunger and malnutrition, a ‘covert famine’ that stunts their development, saps their strength and cripples their immune systems’’ (FAO, 2002, 2004).

In the present time the pressing challenge is, therefore, to produce more food and ensure food security regionally in order to alleviate poverty and under nourishment and, at the same time, to improve human health and welfare.

Although poverty and under nourishment is increasing in large cities also, 80% of the undernourished and poor live in rural areas (FAO, 2005). They are not likely to be fed by enhanced industrialization and, as the 1996 World Food Summit recognized, small scale and sustainable agriculture, could provide food to reduce hunger in these areas. Promoting local agriculture is a goal of the Millennium Development Project (UN Millennium Project, 2005).

Another challenge is to feed the growing world population in the long term. As the maximum world production of cereal grains is estimated at about 3300 Mt, 60% more than today (Gilland, 2002), the capability to produce cereal grains and animal protein may be levelling off rapidly. Therefore, the gap between the amount of food produced and the global population to feed is likely to increase till the year 2050.

This leads to two possible levers to counteract the current under nourishment of many populations and feed global population: the increase of the agriculture production and the action to curb the population growth curve. There is a widespread agreement on this point as found out in the 1996 World Food Summit and several other international *fora*.

In this setting, future growth of the agricultural sector seems, therefore, essential at global level also. This paper addresses the question of what pathways and technological resources are available to help meeting this challenge and what are the associated drawbacks?

2. Increasing production to provide food security

The increase of food production *per capita* could be obtained by one of several means, or a combination of them, such as

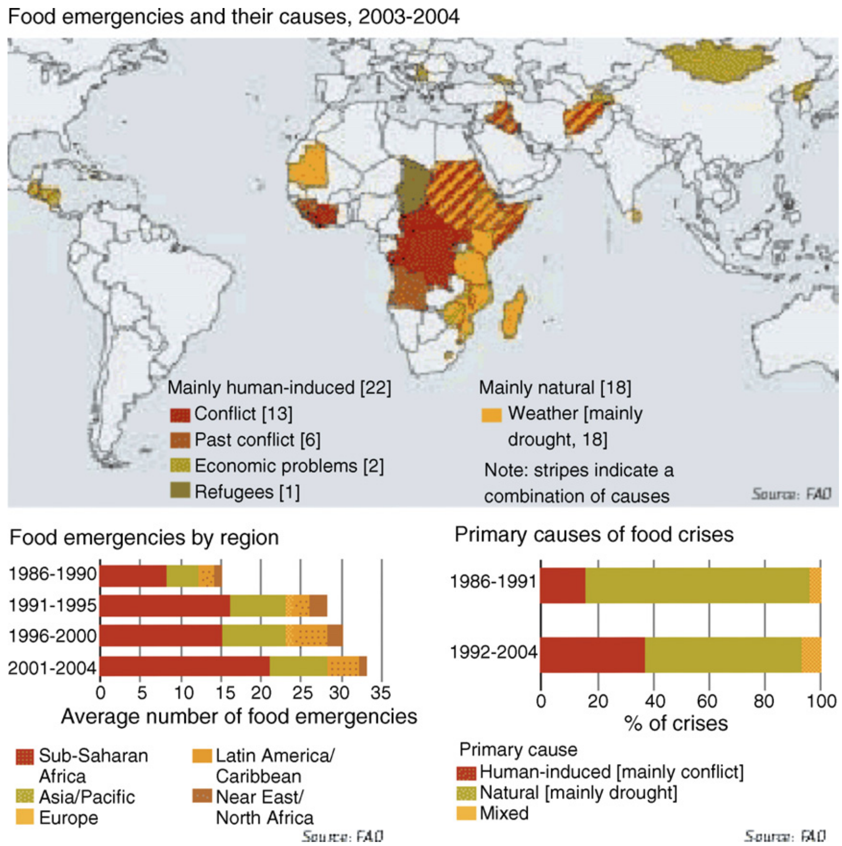

Fig. 2 – Regions of the world with food emergencies in latest years and their causes (*Source*: FAO, 2005).

increasing the area of agricultural land, enhancing the yield of crops through the use of agrochemicals, organic fertilizers, biological controls, and improved soil and water management. Furthermore, using more productive plants and plant varieties resistant to pests, and promoting the use of genetically modified organisms (GMOs) resistant to pests and diseases could help. In all of these tentative solutions some experience was obtained worldwide already. Results may be encouraging, but some are controversial.

To increase the area of agriculture land does not seem to be an easy task. Actually, the current trend is the decrease of agriculture land (hectares per inhabitant) in all regions of the globe. For example, in Latin America and Caribbean this surface will decrease from 0.40 ha/inh in 1990 to 0.32 ha/inh in 2010; in North Africa and Middle East the decrease is from 0.28 to 0.18 ha/inh in the same period; in South Asia the decrease is from 0.22 to 0.16 ha/inh (Alexandratos, 1999). This is partly due to population growth but there is also a net loss of agricultural land due to erosion, reduction of fertility, salinization and desertification of soils. New land could be found only with the cost of sacrificing forest areas, many of them classified as ecological reserves and natural parks (Alexandratos, 1999).

Another major problem is scarcity of water. Not only drinking water is scarce but also water for irrigation is scarce in Africa, Middle East, Asia and nearly everywhere. One should keep in mind that the production of 100 kg of wheat requires 50,000 l of water, and 200,000 l of water are needed to produce 100 kg of rice. Water resources available *per capita* decrease everywhere and many countries are already using for irrigation "fossil" waters pumped out from deep aquifers that will be exhausted in 20–30 years (UNEP, 2005). Better management of water resources is needed in many regions and use of plant varieties better adapted to regional weather conditions would increase water use efficiency.

In the present time, probably the immediate response to the need for increasing production of food is a more intensive use of agrochemicals. Agrochemicals include two large groups of compounds: chemical fertilizers and pesticides. The use of chemical fertilizers tremendously increased worldwide since the 1960s and largely was responsible for the "green revolution", i.e. the massive increase in production obtained from the same surface of land with the help of mineral fertilizers (nitrogen, phosphorus, potassium) and intensive irrigation. This has been the success story of rice, corn and wheat productions that increased worldwide (Borlaugh and Dowswell, 1993). This revolution was assisted also with the introduction of more productive varieties of rice and wheat (dwarf wheat).

Notwithstanding the increased production, massive use of mineral fertilizers caused serious contamination of aquifers, especially with nitrate, decreasing the quality of water for human consumption (Schroder et al., 2004; Camargo and Alonso, 2006). This is the case for vast regions in developed countries such as France, as well as in other developing countries. Fertilizers of different type, such as phosphate and super phosphate fertilizers, produced from fosforite and phosphoric acid, raised problems of environmental contamination with heavy metals, such as cadmium and arsenic, and

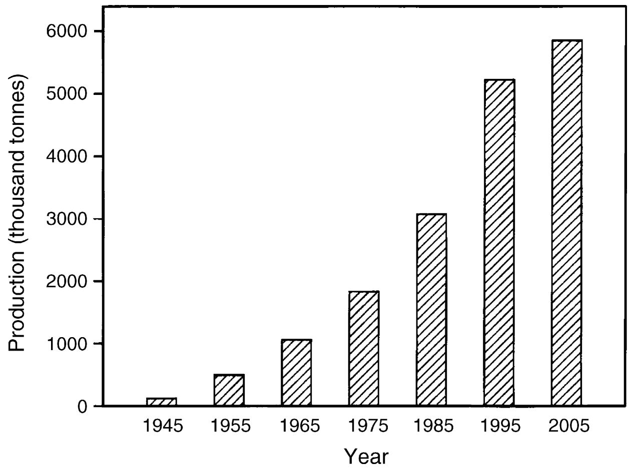

Fig. 3 – World production of formulated pesticides. Data for year 2005 is estimated (*Source*: Agrochemical Service, 2000).

radio nuclides of uranium and thorium series (Anonymous, 1991; Rutherford et al., 1995). Furthermore, the excess of nitrate and phosphate fertilizers caused serious problems of eutrophication of water bodies in Europe, Brazil, Thailand, Malaysia, etc. (UNEP, 2005).

The use of pesticides, including insecticides, fungicides, herbicides, rodenticides, etc., to protect crops from pests, allowed to significantly reduce the losses and to improve the yield of crops such as corn, maize, vegetables, potatoes, cotton, as well as to protect cattle from diseases and ticks and to protect humans from malaria vectors. The world has known a continuous growth of pesticide usage, both in number of chemicals and quantities, sprayed over the fields (Fig. 3). Pesticides are poisons intentionally dispersed in the environment to control pests, but they also act upon other species causing serious side effects on non-target species. Residues of pesticides contaminate soils and water, remain in the crops, enter the food chain, and finally are ingested by humans with foodstuffs and water (Barceló and Hennion, 1997; Taylor et al., 2003).

Insect pests develop resistance to insecticides and, as a consequence, chemical companies continuously synthesize new chemicals. In the European Union there are more than 800 chemicals registered as pesticides. However, we know very little about the environmental behaviour of these chemicals and about their effect upon human health (Sharpe, 1999; EEA, 2005).

The application of different agrochemicals varies with the region. For instance, in North America and Western Europe due to high costs of labour the chemical control of weeds is heavily done with herbicides, contrasting to East Asia and Latin America where herbicides are much less used (Fig. 4). In the tropical regions, where insect pests and plant diseases are more frequent, pesticides are generally applied in massive amounts, both in small farms as well as in cash crops, i.e. industrial plantations such as banana, coffee, maize and cotton. The residues of pesticides, especially the organochlorine and organophosphorous compounds, are found in soils, atmosphere and in the aquatic environment in relatively high concentrations (Carvalho et al., 1997). Studies performed in people living in rural areas of some countries, such as Costa Rica and Nicaragua, indicated direct exposure of many workers to the chemicals and acute poisoning with effects on reproduction and central nervous system (Duszeln, 1991; Muñoz-de-Toro et al., 2006; Bretveld et al., 2006). The population at large is exposed also to residues that are dispersed in the environment (Taylor et al., 2003). Recent studies, carried out for example in coastal areas of Mexico, Nicaragua and Vietnam, show that aquatic species, such as clams and oysters, that are important components of the diet

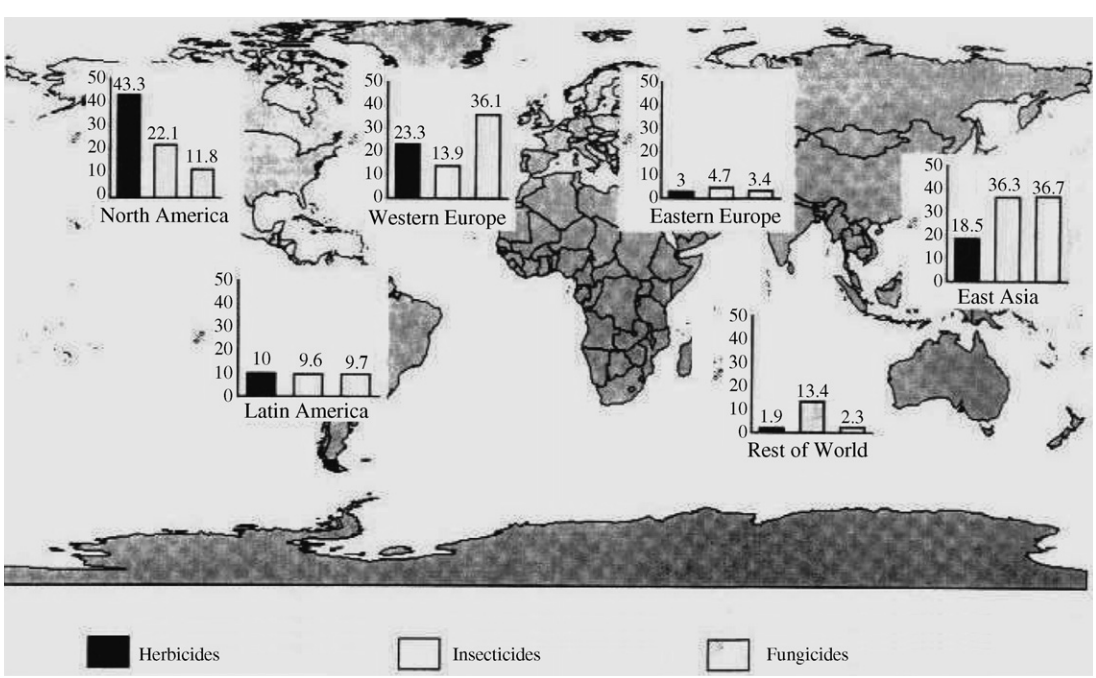

Fig. 4 – Use of pesticides by region in 1993, based on sales value (reproduced from Carvalho et al., 1997).

of riverine populations, may contain relatively high concentrations of DDTs, lindane, HCHs, endosulfan, toxaphene, chlorpyrifos amongst other crop protection chemicals (Carvalho et al., 1997, 2002; Nhan et al., 1999; Taylor et al., 2003; Carvalho, 2005).

Assessing past experience of increasing the production of food through using higher amounts of agrochemicals, suggests that this procedure is likely to cause more damage to the environment and to degrade food and water quality further. This does not automatically imply that agrochemicals are useless or totally harmful, but current problems call upon much better control of their registration and use (Harris, 2002). This control may require the ban of persistent chemicals, education of farmers and rural workers, and close monitoring of residues in the environment and in foodstuffs.

The use of better cultivars, more resistant to diseases and allowing for higher yields, seems to be a more prudent pathway to contribute to food security. One good example is rice, the grain that feeds more than half of the world population. Several varieties of various species of rice do exist (e.g. *Oriza sativa*, *O. japonica*) with yields ranging from 1–3 t/ha to 5 t/ha. The International Rice Research Institute (IRRI), in Philippines, since the 1960s has continuously developed hybrids with better yields and aim at developing high yield varieties by hybridization and selection as well as by genetic engineering. Results are very encouraging (Khush, 2002). The same pathway should be taken for other agriculture products of large consumption worldwide. In the process of selecting better cultivars, a special role is also played by the use of radiation-induced mutations (irradiation of seeds). This technique, promoted by FAO and IAEA, has allowed for producing healthy varieties of more productive plants, like groundnuts in India (IAEA, 2004).

Another way of improving food security is through increasing the shelf life of foodstuff through irradiation of foods (IAEA, 2003). Actually, this procedure has been largely tested and demonstrated to be effective in delaying spoilage of potatoes, onions, fruits, and many other foodstuffs. However, for the time being this treatment is not of wide public acceptance although it has the potential to replace many chemical additives used for the same purpose that are not totally safe for consumers (Macfarlane, 2002). Increased shelf life of food means also a more stable storage of banked food.

3. Current trends in the use of agrochemicals and food safety

Agrochemicals are an obvious part of current agriculture production systems. Regarding their use, in the present, there are two opposite trends each one related to a geographic region. Developed countries, including European Union, USA and Canada, approved new laws restraining the use of agrochemicals. This legislation aims at protecting consumers through a more thorough toxicological testing of compounds and enforcement of lower concentration limits for the residues tolerated in food and water (Harris, 2002). For example, the maximum permitted concentration of pesticides in drinking water set by the EU is 0.1 μg/l (Directive 80/778/EEC), challenging even the detection limits of current analytical methods (Barceló and Hennion, 1997).

This move is driven by health concerns of the public and consumer associations that perceive the presence of pesticide residues in the environment as detrimental to life quality. Results of scientific research support this point of view. Actually, it has been shown that even in low concentrations, the combined effect of xenobiotic chemicals causes suppression of immune response and hypersensitivity to chemical agents. In many cases, a relationship between organochlorine residues and breast cancer, and between PCBs and reduced sperm count and male sterility has been documented (Uri, 1997; Rivas et al., 1997; Sharpe, 1999; EEA, 2005).

Developed countries go, therefore, in the direction of fewer chemicals and more ‘‘green products’’. Furthermore, new pesticides are less persistent in the environment (more environmentally friendly) than classic pesticides. These new pesticides, however, are more costly when compared with old chemicals, and generally cannot be afforded by developing countries.

Developing countries go in a different direction in these matters. They need to increase the agriculture production and the use of crop protection chemicals seems a simple way for obtaining better crop yields. Therefore, either they use chemicals that are cheap, such as DDT, HCH, BCH, because either their patents have expired and are easy to synthesize or they are even offered by developed countries. In this path the contamination of environment, exposure of the public, and residues in food are higher. Risks to public health are higher too.

Countries in the tropical belt and with industrial capability to produce pesticides, such as India, invest in cheap pesticides as DDT and HCHs. The sales of these pesticides to Bangladesh, Philippines and Latin America, are the route for a massive use of organochlorine compounds in the tropics. However, compound volatilization causes the spread of residues that are transported by atmospheric processes to higher latitudes. Trans-boundary contamination arrives to countries in temperate zones and even to polar regions by this process (Chernyak et al., 1996; Carvalho, 2005).

The ban on the use of these persistent organic pollutants (POPs), that are bio accumulative and toxic, have been the goal of an international agreement recently achieved (UNEP, 2005). However, residues of persistent organic chemicals will remain in the biosphere still for years to come and, at least some of them, with toxic activity (Pelley, 2006; Young et al., in press).

4. The new paradigms

The last decade has seen new developments in food production: the genetic engineering of organisms and the organic chemical-free agriculture.

Biotechnology and release of genetically modified organisms (GMOs), such as engineered soybean, colza, maize and tomatoes, did promise a solution to food security needs and nutritional problems (Khush, 2002). Interestingly, the development of genomics and patented GMOs is in the hands of private research companies and largely surpassed the public research (Pingali and Traxler, 2002).

According to the main biotechnology private companies (Aventis, Monsanto, Novartis, Zeneca, etc.), these GMOs may be resistant to insect pests, to moulds, to frost, to dry conditions, etc., and could revolutionize agriculture (Pingali and Traxler, 2002). For example, soybean and other plants were modified to be tolerant to gliphosate, a common herbicide used to fight weeds allowing for much higher crop yields. However, because the weeds become increasingly resistant to this herbicide the use of these GM plants renders the farmers dependent upon the use of more and more gliphosate. Interestingly, gliphosate is produced by the same company that produces the GM herbicide resistant plants (Sharpe, 1999).

Concerns have been expressed also about the spread of GMOs and the impact on genetic variability of wild plants and the (unknown) risk of health disorders in consumers. Because the precautionary principle has not been observed, many countries, including the EU, are reluctant to license GMOs in spite of optimism and self-confidence of large companies in the economic, social and ecological profits of their products (Nickson, 1999). Moreover, it is not demonstrated that GMOs would solve or contribute to solve the need for increased production of food for a growing world population (Tripp, 2002; Falcon and Fowler, 2002).

Another paradigm has been the development of organic agriculture. Although started in the twenties, has grown so much in the last 20 years that it corresponds to the use of a few millions of hectares already (Tamm, 2001). Organic agriculture respects the normal functioning of ecosystems, avoiding the use of agrochemicals, and leads to food ''free'' of synthetic chemicals and, thus, more healthy. Notwithstanding the health value of better quality agriculture products, organic agriculture does not appear to have the potential for mass production of the amount of calories needed to feed humanity. The development of organic agriculture may, therefore, contribute to improved food safety but does not help to cope with food security. It will be needed to increase agriculture production further.

5. Would it be possible to feed the world population and eradicate hunger?

In order to eradicate hunger and poverty, it has been considered by many authors that key issues to solve are mostly in the economic realm and would require changes in world trade and distribution of food resources (Klassen, 1995; Alexandratos, 1999). Other optimistic prospects, based on agriculture developments, are defended by the UN Millennium Project and aim to halve the rate of extreme poverty in a few years (UN Millennium Project, 2005; Sachs, 2005). Whatever the development plan adopted, agriculture production needs to be increased in various regions of the world currently afflicted with hunger and malnutrition. Various tools have been suggested and can be called upon, such as:

- Selection of pest resistant and high yield cultivars.
- Rational use of water in irrigation, and prevention of contamination of water with chemical residues.
- Intensified agronomy efforts to produce new varieties, prevent soil erosion, salt intrusion, etc.
- Use of carefully selected species, such as cassava, in soils that are impoverished in nutrients.
- Moderate the use of fertilizers and pesticides.
- Education and training of farmers in the correct use of agrochemicals and protection of soils.
- Application of the precautionary principle in the development, testing and introduction of GMOs in the fields.
- Encourage the development of organic farming and integrated pest management (IPM) to reduce the use of synthetic chemicals.

Certainly, other foodstuffs such as meat, milk and fish, need similar care. In this regard, programmes supported by UN agencies (e.g. to control rinder pest, to eradicate the fruit fly) are of the utmost value (IAEA, 2004). Aquaculture has been developed in various regions and further developments shall continue in Africa, Latin America and Asia. Fish from aquaculture is an important source of protein in many countries and this activity is developing rapidly (Ahmed and Lorica, 2002; Thorpe et al., 2006).

Fostering sustainable small scale agriculture, as promoted by the UN Millennium Project, is helping to put in the hands of populations of the most impoverished regions the means to produce their food. If successful, this programme may help to reduce hunger (Sachs, 2005). However, to eradicate hunger and under nourishment seems much more difficult.

The successful control of hunger and under nourishment requires the control of population growth. Despite the conflicting views about the human carrying capacity of Earth (Cohen, 2005), over population will not help to solve under nutrition. Furthermore, technology may not be able to provide in time miraculous solutions to feed a continuously growing population (Gilland, 2002).

The agenda of governments and international organizations, therefore, should include renewed efforts to control demographic growth, contain conflicts in order to stabilize the functioning of society and agriculture activities, support sustainable agriculture programmes in impoverished regions, educate agriculturalists in the use of agrochemicals, prevent soil erosion and degradation of water resources, protect genetic diversity, and apply the precautionary principle in the introduction of GMOs. The success of these efforts has to be achieved at regional level, especially in the most impoverished regions.

6. Final remarks

World agriculture needs to keep up with continuous growth of world population and, moreover, to develop further in order to reduce the number of undernourished people and to promote health and welfare. A second ''green revolution'' in agriculture seems unlikely, and enhanced production will make use of more agrochemicals, intensive irrigation and plant varieties with better yields. Further scientific developments may come on the scene to help producing better and safer food.

The increase in the availability of food *per capita*, i.e. securing sufficient food for the world population, might be obtained through several technological means available already. However, in the use of these technological means the precautionary principle should be applied and food safety, as well as environment protection and biodiversity should be ensured. Otherwise, unwise application of technological tools may further deteriorate human health and environmental quality and compromise future development of human societies.

The size of the tasks to be implemented as well as the complexity of problems to be solved requires better coordination than ever amongst nations. It would be highly desirable that international organizations, such as the UN family of organizations, should excel in their capacities, better coordinate efforts, and take leadership.

REFERENCES

Agrochemical Service, 2000. Wood Mackenzie Consultants Limited. Edinburgh, UK.

Ahmed, M., Lorica, M., 2002. Improving developing country food security through aquaculture-lessons from Asia. Food Policy 27, 125–141.

Alexandratos, N., 1999. World food and agriculture: outlook for the medium and longer term. Proc. Natl. Acad. Sci. U.S.A. 96, 5908–5914.

Anonymous, 1991. The causes and effects of phosphates in the environment. Going green. Phosphorus Potassium 172, 18–22.

Barceló, D., Hennion, M.-C., 1997. Trace determination of pesticides and their degradation products in water. Techniques and Instrumentation in Analytical Chemistry, vol. 19. Elsevier, Amsterdam, p. 542.

Borlaugh, N., Dowswell, C.R., 1993. Fertilizer: to nourish infertile soil that feeds a fertile population that crowds a fragile world. In: Proceeding of the 61st International Fertilizer Association Annual Conference.

Bretveld, R.W., Thomas, C.M.G., Scheepers, P.T.J., Zielhuis, G.A., Roeleveld, N., 2006. Pesticide exposure: the hormonal function of the female reproductive system disrupted? Reprod. Biol. Endocrinol. 4, 30.

Camargo, J.A., Alonso, A., 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. Environ. Int. 32, 831–849.

Carvalho, F.P., 2005. Residues of persistent organic pollutants in coastal environments—a review. In: Gomes, F.V., Pinto, F.T., Neves, L., Sena, O., Ferreira, O. (Eds.), Proceedings of the First International Conference on Coastal Conservation and Management in the Atlantic and Mediterranean (ICCCM'05), Tavira, Portugal, April 17–20. FEUP, Universidade do Porto, ISBN: 972-752-083-9 pp. 423–431.

Carvalho, F.P., Fowler, S.W., Villeneuve, J.-P., Horvat, M., 1997. Pesticide residues in the marine environment and analytical quality assurance of the results. In: Proceedings of an International FAO/IAEA Symposium on the Environmental Behaviour of Crop Protection Chemicals. IAEA, Vienna, pp. 35–57.

Carvalho, F.P., Villeneuve, J.-P., Cattini, C., Tolosa, I., Guillén, S.M., Lacayo, M., Cruz, A., 2002. Ecological risk assessment of pesticide residues in coastal lagoons of Nicaragua. J. Environ. Monit. 4, 778–787.

Chernyak, S.M., Rice, C.P., McConnel, L.L., 1996. Evidence of currently-used pesticides in air, ice, fog, seawater and surface microlayer in the Bering and Chuckchi Seas. Mar. Pollut. Bull. 32, 410–419.

Cohen, J.E., 2005. Human population grows up. Sci. Am. (Special issue), 26–33.

Duszeln, J., 1991. Pesticide contamination and pesticide control in developing countries: Costa Rica, Central America. In: Richardson, M.L. (Ed.), Chemistry, Agriculture and the Environment. The Royal Society of Chemistry, London, pp. 410–428.

EEA, 2005. Environment and Health. European Environment Agency, EEA Report No. 10.

Falcon, W.P., Fowler, C., 2002. Carving up the commons—emergence of a new international regime for germplasm development and transfer. Food Policy 27, 197–222.

FAO, 2002. The State of Food Insecurity in the World 2002. Economic and Social Department, Food and Agriculture Organization of the United Nations, Rome.

FAO, 2004. The State of Food Insecurity in the World 2004. Economic and Social Department, Food and Agriculture Organization of the United Nations, Rome.

FAO, 2005. The State of Food Insecurity in the World 2005. Economic and Social Department, Food and Agriculture Organization of the United Nations, Rome.

FAOSTAT, 2001. Food and agricultural organization statistics database (FAOSTAT). Available from http://www.fao.org.

Gilland, B., 2002. World population and food supply. Can food production keep pace with population growth in the next half-century? Food Policy 27, 47–63.

Harris, C.A., 2002. The regulation of pesticides in Europe—Directive 91/414. J. Environ. Monit. 4, 28–31.

IAEA, 2003. Radiation processing for safe, shelf-stable and ready-to-eat food. In: IAEA TECDOC Series No. 1337, International Atomic Energy Agency, Vienna.

IAEA, 2004. Genetic improvement of under-utilized and neglected crops in low income food deficit countries through irradiation and related techniques. In: IAEA TECDOC Series No. 1426, International Atomic Energy Agency, Vienna.

Khush, G.S., 2002. The promise of biotechnology in addressing current nutritional problems in developing countries. Food Nutr. Bull. 23 (4), 354–357.

Klassen, W., 1995. World food security up to 2010 and the global pesticide situation. In: Proceedings of the Eighth International Congress on Pesticide Chemistry, Washington, DC. American Chemical Society, Washington, DC, pp. 1–32.

Macfarlane, R., 2002. Integrating the consumer interest in food safety: the role of science and other factors. Food Policy 27, 65–80.

Muñoz-de-Toro, M., Durando, M., Beldoménico, P.M., Beldoménico, H.R., Kass, L., García, S.R., Luque, E.H., 2006. Estrogenic microenvironment generated by organochlorine residues in adipose mammary tissue modulates biomarker expression in ERα-positive breast carcinomas. Breast Cancer Res. 8, R47.

Nhan, D.D., Manh, A.N., Carvalho, F.P., Villeneuve, J.-P., Cattini, C., 1999. Organochlorine pesticides and PCBs along the coast of North Vietnam. Sci. Total Environ. 237/238, 363–371.

Nickson, T.E., 1999. Environmental monitoring of genetically modified crops. J. Environ. Monit. 1, 101–105.

Pelley, J., 2006. DDT's legacy lasts for many decades. Environ. Sci. Technol. 40, 4533–4534.

Pingali, P.L., Traxler, G., 2002. Changing locus of agricultural research: will the poor benefit from biotechnology and privatization trends? Food Policy 27, 223–238.

Rivas, A., Nicolas, O., Olea-Serrano, F., 1997. Human exposure to endocrine-disrupting chemicals: assessing the total estrogenic xenobiotic effect. Trends Anal. Chem. 16, 613–619.

Rutherford, P.M., Dudas, M.J., Arocena, J.M., 1995. Trace elements and fluoride in phosphogypsum leachates. Environ. Technol. 16, 343–354.
Sachs, J.D., 2005. Can extreme poverty be eliminated? Sci. Am. (Special issue), 34–43.
Schroder, J.J., Scolefield, D., Cabral, F., Hofman, G., 2004. The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. Environ. Sci. Policy 7, 15–23.
Sharpe, M., 1999. Towards sustainable pesticides. J. Environ. Monit. 1, 33–36.
Srinivasam, C.S., Irz, X., Shankar, B., 2006. An assessment of the potential consumption impacts of WHO dietary norms in OECD countries. Food Policy 31, 53–77.
Tamm, L., 2001. Organic agriculture: development and state of the art. J. Environ. Monit. 3, 92–96.
Taylor, M., Klaine, S., Carvalho, F.P., Barcelo, D., Everaarts, J. (Eds.), 2003. Pesticide Residues in Coastal Tropical Ecosystems. Distribution, Fate and Effects. Taylor and Francis, London.
Thorpe, A., Reid, C., Anrooy, R., Brugere, C., Becker, D., 2006. Asian development and poverty reduction strategies: integrating fisheries into the development discourse. Food Policy 31 (5), 385–400.
Tripp, R., 2002. Can the public sector meet the challenge of private research? Commentary on ''Falcon and Fowler'' and ''Pingali and Traxler''. Food Policy 27, 239–246.
UN, 2001. World Population Prospects. The 2000 Revision. Population Division, Department of Economic and Social Affairs. United Nations, NY.
UN 2005. World Population Prospects. The 2004 Revision. Highlights. Population Division, Department of Economic and Social Affairs. United Nations, NY.
UNEP, 2005. Geo Year Book 2004/5. An Overview of our Changing Environment. United Nations Environment Programme, Nairobi.
UN Millennium Project, 2005. Investing in development: a practical plan to achieve the millennium development goals. United Nations Millennium Project. Available from http://www.unmillenniumproject.org.
Uri, N.D., 1997. A note on the development and use of pesticides. Sci. Total Environ. 204, 57–74.
Young, J.C., Freeman, A.D., Bruce, M.R., Williams, D., Maruya, K., in press. Comparing the mutagenicity of toxaphene after aging in anoxic soils and accumulating in fish. Ecotoxicol. Environ. Safe.

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