Challenges, Options and Future Research Needs

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Chapter 16
Challenges, Options and Future Research Needs AU1

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Contents

16.1 Global Challenges

To be ready and focused to meet the challenges of the twenty-first century, the United Nations Environment Programme (UNEP) highlights six priorities, which are climate change, disasters and conflicts, ecosystem management, environmental governance, harmful substances and resource efficiency. The United Nations and its Millennium Goals consider environmental sustainability to be one of the fundamentals rights of individuals. To achieve global environmental sustainability, four targets have been established, which include (a) the integration of the principles of sustainable development into country policies and programmes and reversion of the loss of environmental resources; (b) reduction of biodiversity loss; (c) reduction of

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the proportion of the population without sustainable access to safe drinking water and basic sanitation; and (d) achievement of a significant improvement in the lives of slum dwellers. According to the Food and Agricultural Organization of the United Nations (FAO) other global issues are avian influenza, biodiversity, bioenergy, climate change, food safety, trade, water and world food situation.

The aim of this final chapter is to highlight the future research needs to optimize the contribution of microorganisms to achieving these goals, particularly in the areas of waste management, soil degradation, population growth and diseases, energy demand and climate change. Microorganisms can contribute to solve current environmental challenges, and it is suggested that further research needs should be oriented towards the improvement of soil quality and fertility, the adaptation of agricultural management and technologies to climate change and the development of renewable energies. Research on the use of microorganisms to abate climate change is of particular interest and more efforts are recommended in this direction.

16.1.1 Waste Management

Historically, it was the scarcity of new materials that has been the driving factor for recycling of used materials. During the last decades in many countries, traditional recycling seems to have been gradually forgotten, and centralized landfills or incineration plants are often a simple answer to growing waste problems. In countries where population density is high and the value of preserved nature along with minimal carbon foot-print is increasingly demanded, many of them in Europe, environmentally sound waste management programmes have been introduced. AU3

According to the European Environment Agency (EEA) (2007), Europe (EU-15) and EFTA (Iceland, Norway, Switzerland, and Liechtenstein) produce almost 1,000 mio tonnes of waste each year. The United Kingdom alone produces more than 400 mio tonnes of waste each year, and of this, about 35 mio tonnes is municipal solid waste. The problem of waste disposal is recognized as one of the most serious environmental problems. Composting, a waste management strategy that exploits microorganisms to do the job, has been suggested as one sustainable option. There are three main reasons for the growth of the composting industry in the UK: legislation for biodegradable municipal solid waste, environmental benefits and economic benefits. Green-waste comprised the majority (92% in 1998) of municipal wastes produced in the UK. The three main regulatory drivers for composting are the EU landfill directive (EC 1999), the UK Waste Strategy 2000 (DETR 2000) and the EU Animal By products Regulations (EC 2003). These have increased interest in composting of garden, tree, and food-processing organic wastes. As a result, in 2005/2006, 3.4 mio tonnes of source segregated waste was composted, an increase of 28% compared with the previous year. The majority of waste was composted using open air mechanically turned windrows, with only 14% composted in-vessel. Agriculture was the largest market sector, with one million tonnes supplied, being the majority used on arable and cereal crops. But, also AU4

BookID 161216_Insam_ChapID 16_Proof# 1 - 7/9/09

horticulture and landfill restoration/daily cover accounted for approximately a quarter of a million tonnes each. The annual turnover of the composting and biological treatment industry was estimated at just over £90 million (Nikitas et al. 2008).

For a very long time, little research has been dedicated to improve microbial processes for waste management, but this seems to be changing. Habitats that are so extremely variable in both time and space like compost heaps are increasingly attracting scientists. Optimization of other waste management strategies that exploit the use of microorganisms including anaerobic digestion, enzymatic hydrolysis and fermentation is also receiving a great amount of attention (see Chap. 2, Braun et al. 2010; Chap. 4, Wett and Insam 2010).

Future research needs in this area include the improvement of rapid and robust measurement tools, identification and isolation of efficient microorganisms under different conditions of temperature, substrate or humidity, study of the metabolic processes of degradation and development of new added-value products.

16.1.2 Land Degradation and Soil Erosion

Land degradation is arguably one of the major global environmental challenges. Land degradation leads to a significant reduction of the productive capacity of land. Human activities contributing to land degradation include unsuitable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper crop rotation and poor irrigation practices. Natural disasters, including droughts, floods and landslides, also contribute to land degradation. Soil erosion is a major factor in land degradation and has severe effects on soil functions – such as the soil's ability to act as a buffer and filter for pollutants, its role in the hydrological and nitrogen cycle, and its ability to provide habitat and support biodiversity. About 2,000 mio ha of soil, equivalent to 15% of the Earth's land area, have been degraded through human activities. The main types of soil degradation are water erosion (56%), wind erosion (28%), chemical degradation (12%) and physical degradation (4%). Causes of soil degradation include overgrazing (35%), deforestation (30%), agricultural activities (27%), overexploitation of vegetation (7%) and industrial activities (1%) (UNEP 2002).

Soil salinisation is a major problem that may occur in two ways: (a) intrusion of saline seawater into deep coastal aquifers and (b) evaporation of excess irrigation water often associated with poor soil drainage, which leaves dissolved salts in the soil. A reduced expansion of irrigated area by the year 2020 and an increased investment in drainage to deal with salinisation are expected (Garret 2005). Nevertheless, problems of salinisation will still remain or even increase, as irrigation systems with inadequate drainage continue to age. On the other hand, a considerable amount of unsustainable irrigated land is projected to go out of production and new opportunities for rehabilitation of degraded lands and sustainable pasture management systems are expected to be developed. AU5

Microorganisms will play an essential role in the rehabilitation of degraded lands, as they contribute to the conversion of carbon, nitrogen and other elements in the environment and increase soil fertility. Microorganisms affect soil structure by producing metabolites that bind soil particles together and physically enmesh particles with filaments. This stabilization of micro-structures may be carried through to stabilization of meso-structure, leading to sustained increases in porosity, at a number of scales. This, in turn, has implications for the capacity of soils to retain water since such properties relate to pore architecture and the range and location of hydrophobic and hydrophilic sites within the pore network (Allton et al. 2007).

Soil stability is important for landscape dynamics with respect to their ability to cope with externally forced change, such as wet–dry cycles and land management practices. Cropping and tillage practices are already known to influence run-off and soil losses, and to influence the microbial community (Jackson et al. 2003). Compost and biochar are extensively used as soil amendments. The impact of these amendments on the microbial structure will have a direct impact on the soil structure and thus requires further research. Other future research needs in this area include (a) the identification of microbial components which contribute to soil structure stability, (b) the understanding of the processes governing a microbiologically active soil, and (c) the relationships between the soil microorganisms, soil structure and hydrology.

16.1.3 Population Growth, Food Demand and Diseases

According to the last UN 2008 Revision of World Population Prospects (UN 2009), world population is projected to reach 7 billion early in 2012, up from the current 6.8 billion, and surpass 9 billion people by 2050. Most of the additional 2.3 billion people will enlarge the population of developing countries, while the population of the more developed regions is expected to change minimally.

There are concerns that water scarcity, soil depletion, the lack of technology adoption and dissemination, political and civil conflict, and the continued threat of human disease epidemics, plant diseases and animal diseases pose a grave threat to the food security of growing populations in the developing world.

There are ominous signs. Progress in hunger reduction slowed considerably during the late 1990s: between 1995 and 2001, the number of undernourished people in the developing world increased by more than 18 mio. If China is excluded from consideration, the number of undernourished people in the developing world increased by nearly 28 mio during this period. In addition, there are indications that price fluctuations are rising as world cereal stocks are reduced. Moreover, micronutrient malnutrition is widespread, and its consequences are significant. The majority of the world's hungry people depend heavily, both directly and indirectly, on growth in the agricultural sector for both food and their livelihoods, either as farmers or as net purchasers of food. Most of the world's hungry, approximately

80%, live in rural areas, where access to markets, health care, education, and infrastructure such as telecommunications and roadways is scarce. These areas are often characterized by poor quality of natural assets, a fragile natural resource base.

At present, low agricultural investments undermine the development of new agricultural technology and contribute to marginal levels of irrigation efficiency and lack of improvement in water use efficiency. In addition, investments in many sectors, including education, social services, and health, are low in developing countries. The lack of growth in agricultural yields is the outcome of all of the above and also partly a result of weak income growth in developing countries and only moderate income growth in industrialized countries. Future research needs in this area should focus in the implication of microorganisms in (a) improving water management and irrigation efficiency, (b) adaptation to climate change, (c) increase of crops yields, and (d) improved strategies to combat pest problems in agriculture. All these will contribute to the increase of crop production and thus facilitate food security.

16.1.4 Energy Demand

According to the reference case projection from the "International Energy Outlook 2008," the world energy consumption is projected to expand by 50% from 2005 to 2030 (EIA 2008). Energy demand in the Organisation for Economic Co-operation and Development (OECD) economies is expected to grow slowly over the projection period, at an average annual rate of 0.7%, whereas energy consumption in the emerging economies of non-OECD countries (including India and China) is expected to expand by an average of 2.5% per year.

High prices for oil and natural gas are expected to continue throughout the period and are likely to slow the growth of energy demand in the long term, nevertheless world energy consumption is projected to continue increasing strongly as a result of robust economic growth and expanding populations in the world's developing countries. Thus, high prices for oil and natural gas as well as rising concern about the environmental impact of fossil fuel use improve the prospects for renewable energy and coal with consumption increasing by 2.1% and 2.0%, respectively. As coal's costs are comparatively low relative to the costs of liquids and natural gas, and abundant resources in large energy-consuming countries make coal an economical fuel choice. In the absence of policies or legislation that would limit the growth of coal use, the United States, China, and India are expected to turn to coal in place of more expensive fuels. The only countries for which decreases in coal consumption are projected are OECD Europe and Japan, where populations are either growing slowly or declining, electricity demand growth is slow, and natural gas, nuclear power, and renewables are likely to be used for electricity generation rather than coal. Much of the growth in renewable energy consumption is projected to come from mid- to large-scale hydroelectric facilities in non-OECD Asia and Central and South America, where several countries have hydropower facilities either planned or under construction.

Europe, where many countries are obligated to reduce greenhouse gas emissions under the Kyoto Protocol treaty, has set a target of increasing the renewable energy share to 20% of gross domestic energy consumption by 2020, including a mandatory minimum of 10% for biofuels. Future research needs in this area should focus in (a) optimisation of microbial processes (e.g., hydrolysis, fermentation) to produce biofuels, including biogas, (b) development of novel enzymatic processes to reduce the cost of biofuel production, (c) development of microbial fuel cells, and (d) production of biofuels from microorganisms, e.g., biodiesel form algae.

16.1.5 Climate Change

Climate change and the vulnerability of energy supplies are two of the biggest threats to our security. Without urgent action, irreversible changes to the climate system are possible. According to the Intergovernmental Panel on Climate Change (IPCC) climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

IPCC's Third Assessment Report stated that there are evidences that human activities are attributable of the warming observed over the past 50 years (IPCC 2001). Carbon dioxide (CO_2) is the greenhouse gas that makes the largest contribution from human activities. It is released into the atmosphere by for example the combustion of fossil fuels, the burning of, for example, forests during land clearance and from certain industrial and resource extraction processes and composting. In addition to CO_2, the composting process naturally produces some methane (CH_4) and nitrous oxide (N_2O). Methane (CH_4) has a global warming potential 23 times higher than CO_2, and the largest source of CH_4 emission is from landfill sites (during the anaerobic methanogenic stage), where it escapes through the landfill cover into the atmosphere. N_2O is also a greenhouse gas with an extremely high global warming potential (~310) and it can also be generated in landfills through the processes of nitrification and denitrification; is linked to methanotrophic activity and therefore cannot be ignored when considering methods to reduce global warming (Chapman and Antizar-Ladislao 2007).

According to the UN Framework Convention on Climate Change, a stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate change should be achieved. Technological options for reducing net CO_2 emissions to the atmosphere include: (a) reducing energy consumption, for example by increasing the efficiency of energy conversion and/or utilization (including enhancing less energy-intensive economic activities), (b) switching to less carbon intensive fuels, for example natural gas instead of coal, (c) increasing the use of renewable energy sources which emit little or no net CO_2, (d) sequestering CO_2 by enhancing biological absorption capacity in forests and soils, (e) capturing and storing CO_2 chemically or physically. Further research in this area should focus in enhancing biological absorption capacity in forests and soils where microorganisms play a crucial role. The design or selection of microorganisms for CO_2 capture presents a great potential to reduce green house emissions to the atmosphere.

16.2 Contribution of the Microorganisms to Solve Current Global Challenges

Microorganisms can contribute to solve current global challenges, particularly those aforementioned using a number of different strategies, such as the conversion of organic waste to soil amendment or to energy. Use of microorganisms to abate climate change, combat pathogens, improve soil fertility are also offering a great potential. Here a few microbial strategies are highlighted. They have been selected as they offer a great potential for a sustainable development.

Agriculturalists since ancient times have recognized significant benefits of soil organic matter to crop production, including (a) it serves as a slow released source of N, P and S, for plant nutrition and microbial growth; (b) it possess considerable water-holding capacity; (c) it acts as a buffer against changes in pH of the soil; (d) its dark colour contributes to absorption of energy from sun and heating of the soil; (e) may act as plant-growth stimulants; and (f) binds micronutrient metal ions in the soil (McCarthy et al. 1990).

Composting is an aerobic process where organic materials are biologically decomposed. Conventional composting processes typically comprise four major microbiological stages in relation to temperature: mesophilic, thermophilic, cooling and maturation, during which the structure of the microbial community also changes, and the final product is compost (see Chap. 1, Insam et al. 2010; Chap. 5, Domínguez et al. 2010; Chap. 12, Minz et al. 2010; Chap. 13, Bastida et al. 2010). Compost has been widely used as soil conditioner and soil fertilizer. This practice is recommended, as soil fertility needs more than ever to be sustained. Food demand is increasing rapidly in non-OECD countries, and it is in those countries particularly where organic waste needs to be diverted from landfill sites to composting practices, so compost can enhance soil fertility. In OECD countries, where composting of organic waste is already established, also its use as a landfill cover to abate greenhouse gas emissions has shown to be promising (Chapman and Antizar-Ladislao 2007). The addition of compost can minimize land degradation and soil erosion. Additionally, composting can contribute to achieve sufficient hygienisation of organic wastes and control soil born and air born pathogens by promotion of beneficial microorganisms and suppression of harmful microorganisms (see Chaps. 11–14) and Insam et al. (2002).

Frequently agrochemicals are not applied following a sustainable approach, and some undesired consequences have been observed such as disease resistances, elimination of beneficial microbes, plant toxicity and contamination of soil, rivers or aquifers. Alternatives to chemical control or synergic strategies are thus necessary for a more sustainable control of pathogens. In addition with climate change and globalization new diseases are appearing that need to be fought. The role of microorganisms to abate climate change should be further explored, and thus further research is needed for example to improve the use of compost to oxidize methane emitted at landfill sites to carbon dioxide, as methane is a potent greenhouse gas, with a global warming potential 23 times higher than carbon dioxide.

Biomass waste releases carbon as it decomposes, but it can be burned in a kiln by pyrolysis (burning of biomass under controlled, low-oxygen conditions) to create biochar. A lot of attention is given to the use of biochar and its use to mitigate greenhouse gas emissions. Biochar has the potential of sequestering bions of tonnes of carbon in the world's soils, specifically from agriculture and forestry residual biomass. It is suggested that the biochar system will sequester carbon for at least 100 years as compared to plants or trees that will only sequester carbon for 15 or 20 years. Biochar also provides plenty of surface area for beneficial fungi and bacteria to grow, which seems to reduce the need for fertilizers. It has been suggested that biochar can be used to address some of the most urgent current environmental problems, such as soil erosion, food insecurity, water pollution from agrochemicals, and climate change (Tenenbaum 2009). Further research is required AU6 to obtain reliable data on the agronomic and carbon sequestration potential of biochar, and also on the use of pyrolysis to optimize biochar properties. The ability of biochar to decrease emissions of nitrous oxide and methane is intriguing and requires further research.

Bionergy is seen as one of the primary possibilities for preventing global warming. At present, the immediate factor impeding the emergence of an industry converting biomass into liquid fuels or biogas on a large scale is the high cost of processing, rather than the cost or availability of feedstock (EEA 2008). The goal of second generation biofuels is to extend the amount of biofuel that can be produced sustainably by using biomass comprised of the residual non-food parts of current crops, as well as other crops that are not used for food purposes and also municipal, industrial and construction waste. Second generation biofuels are expected to reduce net carbon emission, increment energy efficiency and reduce energy dependency, potentially overcoming the limitations of first generation biofuels. New techniques have been devised for the utilization of second generation biomass feedstock for energy production, including thermo-chemical conversion (i.e. combustion, gasification, pyrolysis, liquefaction, hydrothermal upgrading), biochemical conversion (i.e. fermentation and anaerobic digestion) and extraction of vegetable oils. Direct combustion, gasification, pyrolysis, liquefaction or hydrothermal upgrading are chemo-technical approaches. Another approach is to develop a process that works universally for all feedstock, converting carbon-based feedstock into hydrogen and carbon monoxide plus remaining components. This could use coal or natural gas and turn it into liquid fuels combining microbes that turn the "synthesis gas – syngas" straight into ethanol. Fermentation is an anaerobic process by which yeast converts sugars such as glucose, fructose and sucrose into ethanol and carbon dioxide. The anaerobic digestion process consists of three steps: a hydrolysis step in which organic compounds, such as polysaccharides, proteins, and fat are hydrolyzed by extracellular enzymes, an acidification step in which the products of the hydrolysis are converted into H_2, formate, acetate and higher molecular weight volatile fatty acids, and a third step in which biogas, a mixture of carbon dioxide and methane, is produced from hydrogen, formate, and acetate. The complete methanogenic conversion occurs by mixed microbiological communities yielding methane as the sole reduced organic compound (see Chap. 3, Plugge et al. 2010). Only bioethanol and biodiesel are presently produced as fuel on an industrial scale. Including ethyl-tertio-butyl-ether partially made with bioethanol, these fuels make up more than 90% of the biofuel market (Boehmel et al. 2008).

References

Allton KE, Harris JA, Rickson RJ, Ritz K (2007) The effect of microbial communities on soil hydrological processes: A microcosm study utilising simulated rainfall. Geoderma 142:11–17

Bastida F, Hernández T, García C (2010) Soil degradation and rehabilitation: microorganisms and functionality. In: Insam H, Franke-Whittle IH, Goberna M (eds) Microbes at work. From wastes to resources. Springer-Verlag, Heidelberg

Boehmel C, Lewandowski I, Claupein W (2008) Comparing annual and perennial energy cropping systems with different management intensities. Agric Syst 96:224–236

Braun R, Drosg B, Bochmann G, Weiß S, Kirchmayr R (2010) Recent developments in bio-energy recovery through fermentation. In: Insam H, Franke-Whittle IH, Goberna M (eds) Microbes at work. From wastes to resources. Springer-Verlag, Heidelberg

Chapman M, Antizar-Ladislao B (2007) Biotic landfill CH_4 emission abatement using bio-waste compost as a landfill cover. In: Lehmann EC (ed) Landfill research focus. Nova Science, New York, pp 27–52

Domínguez J, Aira M, Gómez-Brandón M (2010) Vermicomposting: earthworms enhance the work of microbes. In: Insam H, Franke-Whittle IH, Goberna M (eds) Microbes at work. From wastes to resources. Springer-Verlag, Heidelberg

EEA (2007) The road from landfilling to recycling: common destination different routes. Brochure No 4/2007

EEA (2008) State of renewable energies in Europe 2006. http://www.energies-renouvelables.org/observer/stat_baro/barobilan/barob-ilan6.pdf. Accessed 8 May 2009

EIA (Energy Information Administration) (2008) International Energy Outlook 2008. http://www.eia.doe.gov/oiaf/ieo/world.html AU7

Garret JL (2005) 2020 Vision for food, agriculture and the environment. International Food Policy Research Institute (IFPRI), Washington. http://www.ifpri.org/2020/dp/dp06.pdf AU8

Insam H, Riddech N, Klammer S (2002) Microbiology of composting. Springer-Verlag, Berlin, p 632

Insam H, Franke-Whittle IH, Goberna M (2010) Microbes in aerobic and anaerobic waste treatment. In: Insam H, Franke-Whittle IH, Goberna M (eds) Microbes at work. From wastes to resources. Springer-Verlag, Heidelberg

IPCC (2001) Climate change 2001: the scientific basis. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds),Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK

Jackson LE, Calderon FJ, Steenwerth KL, Scow KM, Rolston DE (2003) Responses of soil microbial processes and community structure to tillage events and implications for soil quality. Geoderma 114:305–317

McCarthy P, Clapp CE, Malcolm RL, Bloom PR (1990) Humic substances in soil and crop sciences: selected readings. American Society of Agronomy, Inc. Soils Science Society of America, Inc. Madison, WI, USA

Minz D, Green SJ, Ofek M, Hadar Y (2010) Compost microbial populations and interactions with plants. In: Insam H, Franke-Whittle IH, Goberna M (eds) Microbes at work. From wastes to resources. Springer-Verlag, Heidelberg

Nikitas C, Pocock R, Toleman I, Gilbert EJ (2008) The state of composting and biological waste treatment in the UK 2005/06. The Composting Association

Plugge CM, van Lier JB, Stams AJM (2010) Syntrophic communities in methane formation from high strength wastewaters. In: Insam H, Franke-Whittle IH, Goberna M (eds) Microbes at work. From wastes to resources. Springer-Verlag, Heidelberg

Tenenbaum DJ (2009) Biochar: carbon mitigation from the ground up. Environ Health Perspect 117:A70–A73

UN (2009) 2008 revision of world population prospects. http://www.un.org/esa/population/unpop.htm.Accessed 8 May 2009

UNEP (2002) Global Environment Outlook 3 (GEO-3). United Nations Environment Programme

Wett B, Insam H (2010) A novel 4 chamber biogas reactor. In: Insam H, Franke-Whittle IH, Goberna M (eds) Microbes at work. From wastes to resources. Springer-Verlag, Heidelberg