Journal of Integrative Agriculture
2012, 11(1): 1-8

Available online at www.sciencedirect.com
ScienceDirect

January 2012

COMMENTARY

Making More Food Available: Promoting Sustainable Agricultural Production

Rudy Rabbinge[1] and Prem S Bindraban[2, 3]

[1] *Food Security and Sustainable Development, Wageningen UR, PO Box 88, 6700AB, Wageningen, the Netherlands*
[2] *ISRIC-World Soil Information, PO Box 353, 6700AJ Wageningen, the Netherlands*
[3] *Plant Research International, Wageningen UR, PO Box 616, 6700AP, Wageningen, the Netherlands*

INTRODUCTION

During the 20th century food availability worldwide has increased considerably. The increase in population was outnumbered by the productivity increase in agriculture mainly by higher yields per ha. Globally there is more food available per person than ever before. In the coming decades the world population will further increase and diets will change requiring a doubling of plant production worldwide by 2050. Especially the increase in demand will be substantial in Asia and sub-Saharan Africa.

The strategies to attain food security in these two continents have to be different, making use of agro-ecological potentials and eliminating limitations through measures that are geared to location specific conditions (WRR 1995; InterAcademy Council 2004). It is important in this regard to note the production systems in agriculture evolve over time depending on the development stage of society because of their changing desires, advances in technology and institutional and market conditions (Pingali 1997). With regard to the entire national and global food system, revolutionary changes take place in different stages and components of food production (e.g., Fig. 1) to processing, market and institutional structures to manage food distribution, such as private of public storage of food, and in the competition in allocation of natural resources to produce different goods and services.

In this paper historical trends will be discussed and possibilities for food security in the decades to come will be described as will be the way to do that by addressing the major challenges for the 21st century. These options will be illustrated indicating that ecological modernization based on basic principles offers opportunities and chances that should be optimally utilized. That may also contribute considerably to the conservation of natural ecosystems and the better use of ecosystems services.

MEGATRENDS IN AGRICULTURE

Agricultural development during the last decades may be characterized with six megatrends overarching and major changes that occur everywhere and at places less and others very pronounced (Rabbinge 1995). These trends occur worldwide, but are not explicitly visible in every place. Nevertheless they may be seen as typical changes in worldwide agriculture and the global food system. The following megatrends are distinguished.

Productivity rise per ha, per man-hour, and per kg input

The yield increases in the major staple crops explain more than 70% of all food (rice, wheat and maize) production increase revealing the importance of this strategy to limit expansion of agricultural land into natural lands for food production. The yield increases per ha were such that for example average yields of wheat in the Netherlands went up from 800 kg ha^{-1} in the year 1400 to 1800 kg ha^{-1} in 1900 and 9000 kg ha^{-1} in 2000, while associated labour requirements dropped from

Received 10 November, 2011 Accepted 9 December, 2011
Rudy Rabbinge, E-mail: rudy.rabbinge@wur.nl; Correspondence Prem S Bindraban, E-mail: Prem.Bindraban@wur.nl

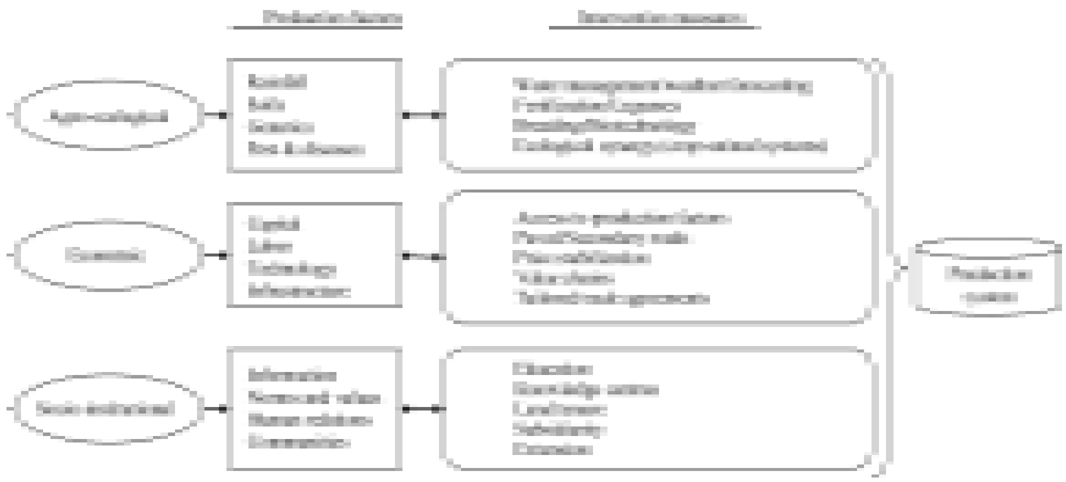

Fig. 1 Production systems are a consequence of complex interaction of agro-ecological and economic conditions within a socio-institutional environment (Bindraban *et al*. 2009).

some 600 h ha^{-1} in the year 1400 to 240 h ha^{-1} in 1900 and only 12 h ha^{-1} in 2000. Unexpectedly and counter-intuitively yield per kg external agro-chemical input increased 2-4 times during the last four decades which means that eco-efficiency increased considerably. More precise application of these inputs in time, space, amount and composition, tuned to the condition of the crop in the field rather than preventive and untargeted applications, as in precision agriculture and integrated pest, disease and weed management have been at the base of these favourable achievements. Improvement of overall management increases use efficiency of resources, in line with the statement by de Wit (1992) that 'most production resources are used more efficiently under improving conditions of resource endowment'. That synergism is theoretically well described and in practical experience of many farmers very visible. Fig. 2 illustrates this by showing that changes in other management practices than fertilization increases the efficiency of fertilizer use (de Wit 1979). Also see the illustrative experiment in Fig. 3. Several of these interrelated input variables can be found for instance in de Koning *et al*. (1995) that describes agricultural production opportunities for the European Union.

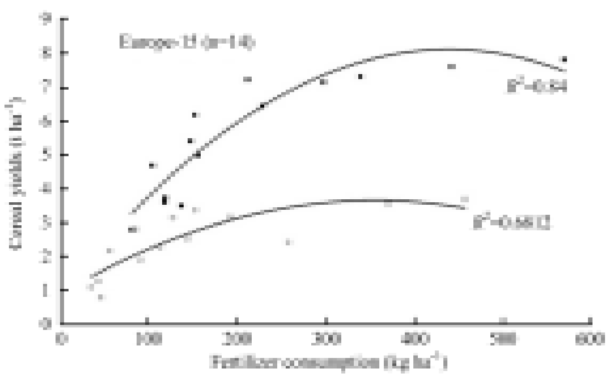

Fig. 2 Cereal yields (t ha^{-1}) as associated with fertilizer consumption for 1961 (open dots) and 2000 (closed dots) (from Bindraban *et al*. 2008).

Changes in the character of agricultural production

More and more industrial technologies are used in agro-ecosystems and as a result production conditions are affected such that crop and animal husbandry systems can be optimized and meet more stringent societal demands. Most impressive is modern glasshouse cultivation where the climate is fully controlled and fertigation in combination with recycle systems to maximize use efficiency of nutrients and water, while biological control in combination with resistance breeding limit input of pesticides to a minimum. Energy use in glasshouses is already considerable reduced and even energy producing glasshouses have already been introduced where surplus energy in summer is stored in the aquifer and used in winter (Sonneveld *et al*. 2010). Zero energy use is already possible and energy production with glasshouses is no longer in its infancy.

(Illustrative experiments by P. S. Bindraban)

Fig. 3 Interaction in agro-eco-production systems. An integrated agro-ecological approach is essential because of the strong interactions between production factors. Plant 1 (from the left) is grown in a poor unfertilized soil with little water and remains small. Adding water would be expected to improve growth, which is not the case as the poor soil fertility puts a stronger limit to its growth (plant 2). Adding fertilizers rather than water does enhance growth indicating that the strongest limiting production factor (i.e., nutrients) was eliminated (plant 3). At the same time this third plant shows that water is used more efficiently under these fertilized conditions as the same amount of water was applied as in plant 1. Adding both nutrients and water boosts growth to a level where neither of these factors is limiting but where other factors, like radiation, set a ceiling to growth (plant 4).

Chain management

The third megatrend concerns the change in food systems where all parts of the chain from soil to shelf or from spade to plate are considered. Integration of the activities in the chain provide opportunities to optimize input/output relations over the entire chain and not only per isolated activity. Tracing and tracking enable auditing of production and trading systems to guarantee that chain actors minimize environmental and health effects and maximize biosafety and profit by matching consumer demand with products of specific quality and optimal production practice (Galiæ *et al*. 2011).

Multiple objectives

A fourth megatrend concerns the need to address multiple objectives simultaneously. To justify a licence to produce, agriculture has to address not only production and economic objectives, but also environmental and other societal objectives such as maintaining landscape scenery, guaranteeing animal welfare, securing safe labour circumstances, and maintaining nature and biodiversity. Combining these multiple objectives requires agro-eco-production systems that make maximal use of ecological knowledge, but is not dogmatic or based on bans, myths and unjustified claims (Bindraban and Rabbinge 2011). Therefore no bans on fertilizers, pesticides or GMO's, but careful and thrifty use and with maximal use of basis ecological and physiological principles. That has considerable consequences for the way of farming and managing farming systems. It requires clear choices, such as maintaining functional biodiversity on the farmland, but these objectives should not be confused with the maintenance of structural biodiversity as found in undisturbed or scarcely affected ecosystems (Schneiders *et al*. 2011).

Food and health

The fifth megatrend concerns the increasing connection between food and health (Szakály 2011). Healthy aging, but also the first 1 000 d of human life require specific fine-tuned diets based on good understanding of the physiological background of diseases, deficiencies and genetic determined traits. That results in fine-tuning of food to specific genetic characteristics contributes to preventive public health care (Marino *et al*. 2011).

Biobased economy

The sixth megatrend concerns the increasing importance of biobased economy (Vandermeulen *et al*. 2011). The role of biological organisms such as plants, microorganisms, animals, and fungi in producing specific molecules and compounds is more and more seen as effective and efficient sustainable solutions. It will replace part of the chemistry fully based on fossil material such as gas, oil and coal, by the plant as factory. The paradigm of building molecules through synthesis on basis of ethene may be replaced by separation and purifying techniques.

These megatrends characterizing the changes in agriculture, agribusiness, food, biotechnology, and chemistry that occur everywhere although the phase of development may differ. The megatrends may be used to identify specific development pathways for region and specific conditions to address the big challenges for the future food situation.

CHALLENGES

These megatrends may continue but it is very clear that substantial challenges are demanding a considerable change in the way agro-food systems may function in the future. Moreover the expansion of objectives are challenges, sometimes threats but merely opportunities for the new agriculture. These challenges have to be addressed by the agricultural systems and agricultural sciences of the future. The first and the foremost challenge is securing sufficient food of good quality and composition tuned to the needs of the ever growing world population. The population increase up to 9-10 billion in 2050 as such requires more food, but more importantly the diet changes towards more animal proteins when people/nations become more wealthy; therefore doubling plant production before 2050 is necessary.

This in turn calls for a double or ever green revolutions, discontinuities in productivity increase per ha and no expansion of agricultural area. This is necessary because it will reduce environmental side effects, provide viable economic systems, ensure continuity of production systems, and save many hectares for structural biodiversity and sustenance of ecosystems services (see also Fig. 4).

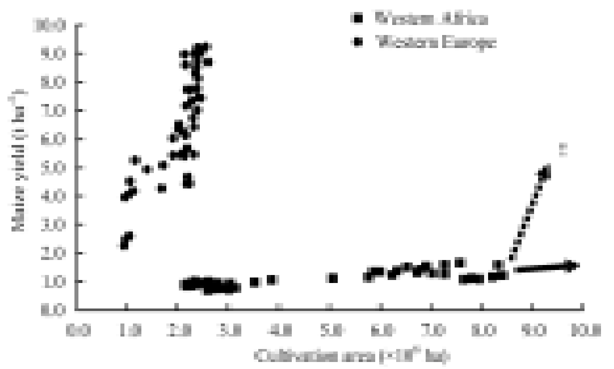

Fig. 4 Different routes through which the increase in food volumes have been realized. Dotted arrow indicates desired yield increase strategies to minimize claims on additional land. Based on FAO data (2009) from Bindraban *et al.* (2009).

The second challenge for agricultural systems is dealing with environmental, and more specifically climate change. Agricultural systems have to become less vulnerable to shifts in temperature and sudden weather events. They should be robust, but that requires varieties bred for ever harsher circumstances and/or adequate agronomic measures or appropriate land use. Even with less water and less hectares, robust production systems should reduce the vulnerability of agriculture to climate change (Declaration of the Hague 2010). That is climate smart agriculture, a real challenge for the agriculture of the future.

The third challenge concerns the need for better food fine-tuned to the dietary needs and as a continuity of the mega-trend of food and health to address the wish to healthy infancy and ageing. There are ample opportunities as knowledge and expertise increase, especially of the generic basis of health and the relation with habits and diets.

The fourth challenge for world agriculture is the growing demand from the biobased economy. The shift in paradigm from petro-chemistry based economy to a more biobased economy is urgently needed and that requires an interdisciplinary approach of biosciences and chemical and physical sciences. The biobased economy offers new chances and is promising, not because we are out of oil, or because we have to raise the dikes, but because it offers new avenues of less dependence on fossil energy, cleaner, less losses and more tuned to the changing needs of an affluent society.

The challenges may be addressed by incremental change but a unifying concept is needed to enable a thought through productive way of working. The principles of production ecology offer such a framework.

PRINCIPLES OF PRODUCTION ECOLOGY

Agriculture, the production of plants and animals making use of land, water, nutrients and the sun is based on elementary physical, chemical, biological and ecological principles. These principles dictate the potentials and limitations of primary production (van Ittersum and Rabbinge 1997).

The potential yield level is determined by the growth-defining factors, i.e., incoming solar radiation, temperature and characteristics of the crop when the crop is optimally supplied with water and nutrients and is completely protected against growth-reducing factors. Water-limited and nutrient-limited yield levels are lower than the potential, due to a suboptimal supply of water and/or nutrients, respectively. The actual production level is determined by actual supplies of water and nutrients, and by the degree that the crop is protected against growth-reducing factors or escapes their effects.

Farmers may influence the growth factors and yield levels by various cultivation practices. The actual yield level can be improved to attainable levels by yield-protecting and yield-increasing measures. Yield-increasing measures are related to non-substitutable inputs such as water and nutrients, whereas inputs related to yield protection are often substitutable to some extent. Given a certain location and plant species, the growth-defining factors and thus the potential production level can only be influenced indirectly via breeding and management tactics such as sowing date and plant spacing.

Thus various levels of production may be distinguished: potential, attainable, actual and available food. Attainable yields are determined by nutrient and water available, actual production level by crop growth reducing factors such as pests, diseases and weed, and the available food is determined by post-harvest losses.

OPTIMIZING AGRO-ECOLOGICAL PRODUCTION SYSTEMS

These basic production-ecological principles indicate that 'most production resources are used more efficiently under improving conditions of resource endowment'. In other words, simultaneous use of water and fertilizers and/or a mix of fertilizers have synergistic effects. Nutrients will be used more efficiently by crops when provided with sufficient water, and/or when protected against diseases.

In addition, applying inputs at the right place (e.g., near the roots), at the right time (e.g., when crop growth is fast), in the right amounts and at the right composition will yield most efficient use of resources. Advanced technologies can optimize such inputs through integrated nutrient (INM), pest (IPM) and crop (ICM) management. Integrated approaches make high production systems most effective in resource use efficiency, while limiting impact on the environment (Glendining *et al*. 2009). Excessive use of inputs, e.g., excess fertilizer, used with the intention of reducing risk, might jeopardize the environment (Cui *et al*. 2006). Lack of such inputs leads to degradation of land (Stoorvogel 1993), which might push already poor people into a downward spiral of poverty.

Technological innovations, including advanced and conventional breeding, and information and communication technology, will be essential for optimal use of natural resources. But they must be properly designed for prevailing conditions, or used when favourable conditions are created for the technology to work. Integrated approaches could limit claims on land and other resources and should be further developed. Much can be done to increase yield while containing adverse environmental affects, yet the rate at which yield can be increased will be slow because of the dwindling availability of resources.

Yield increases in arable crops may help considerably but the recoupling with animal husbandry may even lead to much higher efficiencies. The use of external inputs and the implementation of sophisticated livestock systems will lead to a dramatic increase of efficiencies at farm level (Lantinga and Rabbinge 1997).

FOOD SECURITY GLOBALLY

The increase of world food production in absolute terms and per capita has not resulted in regional food security and abolishment of hunger. On the contrary, the number of people has increased in some regions in absolute and in relative terms. Europe, the America's and parts of Asia are completely self-reliant but not so in other continents.

Food security in Asia

Based on the principles described above it may be analysed/explored what potential yield level may be achieved at various agro-ecosystems in Asia. The growth of the population in Asia and the change in diet is showing an enormous increase in demand. However, increase of agricultural productivity by expansion of cultivated land is virtually impossible, as nearly all well-endowed land is already in use and due to urbanization that acreage in fact decreases (Chen 2007). The situation in Asia is very different from Africa where ample land is still available.

For Asia the only way to go is "increased productivity per ha", while reducing the environmental load. The gap between actual and potential productivity per ha is in many crops still considerable; however in irrigated rice the increase in yield by improved pest and disease control and better availability of water and nutrients is limited. Here however a transformation of inundated rice cultivation in water saving cultivation has shown to reduce water requirement by half or more and to increase use efficiency of nutrients. Significant amounts of water can be made available for other agricultural production, urban or industrial water (Hengsdijk *et al*. 2006).

More specifically for the host country of the Science Forum, China, such increased productivity per ha is of particular interest. The intention to fulfil the challenge of production of more than 150 million tons of food more in 2050 than in 2010 may be partly fulfilled with the present crops but the intention to increase potato in the diet and give the crop a pivotal place in productivity rise is very useful. Potato with its high harvest index, efficient water use and its possibility to produce also in an incomplete growing season may indeed be very attractive. However, diseases and requirement of sufficient inputs may indeed require a very sophisticated production system.

Yet another great opportunity is to dramatically lower environmental pressure and reduce cost of production. Excessive use of N fertilizers in China where grain production increased by 71% from 1977 to 2005, while N application increased by 271%, is estimated at some 89 to 104 kg N ha^{-1} yr^{-1}, totalling about 11.8 million tons. If this 'excess' N fertiliser was instead used in sub-Saharan Africa, it would represent an average annual N fertilisation rate of 68 kg N ha^{-1} over 174 million ha of cropland, which could lead to a potential doubling of cereal productivity in sub-Saharan Africa (Keating *et al*. 2010).

Food security in Africa

The absence of a green revolution in sub-Saharan Africa has been analysed in detail in a study of the InterAcademy Council (2004). Absolute production increased but population growth was higher and a multitude of causes affected the absence of a stronger growth in productivity. Opportunities are certainly there and the promise and potential of African agriculture can indeed become reality when the policy measures are taken and the appropriate institutions and instruments are present. That is now taking place under the guidance of former UN Secretary General Kofi Annan (AGRA 2011).

Environmental issues may determine the research agenda of the future as high productivity can be very well combined with a great agro-biodiversity. That may help to limit pesticide use and to stimulate advanced ecological literacy. Ample opportunity for yield increase in all production systems is possible, but difficult in rice ecosystems.

In high productive rice systems the need for an increase in the yield ceiling (potential yield) may be necessary. Research to increased photosynthesis and introducing C4 characteristics in the C3 rice plant was started about a decade ago and is resulting nowadays in prototypes that may be full-fledged producing varieties within 10 yr. The need for increasing the ceiling is as important as the increase in nutritive value and also there is considerable progress, by the introduction of the modern biotechnological methods, such as cisgenesis and transgenesis. The greatest progress however is found in developing best ecological means in crop and cropping systems, and to improve food systems as holistic systems.

Best ecological means in farming systems are promoting efficient use of natural resources and optimal use of biological control. Precision agriculture, integrated pest, disease and weed management are key in such systems. It requires sophisticated knowledge and insight in the way biological processes may best be used. Agrobiodiversity is fundamental in that approach leading to high productivity per ha and very low use of pest and disease control with pesticides. This high productivity per ha safeguards conservation of natural ecosystems and also enables the better use of ecosystems services such as good freshwater, nature parks, etc.

Food security in Latin America

The production capacity of Latin America is more than twenty times that amount of food needed for self-sufficiency (WRR 1995). It is not surprising therefore that current most extensive expansion of agricultural land takes place on this continent. Advanced insights in agronomy and the introduction of African Bracchiaria grass species allowed the utilization of the vast areas of the Cerrado savannah in Brazil. Starting with the conversion for grassland, the lands are turned into soybean cultivation. Increasing areas in the Chaco in Argentina (Gasparri and Grau 2009) are used for grassland and soybean, though production risks are high due to highly variable rainfall. The global importance of Latin America in providing food, feed and fuel to the world is so vast that it even becomes a concern for the international community as to how Latin American countries manage their natural resources. Overexploitation of the enormous biodiversity of world largest rainforest area, for instance, would not only affect the economy and ecology of Latin America, but of the world as a whole (Santilli *et al*. 2005). Intensification and integration of crop-livestock production systems inherit great potential to limit the loss of biodiversity due to reduced expansion.

Urbanization

The number of people living in urbanized areas has surpassed the number in rural areas in 2010 and the need for fresh food and appropriate diets for the growing urban population can be partly fulfilled with metropolitan agriculture that offers a productive, environmentally safe and sustainable way of producing in metropolitan area (Smeets 2009).

In highly populated areas the Metropolitan agriculture may take place in agro-production parks using integration of various agriculture or horticultural related activities.

Vegetables and flowers grown in glasshouses on hydroponics may be combined with aquaculture, intensive cattle breeding in feed labs or dairy farming. That results in mutual gains and considerably less energy use or waste production. Typical examples are found in some big/large cities such as Shanghai, Amsterdam/Rotterdam, Sao Paulo or Detroit. These forms of agro-production parks could help considerably in the strongly urbanizing Asian continent.

The opportunities for food security in Asia are there, the challenges are stimulating and the role of research is for that reason indispensable.

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(Managing editor WENG Ling-yun)