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Megatrends in agriculture – Views for discontinuities in past and future developments

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ABSTRACT

Despite great concerns to meet the ever growing food demand in the past, megatrends in agriculture has resulted in growing food availability per person and reducing adverse environmental impact. The bleak future that is portrayed to secure sufficient food for all can be resolved with increased ecological literacy and compliance with production ecological approaches. Yet, these opportunities may not be easily attained, certainly so with dominating dogmatic views on agro-ecological practices that do not comply with or even reject basic ecological principles.

1. Megatrends

Alarming views and daunting challenges continuously portrays whether sufficient food for all for the coming four to five decades can be ensured (FAO, 2011). Throughout history, comparable bleak perspectives have dominated our view, such as by Malthus (1798), Ehrlich (1968), and Brown (1995). Yet, development throughout history has seen forward leaps leading to discontinuities in productivity, efficiency and efficacy and, transformations in land use and societal demand. These megatrends in agricultural development result from driving forces such as growing insights, technological innovations and societal change. We describe these trends and drivers in this paper, address new challenges that we will face and explore possibilities and potentials to reach new quantum leaps while responding to some threats, and demonstrate the promises of future agriculture for food security and sustainable development.

1.1. Productivity rise

Agriculture has shown over the last 1000 years dramatic shifts in productivity per hectare, per man hour, per animal and counter-intuitively during the last four decades per kg external inputs. In the Netherlands, for instance, the yields of wheat went from 800 kg ha^{-1} in the year 1400 to 1800 in 1900 and 9000 in 2000, while associated labor requirements dropped from about 600 h ha^{-1} in the year 1400 to 240 in 1900 and only 12 in 2000. 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 external inputs in time, space, amount and composition, tuned to the condition of the crop in the field as in precision agriculture and integrated pest, disease and weed management, rather than preventive and untargeted applications, have been at the base of these favorable achievements. Improvement of overall management increases use efficiency of resources (e.g. Rockström, 2003; Glendining et al., 2009), in line with the statement by De Wit (1992) that 'most production resources are used more efficiently under improving conditions of resource endowment'. Hence the interaction of mechanization based on an increasing amount of information allow the application of the right amounts of fertilizers and other agro-chemicals at the right time and place depending on the cropping system, leading to high use efficiencies. Application of insights of precision agriculture is feasible also under non-mechanized systems (Florax et al., 2002). Green revolutions, primarily targeting main crops rice, maize, wheat and potato, led to discontinuities in yield increase in the whole world, except on the sub Saharan African (sSA) continent (Bindraban et al., 2008). The green revolution in sSA is now underway fulfilling the promise and potential of African agriculture (InterAcademy Council, 2004; AGRA, 2012).

1.2. From habits and skills to science-based agro-ecosystems

Over the past millennia, several apparently independent centers of domestication had developed over the globe. To prevent soil

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depletion and diseases pressure, various practices were implemented, such as crop rotation, including legumes, green manure application, and manure from grazing cattle in neighboring grasslands. With the development of cities, organic waste from urban areas was applied. During the past century, agriculture practices have moved away from habits and skills because of increased understanding of the production processes into systematically organized and controlled ways of production. The growing insights in production ecological and environmental issues in combination with advances in bio- and ICT-technologies have led to significant changes in production systems. Most impressive is modern glasshouse cultivation where the climate is fully controlled and fertigation in recycling systems maximize use efficiency of nutrients and water, and biological control in combination with resistance breeding minimize input of pesticides. Surplus energy in summer is stored in the aquifer and used in winter to minimize energy use even leading to the net production of energy by glasshouses (e.g. Sonneveld et al., 2010). Though with different features, similar principles to maximize use efficiencies of inputs are also applicable in open agro-ecosystems. The tremendous increase of the knowledge of the basic principles (physical, chemical, physiological and ecological) has resulted in fine tuning, precision, recycling and use of biological traits based on advanced insights of the functioning of agro-ecosystems (Rabbinge, 2012). Even so, actual field observations and human decision making remains essential to pursue integrated management practices for curative measures rather than taking preventive measure such as by remote decision making in large scale production systems (Bindraban et al., 2009a).

1.3. Multiple objectives in agriculture and land use

Starting from generation of work and income through agriculture, the sector increasingly broadened its objectives. Total use of agro-chemicals has for instance dramatically reduced in many developed nations without yield penalty and even with continued agricultural productivity increase, while reducing environmental pressure. Farms further integrate plant and animal production for environmental care, care for health and wellbeing of animals and, conservation of nature and cultural inheritance of landscape elements to also stimulate tourism and recreation (FAO, 1999). Such a broad set of functions cannot be carried out by a single farm, which calls for regional coordination to blend an array of farms scattered in the landscape, creating a greater diversity of the landscape (Van Mansvelt et al., 1998; Clemetsen and van Laar, 2000). Combining multiple functions, when properly managed, does not reduce productivity and result in attractive agricultural landscapes. The higher productivity of agro-ecosystems as a result of better understanding and appropriate interventions has resulted in much more possibilities of saving land for nature and biodiversity in undisturbed ecosystems. In contrast, maintaining low levels of production leads to expansion of production land which inevitably cause loss of ecosystems (Gibbs et al., 2010).

1.4. Food chains, tracking & tracing

Integration of activities in the chain provides opportunities to optimize input/output relations over the entire chain and reduce food losses. 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 agreed-upon production practice (e.g. Galić et al., 2012). From soil to shelf, from seed to meat are slogans that point to development of food systems approach that incorporate production processing, accessibility and utilization (Rabbinge and Linnemann, 2009). Such an overarching approach is needed to catalyze dietary changes in an affluent world and to improve nutrition security in developing countries. Modern technology such as GMO's in breeding, or DNA-printing in tracing and tracking are common trails. DNA finger printing technologies support tracking and tracing of legally logged wood. In Brazil, separate logistical systems warrant against mixing up of GMO and non-GMO soybean.

1.5. Fine-tuning diets for health and ageing

Insight in societal factors on prevalence of human diseases (Siegel et al., 2012) result in fine-tuning of food items to specific genetic characteristics of people at different age and thus contributes to preventive public health care (Marino et al., 2011). Growing insight of the relation between human conditions like age, sex, genetic composition etc. and food requirement have led to improving health (Szakály et al., 2012). Healthy ageing, but also the first 1000 days of human life require specifically fine-tuned diets based on good understanding of the physiological background of diseases, deficiencies and genetically determined traits.

1.6. Bio-based economy

The role of biological organisms such as plants, micro-organisms, animals and fungi in producing specific molecules and compounds is increasingly seen as effective and efficient sustainable solutions (Vandermeulen et al., 2011). It will replace part of the chemistry based on fossil material such as gas, oil and coal, by the plant as factory. The introduction of biorefinery has made considerable contributions already, but the majority of possibilities are yet to be exploited as many new approaches are still in their infancy. At present biofuel is still seen as an important driver for the biobased economy, but the low total energy surplus (in net terms less than 1%; Bindraban et al., 2009b) should be the most important argument not to see it as a prime goal, but more as a secondary or last goal to make use of leftovers from other production chains for materials, flavors, fragrant and other high value products. The concept of cascading and bio-refinery will lead to higher value at various parts in the supply chain and much higher efficiencies and efficacies, of use of natural resources and energy (Westenbroek, 2010).

2. Drivers

Discontinuities in agriculture and the world food system could be realized because of increased ecological literacy, advances in technology, changing desires in society and organizational insights, and more recently, energy and climate concerns.

2.1. Ecological literacy

The real breakthrough in understanding plant growth occurred with the discovery in 1840 by the German chemist Liebig that only water, minerals and nitrogen was needed for the growth of plants. Optimum growth conditions are obtained when crops are foreseen from all the water and nutrients required for their growth and when protected against pest, diseases and weeds (Van Ittersum and Rabbinge, 1997). Plants convert a maximum of 2.5% of the solar radiation through their photosynthetic mechanism in biomass under such optimal growth conditions (Spedding, 1988). Per kilogram of biomass production plants transpire about 250–300 l of water (Monteith, 1990) to dispose of the 97.5% energy.