Global soil use in biomass production: opportunities and challenges of ecological and sustainable intensification in agriculture

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Globale Benutzung für Biomasseproduktion: Optionen und Herausforderungen einer ökologischen und nachhaltigen Intensivierung der Landwirtschaft

1 Introduction

The human population growth rate peaked in the years 1962–1963 at ~ 2.2 % per year and decreased to ~ 1.1 % in 2013 (United States Census Bureau, 2013). Nonetheless, the world's population continues to increase and is estimated to reach 9.38 billion people and an annual growth rate of 0.5 % in 2050 (United States Census Bureau, 2013). The eminent question remains about how to feed the world's population today, with 870 million people being chronically undernourished in the period 2010–12 (FAO, WFP & IFAD, 2012), as well as in the future. Earlier estimates of a number of undernourished decreasing to 680 million people until 2010 (FAO, 1999) were too optimistic. Agricultural growth is seen as the most important factor to reduce malnutrition, hunger and poverty (FAO, WFP & IFAD, 2012). This goes beyond the mere availability of adequate food quantities and concerns food quality including micronutrients, which are deficient in certain diets. An estimated 50 % of the world's population are subject to micronutrient deficiencies (Cakmak, 2002). Fertile soils and their sustainable use are one of the important keys for food security today and in the future. Soils, however, face several threats. Global developments such as urbanization,

Summary

The world's increasing population and the need to produce food, feed, fibre and fuel (energy) from agricultural crops puts pressures on global soil resources. Beyond production, soils have manifold environmental functions that must be preserved despite increasing production levels. Today, substantial parts of the world's soil resources are degraded. Urbanization and increased sealing of fertile soils, human-induced erosion and soil compaction, the input of contaminants, increasing nitrogen depositions, a possible scarcity of fertilizer P, and soil organic matter loss due to changing land use and soil management are amongst the severe present and future threats to soil resources. Research shows that agricultural production could be increased worldwide by several approaches such as filling the gap between potential yields and actual yields by improved agricultural techniques, increased agricultural land and reduced post-harvest losses. The highest potentials are seen in temperate rather than in tropical areas with their less resilient soils. Climate change will have a tremendous impact on the availability of agriculturally productive areas and will induce significant shifts between regions. Intensification of agricultural systems should aim at low-input high-yield systems best adapted to the local needs and framework conditions. This requires implementing all possible measures including aspects of organic farming, precision agriculture, reduced tillage, high-efficiency irrigation systems, agro-forestry systems, breeding, mechanization and improved post-harvest storage and handling technologies. The cascade use of biomass for food and feed, industrial raw material, energy production and organic fertilizer is clearly a valuable concept in this context.

Key words: Biomass production, ecological/sustainable intensification, food security, soil degradation, soil resources.

Zusammenfassung

Die zunehmende Weltbevölkerung und die Notwendigkeit, Nahrungs- und Futtermittel, industrielle Rohmaterialien und Energie aus landwirtschaftlichen Produkten zu gewinnen, erzeugen Belastungen für die vorhandenen Weltbodenressourcen. Diese haben neben der Produktionsfunktion noch zahlreiche ökologische Bodenfunktionen, die auch bei zunehmender Produktion gewährleistet werden müssen. Bereits jetzt sind wesentliche Anteile der Weltbodenressourcen degradiert. Die Urbanisierung, Versiegelung fruchtbarer Böden, anthropogen verstärkte Erosion und Bodenverdichtung, der Input von Kontaminanten, die zunehmende Stickstoffdeposition, ein möglicher Mangel an Phosphor-Düngern, der Verlust von organischer Bodensubstanz durch Landnutzungsänderung und Bodenmanagement sind wesentliche Gefährdungen für die Bodenressourcen. Gemäß Literatur erscheint es möglich, die landwirtschaftliche Produktion wesentlich zu steigern, zum Beispiel indem die derzeit vorhandene Lücke zwischen potenziellen und aktuellen Erträgen in vielen Weltregionen durch verbessertes landwirtschaftliches Management geschlossen wird, weiters durch Vergrößerung der landwirtschaftlich genutzten Flächen und Verminderung der Nacherntverluste. Hohe zusätzliche Produktionspotenziale werden weniger in den tropischen als in den gemäßigten Regionen gesehen, bedingt durch weniger resiliente Böden in den Tropen. Klimawandel wird einen enormen Einfluss auf die Verfügbarkeit landwirtschaftlich produktiver Flächen haben, ebenso wie auf die Verteilung der Flächen in verschiedenen Weltregionen. Intensivierung landwirtschaftlicher Systeme sollte auf Niedrig-Input-Systeme mit hohen Erträgen abzielen, die bestmöglich an die lokalen Bedingungen adaptiert sein sollten. Um dies zu erreichen, müssen alle denkbaren Maßnahmen in Betracht gezogen werden, wie z.B. Aspekte der biologischen Landwirtschaft, der Präzisionslandwirtschaft, Minimalbodenbearbeitung, hocheffiziente Bewässerungssysteme, gemischte land- und forstwirtschaftliche Systeme, Züchtung, intelligente Landmaschinentechnik sowie verbesserte Nachernteverfahren und Lagerungstechniken. Die kaskadenartige Nutzung der Biomasse für Nahrungs- und Futtermittel, industrielles Rohmaterial, Energieproduktion und organischen Dünger könnte in diesem Zusammenhang besonders wertvoll sein.

Schlagworte: Biomasseproduktion, Bodendegradation, Bodenressourcen, Ernährungssicherheit, ökologische/nachhaltige Intensivierung.

the need for biomass to substitute fossil fuels and as raw materials for industrial use, along with non-sustainable agricultural and forestry production, are among the most important ones. Food, feed, fibre and fuel are the present demands. “Sustainable intensification” and “ecological intensification” are key words frequently used now for concepts to alleviate the present situation and to meet the future needs of humankind. A major question remains: will the world’s soil resources be sufficient to provide the basis for future biomass production needs and how can soil functions beyond the production function be secured?

2 World soil resources and biomass production

Soil formation and development leads to an enormous diversity of soil types worldwide. Figure 1 shows some of this variability, which is determined mostly by the parent material of soil formation, by climate, vegetation and – of course – by human soil management. The diversity of soil types also leads to a large diversity of soil properties and related soil functions. The major soil functions beyond (i) producing biomass are (ii) biological heritage and gene reserves, (iii) filtering and buffering of contaminants, (iv) source of raw materials, (v) geogenetic and cultural heritage and (vi) physical and spatial basis for infrastructure (Blum, 1998). The human impact on soils dates back to pre-history, when humans settled and started frontier clearings. Agricultural production began approximately 10,000 years ago in Mesopotamia and China. Quite extensive subsistence agriculture and small-scale farms were the starting point – agricultural systems that still exist to some extent in developing countries. Today, most areas are under intensive agricultural use. Moreover, the share of urban areas and protected lands has increased as well, replacing natural ecosystems (Foley et al., 2005). Approximately 37.5 % (2011) of the Earths’ land surface is now being used for agriculture (World Bank, 2013); croplands cover about 1.53 billion ha

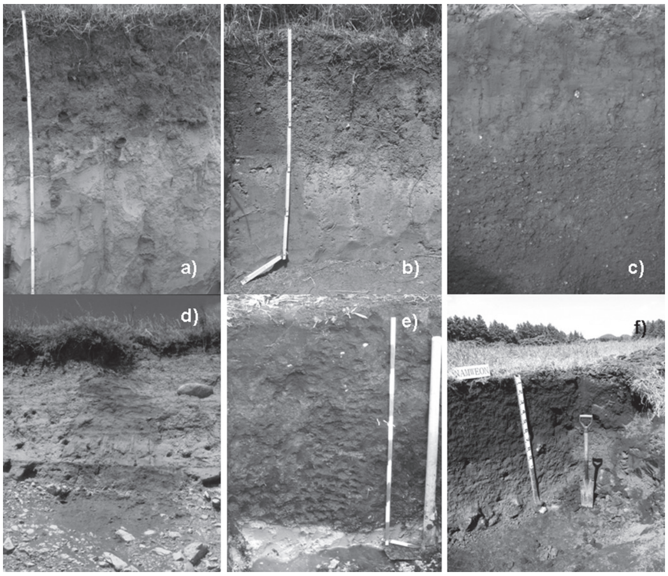

Figure 1: Soils of the world: a) Chernozem in Austria, b) Cambisol in Austria, c) Anthrosol in Germany, d) Fluvisol close to the MacKenzie River in Canada, e) Histosol in Slovenia and f) Andosol in South Korea (Photos: M.H. Gerzabek 1987–2012)

Abbildung 3: Böden der Welt: a) Tschernosem in Österreich (Ziersdorf), b) Braunerde auf Löss (Brunn a.d. Wild, Österreich), c) Kolluvisol in Deutschland, d) Schwemmboden am MacKenzie River, Canada, e) Laibacher Hochmoor in Slowenien, f) Andosol auf Jeju Island in Südkorea (Fotos: M.H. Gerzabek 1987–2012)

and pastures 3.38 billion ha (Foley et al., 2011). Interestingly, Foley et al. (2011) report a net increase of agriculturally used land between 1985 and 2005 of 154 million ha. This increase is mainly due to growing agricultural use of tropical soils, whereas in temperate regions agriculturally used area has tended to stagnate or decrease. The latter authors report that 62 % of the agriculturally used land is used directly for human nutrition, 35 % for fodder production and 3 % for bioenergy and industrial raw materials. Haberl et al. (2007) published world maps of net primary production (NPP) and the human appropriation of NPP. In temperate regions the NPP ranges between 400 and 800 gC/m²/yr, in tropical regions the values can be twice as high. Note that in several regions of the world such as parts of Europe, eastern North America, India, Indonesia and China, the human appropriation of NPP already exceeds 70 % or even 80 %. Tropical regions exhibit the highest potential for an increase in agricultural production and human appropriation of NPP. Nonetheless, tropical soils are often of low resilience and can be degraded quickly by non-sustainable agricultural management. In some areas we can realistically expect increases in biomass production in a sustainable way. In the Danube and Black Sea region and in eastern South America, a sustainable increase of biomass production of ~ 30 % or more seems feasible (IIASA & FAO, 2010).

3 Threats to the world's soil resources

According to Eswaran et al. (2001), up to 70 % or 35.922 mill. km² of the land in dry areas are degraded worldwide. Degradation can mainly involve desertification (degradation in arid and semi-arid areas), salinization and organic matter decline. Another important issue is soil biodiversity. Soil organisms have crucial functions on the soil and ecosystem level. The most important are the decomposition, humification and stabilization of organic matter, emission of gases, cycling of plant nutrients, detoxification of organic contaminants, a significant contribution to the build-up of soil structure and its stability, and last but not least their role in soil formation itself. It is well established that increasing land-use intensity decreases biodiversity/species richness in agricultural soils (Blum et al., 2009). Specifically, monocultures with annual plants impact biodiversity and thus reduce the resilience of the soil system.

One factor that has not yet been extensively discussed is the permanent increase of atmospheric inorganic nitrogen deposition following the growth of industrial, agricultural and other human activities. The Haber-Bosch process to convert atmospheric N_2 to fertilizer is an important driver in this context. In the 19th century the annual inorganic nitrogen deposition in most regions of the world was below 5 kg N ha^{-1}. In the early 1990s, large areas in North America, Europe, India and China exhibited annual deposition levels exceeding 10 kg N ha^{-1}. The prognosis for 2050 shows levels of more than 20 kg and up to 50 kg N ha^{-1}.yr^{-1} even for parts of South America and Africa (Galloway et al., 2004). The increased deposition might be beneficial for some agricultural soils and might reduce the need for inorganic fertilizers. In sensitive ecosystems such as forests and alpine areas, along with soil organic matter-rich histosols/peat areas, the effect of the elevated N-deposition might be detrimental by disturbing the balance between major essential nutrients. This could induce secondary nutrient deficiencies. Enhanced Som decomposition can also be envisaged. In contrast to nitrogen, the phosphorous supply to agricultural crops might be increasingly difficult to maintain in the future. There is a controversial debate on whether rock phosphate reserves have already peaked or will

peak in the mid-21st century. In any case, we will have to devote efforts to increase P use efficiency and recycling to secure the supply of this important plant macronutrient for the generations to come (CORDELL et al., 2011).
Another important point – not further dealt with here – is the ownership of land and the soil property rights. Depending on the individual regional or local concepts, this might interfere with sustainable soil use. WINIWATER et al. (2012) provide a comprehensive insight into the various concepts in a historical and geographical context. Open access, communal, collective and state lands – but also individual full ownership – might introduce non-sustainable land use. In any case, the local soil property rights must be taken into account when fostering sustainable agricultural management practices. The following sections summarize the most important threats to soil resources.

3.1 Sealing

Already in pre-historical times, humans settled in areas with fertile soils. These settlements developed and spread. Today, large cities quite often cover the most fertile agricultural lands. Urbanisation has become a global trend: in many parts of the world, urbanized areas are growing rapidly. In 1900, the urban population reached 19 % of the total population. This value rose to 49 % (3.2 billion) in 2005 and might increase to 60 % (4.9 billion) by 2030 (UN, 2005). Sealing of agricultural soils reached 100 ha per day in Germany (KRIESE, 2010). One factor fostering this development in developed countries is the increasing demand for housing area per person, which in Germany has been increasing by 0.5 m² per year (KRIESE, 2010). In Austria for example, settlements are frequently located on the most fertile soils. This situation is enhanced by the fact that in the Alpine regions of Austria, the areas suitable for settlements are mainly valley floors, where the fertile soils are typically located. Another sealing hotspot is the surroundings of the city of Vienna. Here, the demographic prognosis are an increase in population density of more than 30 % by 2050 (HANIKA, 2010), thus further exacerbating the situation.

3.2 Erosion and compaction

Erosion, the loss of soil due to the impact of wind or water energy, is one of the severest threats to fertile soils worldwide. The total land areas vulnerable to desertification, wind and water erosion amount to 43.3, 55.9 and 32.4 million km², respectively (ESWARAN et al., 2001). The largest affected land areas are located in Asia and Africa. Erosion leads to loss of particularly fertile and bio-diverse soil material rich in organic matter from the top of the soil profile. It also slows down the process of soil formation and development because already weathered material enriched with soil organic matter is lost. In principle, erosion is a natural process, which is reinforced by land management. Human-induced erosion is less a matter of slope steepness than of agricultural practices or forest management. Cropland is generally more susceptible to erosion than pastures and forests. The highest soil erosion in Austria is not recorded in the Alpine areas, but in the lowlands (STRAUSS, 2007). In Europe, approximately 17 % of the total land area is affected by erosion (EEA, 2003). Soil losses worldwide are estimated to reach at least 75 billion tons per year or more (PIMENTEL, 2006). The yearly soil loss rates in the various European countries are estimated to lie between ~ 5 and 27 tons ha^{-1} (EEA, 2003).
Soil compaction is another major physical threat to soil resources, leading to a severe reduction of coarse soil pores and thus influencing pneumatic, hydraulic and heat transport processes. Significant yield reductions due to limited root growth and accessibility of water and nutrients have been reported (EC, 2012). GREGORICH et al. (2011) measured yield reductions of up to 33 %. Consecutive compaction events make the situation worse. The susceptibility of soils to compaction depends on soil texture and the moisture status of the soil and thus varies locally. Soils least susceptible to compaction are sandy soils, those most susceptible are clay soils. A major problem is subsoil compaction because it cannot be easily alleviated by mechanical soil cultivation (in contrast to topsoil compaction). Subsoil compaction also negatively affects crop yield, rooting, soil erodibility, filtering and buffering processes and perhaps even gas emissions (HORN & FLAIGE, 2011).
Intensifying conservation tillage methods, mulching, keeping soil surfaces covered during most of the year and using light-weight machinery at the appropriate times are measures which have to be implemented more aggressively in the future to counteract the present situation.

3.3 Contaminants

The European Environment Agency estimates that 30,000 different chemical substances are currently on the European market (EEA, 2003). 28 % remain with the end user and its final fate is not always known. Industrial and household waste deposits, traffic and industrial emissions, agrochemicals and even organic manures are major sources of contaminants to agricultural soils. An important soil characteristic is the enormous surface area of the soil constituents – the pores created by particles as well as micro- and macro-aggregates. Many soil constituents such as clay minerals, oxides and soil organic matter exhibit a high surface reactivity. Clay minerals adsorb mainly cations due to their permanent negative charge. This charge is induced by substitution of key cations such as Si^{4+} and Al^{3+} by cations of lower positive charge (e.g. Mg, Fe). Oxides have a cationic character due to protonation at a soil pH of less then ~ 8.5, which is the norm rather than the exemption. They can therefore adsorb anionic forms of contaminants. In the case of polycyclic aromatic hydrocarbons (PAHs), even specific interactions of these non-polar substances with goethite have been observed (TUNGEA et al., 2009). Soil organic matter exhibits numerous different interaction mechanisms including cation exchange, formation of complexes, and hydrophobic interactions with non-polar substances. The large surface area and the reactivity of the soil constituents lead to an enormous capacity of soils to bind inorganic and organic contaminants. Model calculations by COSBY (1982) showed that persistent organic pollutants, after equilibration in the environment, will show up mainly in soils (90.5 %) and sediments (9.1 %) and less in air (0.35 %), water (0.01 %) and biota (0.01 %). The advantage of the filtering capacity of soils for pollutants such as heavy metals, radionuclides and persistent organic substances is the reduced mobility of these substances in the ecosystem. This includes a significant and highly important filtering effect that secures the renewal of clean groundwater. The negative aspect is the long storage time of pollutants in soils. This increases their potential entrance into the food chain through root uptake and external contamination following resuspension of contaminated soil particles. The after-effects of the Chernobyl nuclear power accident in 1986 are a case in point. Even today, larger agricultural areas in Belarus, Ukraine and Russia cannot be used for agricultural production, although one physical half-life of the major contaminant, ^{137}Cs (half-life 30 yr), has nearly elapsed since then. CHERNIKOV (2011) estimates that the area of Belarus contaminated with ^{137}Cs exceeding 37 $kBq.m^{-2}$ will decrease until 2016 to 66 % of its original size in 1986. That value is expected to drop to 42 % by 2046. Specifically areas with low nutrient input such as forests and Alpine pastures retain radionuclides like Cs and Sr in the uppermost soil layers. This reflects the effective recycling mechanisms of the vegetation to acquire important plant nutrients such as K and Ca, which are plant-physiologically similar to Cs and Sr, respectively. In 2011 it was reported that in Bavaria a large proportion of wild boar is still contaminated with ^{137}Cs above the limit value for meat and cannot be used for human consumption (WILD & HUND, 2011).

3.4 Soil organic matter loss

Soil organic matter (SOM) has numerous crucial functions in soil and the environment. It influences and/or improves many soil properties including water holding capacity, aggregate stability, erodibility, nutrient and contaminant storing capacity and biodiversity, just to mention the most important ones. The major sources of soil organic matter are dead plant residues, rhizodeposition, as well as dead micro-, meso- and macro-organisms and their excretions. SOM is stabilized in soil by microbial processes, physical protection in (micro-)aggregates and interaction with reactive surfaces of inorganic soil constituents. In fact, Som is the medium- to long-term storage of solar energy. This is because the reduction of CO_2 to assimilation products of plants is the major process of converting solar energy to organic material. Organic carbon in soils and vegetation amounts to approximately 2,300 Gt worldwide, which is considerably more than the 760 Gt C pool in the atmosphere (SOLOMON et al., 2007). Soil is thus both a sink and source of gases relevant for our climate. SOM levels are modified by several processes and factors. Land use change is a major driver of changes (in most cases losses) of SOM. Model calculations show that the conversion of tropical rainforests into arable land leads to yearly C losses of 1.1 ± 0.3 Gt (ACHARD et al., 2004). The overall yearly C loss to the atmosphere due to land use change has reached ~ 1.6 Gt (SOLOMON et al., 2007). Land use changes from pasture or forest to arable land typically lead to Som losses. In Austria the organic carbon stocks of extensive pastures and forests average 119 t C ha^{-1}; the values in arable land reach ~ 60 t ha^{-1} (GERZABEK et al., 2005). In the context of sustainable/ecological intensification, the impact of soil management on SOM levels is at least equally important. Although the results about the effect of minimum tillage methods on SOM quantities are not completely conclusive, most data indicate a slight improvement of SOM levels by conservation tillage methods (e.g. LIEBIG et al., 2004). Even more important might be the change in the SOM depth distribution and SOM characteristics when converting plowed land into minimum tilled land (TATZBER et al., 2008). SOM concentrates more in the uppermost centimetres, improving aggregate stability infiltration capacity and decreasing soil erodibility (LIEBIG et al., 2004). Crop rotation is another significant means to improve SOM levels (BOWMAN et al., 1999). Applying manure and other organic residues improves the SOM status of soils, as demonstrated in numerous long-term experiments (e.g. GERZABEK et al., 1997). The decoupling of crop production and animal husbandry opened an SOM gap for many agricultural regions, resulting in decreasing SOM levels due to the lack of organic fertilizers. The increasing trend to bioenergy production – specifically focussing on annual cropping systems – in many regions of the world tends to put additional pressures on SOM levels of soils. Bioenergy production (biofuel, biogas) implies large areas of monocultures. The positive effects of diverse crop rotations on SOM levels, as referred to above, are lacking in this type of agriculture. Moreover, the second-generation biofuel technology, aiming at using the total plant including straw, will probably lead to a further gap in the SOM budget (RAMPAZZO-TODOROVICH et al., 2010).

4 Opportunities to increase agricultural production

4.1 Potentials of available soil resources

Fertile and productive soils are the basis for global agricultural production. Unfortunately, only a small part of the world's soil resources can be used without any restrictions and its use not hampered by adverse environmental conditions. Fertile and productive soils provide optimal physical, chemical and biological conditions for plant growth, sufficient water and nutrient supply. The potential of soils to meet these demands varies greatly due to the parent material of soil formation, the climate and the vegetation cover. The agricultural productivity of soils clearly differs greatly between geographical and climatic zones. BLUM & ESWARAN (2004) categorized the available soil resources (non ice-covered area) into 9 classes – from class I–III (best to good fertile soils which can be used without or few restrictions for cereal production), classes IV–VI (less suitable for cereal production), VII (should only be used in exceptional cases for cereal production) and VIII–IX (unsuitable). Unfortunately, soils in class I cover only 2.4 % of the ice-free land area and they provide already ~ 40 % of the global production of crops and fodder (BLUM AND ESWARAN, 2004). The quality classes IV, V, and VI, which are frequently found in the tropics, cover ~ 34 % of the land area and subsidise 54 % of the world's population. Production restrictions in these areas are mainly high temperature, aluminium toxicity, low soil pH and low nutrient availability. Recent estimates show that only in Northern and Western Europe and in Eastern Asia are actual cereal yields close to the potential yields based on advanced farming techniques. In various parts of Africa the actual average cereal yields range from below 1 $t.ha^{-1}$ to little more than 2 $t.ha^{-1}$ – compared to potential yields in the range of 6.5 to more than 7 $t.ha^{-1}$ (FISCHER & VAN VELTHUIZEN, 2011). FOLEY et al. (2011) estimate that improving farming techniques for 16 important crops – including cereals, cassava, sugar beet and sugar cane, oil palm, potato and others – and thus increasing their yields to 95 % of the potential yield could partly close the present yield gap. An additional production of 58 % compared to the present level would amount to 2.3 billion t (5.10^{15} kcal). This increase would come close to the estimated need of increasing agricultural production by ~ 70 % until 2050 (FAO, 2009). Importantly, FOLEY et al. (2011) do not – with few exemptions – see the highest potentials in the tropical areas, but rather in the Danube-Black Sea region, northern India, northern and Northwest China and some areas in North America. These regions are located in agro-ecological zones which are not or only minimally constrained concerning agricultural production (IIASA & FAO, 2010).

4.2 Framework conditions and drivers

The world's increasing human population needs not only food, but also biomass for energy and industrial raw material. This places additional pressure on primary production. In the past the need for biomass has constantly grown and, in 2005, the biomass share of total human energy consumption reached 36 % (WINIWARTER et al., 2012). Clearly, food production has the highest priority. Nonetheless, the transition from a fossil carbon society to a biomass carbon society as a greenhouse gas mitigation measure also has high priority, given the observed impacts of fossil energy use on climate and environment.

An important factor to be considered in future scenarios is the increase in the urban population – estimated to reach

70 % of world's population by 2050 – and the diversification and development of life styles and diets: the share of grains in our diet will decrease, vegetables, fruits, meat, dairy products, and fish will increase (FAO, 2009). Another issue is the uneven agricultural produce distribution worldwide. This cannot be solved solely by higher yields and production, but will require effective and fair distribution mechanisms (FAO, 2009). A further important factor that must be counteracted is the present loss or waste of food produced. This amounts to one third of the overall production (GUSTAVSSON et al., 2011). In developing countries the major losses are post-harvest and storage losses, in industrialized countries waste losses are the major problem.

A significant question remains when trying to meet the production and environmental goals including soil protection: Is high-input agriculture still the solution for the future, or is it low-input/high-yield systems? Traditional low-input/low-yield systems will not be sufficient to meet future production needs. The further development of low-input/high-yield systems seems to be crucial because they increase the energy efficiency of the system, which is urgently needed in the context of climate change mitigation (WINIWARTER et al., 2012). Climate change itself is another important factor that will influence agricultural production in the future. Already now we face tremendous changes in the suitability of regions for production of certain crops. On the one hand, we observe losses of productive areas due to e.g.

Measure	Impact on yields/efficiency	Positive effects on soil & environment	Research needs
Closing nutrient cycles, improving organic fertilizer and residue use	high	high (increasing nutrient use efficiency, less losses)	medium
Precision agriculture (minimizing/optimizing site specifically the use of fertilizer and pesticides)	high	high (less agrochemical applications)	medium-high
Mechanization: increasing energy efficiency, decreasing bearing pressure; ICT	medium – high (preventing compaction)	edium-high (improving soil structure, decreasing erodibility)	medium-high
Improving crop rotations	medium	high (SOM built up, soil structure, biodiversity)	medium
Improving bio-energy production systems; low input – high yield (e.g. mixed cropping, mulch systems, double cropping), BLUM et al. (2011)	medium	high (positive effects on SOM, biodiversity)	high
Reduced tillage	medium (better energy efficiency of the system)	high (erosion control, soil structure, SOM built up)	low-medium
High efficiency irrigation systems; planting drought resistant high yield plants in arid areas	high	high (reduced water use, reduction of salinization problems)	medium
Agro-forestry systems	medium (high in case of leguminous trees providing biologically fixed N)	high (erosion control, SOM, biodiversity)	medium-high (searching for site-specific systems)
Breeding and smart breeding of agricultural crops (water and nutrient use efficiency, resistance against diseases)	high	high	high
Improved harvest and post-harvest technologies	high (reducing losses)	medium (reducing pressure on not agriculturally used areas)	low-medium

Table 1: Selected measures towards sustainable/ecological intensification of agriculture
Tabelle 1: Ausgewählte Maßnahmen, die eine nachhaltige Intensivierung der Landwirtschaft begleiten könnten

desertification (see chapter 3.2) and gains in productive land specifically in the northern latitudes. According to Zhang & Cai (2011), Russia, China and the US may expect an increase of total arable land by 37–67 %, 22–36 % and 4–17 %, respectively. On the other hand, South America might lose 1–21 % of its arable land area, Africa 1–18 %, Europe 11–17 %, and India 2–4 %. In contrast, FAO (2009) sees the highest potential for rain-fed cropland expansion in Latin America, Sub-Sahara Africa and the industrialized countries. Nonetheless, these numbers indicate that we have to expect a constant need for adaptation of our agricultural systems locally and regionally.

4.3 Possible steps towards a sustainable intensification

Intensification of agricultural production in a certain region must take into account the needs of soil, environmental protection and society. Developing economically and ecologically sound agricultural systems calls for aiming at the highest energy, water and nutrient efficiency. This goal cannot be reached by single measures or single systems, but rather by incorporating all factors and techniques available. Individual measures, tailored to meet the local and regional requirements, could include aspects of (i) organic farming such as closing nutrient cycles and diverse crop rotations, (ii) precision agriculture that minimizes fertilizer and agrochemical use, (iii) reduced tillage, conservation tillage, which improves soil structure and decreases erodibility of the soil, (iv) high-efficiency irrigation systems, decreasing the share of 70 % of renewable water resources used today for irrigation purposes (Postel et al., 1996), (v) agro-forestry systems for tropical regions, (vi) breeding and smart breeding, (vii) smart mechanization and (viii) improved harvest and post-harvest technologies, handling and storage. Table 1 provides an overview of the suggested measures and attempts to qualitatively assess the possible impacts on productivity and environment. Clearly, it will be important to investigate and take into account the interdependencies of the proposed measures and to examine the complete – quite complex – system to judge their usefulness and efficiency. Last but not least, improvements in agricultural production have significant societal impacts. They are twice as effective for improving the living conditions of the poorest of the world in developing countries as compared to measures in the non-agricultural sector (FAO, 2009).

The bio-refinery concept is an important system approach to alleviate the increasing conflict and competition between agricultural production of food and feed versus fibre and energy offers. This concept uses biomass for different purposes in a cascade. Cereals are a case in point. The grains can be used for food and feed, the straw to extract valuable ingredients such as cellulose and hemi-cellulose as a basis for production of chemicals, pharmaceuticals, enzymes – thus substituting mineral oil. Furthermore, the residues of the extraction process can be used to produce biogas and the remnants of the biogas production can be humified, enriched by urea produced from the gaseous CO_2 and NO_x emissions of the process, and applied as valuable fertilizer, thus closing the organic C and N cycle. Future concepts for biomass use must take into account that organic residues from whatever process cannot be treated as waste, but as valuable raw material for manifold subsequent use.

5 Conclusions

The world's available soil resources are subject to constant changes. Climate change, urbanisation and soil degradation modify the area available for agricultural production and soil fertility. Both losses and gains of agricultural land, specifically cropland, can be envisaged. Feeding the increasing human population should be possible – even in 2050. To reach this goal we need aggressive research and development to implement low-input and high-output agricultural systems that are optimized for energy, water and nutrient efficiency, soil protection and conservation, and minimum environmental impacts. This can be achieved by inter- and transdisciplinary research and development concepts that examine the whole system. The necessary local and regional knowledge to develop tailored agricultural management concepts should be based on participatory approaches involving farmers and local residents. No single production system is likely to meet all our demands. Therefore, research should be open to all methods and concepts without any academic aloofness. We need to objectively investigate what aspects could be used beneficially both to increase agricultural production and save the environment. Priority, however, must be given to concepts preserving the environment and our valuable soil resources for future generations. Agricultural soil use has to be seen as a crucial aspect within the development of a knowledge-based bio-economy. The challenges ahead can only be met using all available technologies, including information and communication technologies, nanotechnology, biotechnology, material science, and chemical process engineering. The role of life science universities and non-university research establishments will be to provide the scientific basis for the conversion of economies to knowledge based bio-economies. Our task is to provide tools for the decision support that will be urgently needed for the complex developments ahead.

Acknowledgements

The author thanks Dr. Michael Stachowitsch for improving the English text.

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Submitted: August 13, 2013
Accepted: December 16, 2013