NJAS - Wageningen Journal of Life Sciences 66 (2013) 65–73

Contents lists available at ScienceDirect

NJAS - Wageningen Journal of Life Sciences

journal homepage: www.elsevier.com/locate/njas

Is agricultural intensification in The Netherlands running up to its limits?

Jules F.F.P. Bos*, A. (Bert) L. Smit, Jaap J. Schröder

Plant Research International, Wageningen University and Research Centre, P.O. Box 616, NL-6700 AP Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 9 October 2012
Received in revised form 24 May 2013
Accepted 17 June 2013
Available online 7 August 2013

Keywords:
Food production
Food consumption
Sustainability
Environment
Resource use efficiency
Biodiversity
Extensification

ABSTRACT

Environmental pressures posed through human activities are expected to further increase due to growing population numbers and increasing per capita consumption. It will be crucial that the sum of all pressures leaves the planet within sustainability thresholds. The huge challenge for agriculture is to double its food production without further deteriorating the environment, but there is little consensus on how to do this. At the global scale, 'sustainable intensification' is seen as an important strategy. At best, intensification improves the utilization of resources, but it also increases emissions per ha and may go hand in hand with specialisation, increases in the scale of farming and regional concentration. A typical example of a sector characterised by intensification, scale enlargement and regional concentration is the Dutch livestock sector. To consolidate and strengthen the Dutch position as second agricultural exporter in the world, this process is still continuing, linked with constant efforts to further improve economic and environmental efficiencies through farm size enlargement and adoption of additional technologies. However, the industrial and inherently resource-intensive character of this livestock production leaves numerous sustainability issues unaddressed, provoking new questions and controversy in Dutch society. Sound policies start with the acknowledgement of trade-offs between population size, food consumption patterns and land spared for nature. Therefore, a legitimate, but seldom asked question is which part of the total effort needed to feed the human population should be on more production and which part on limiting population growth, changing human diets and global redistribution of wealth.

© 2013 Royal Netherlands Society for Agricultural Sciences. Published by Elsevier B.V. All rights reserved.

1. Introduction

Photosynthesis is the chemical process by which green plants capture the energy of sunlight, to convert carbon dioxide, water and minerals into organic compounds and oxygen. The main products of photosynthesis are carbohydrates, which are compounds comprising carbon, hydrogen and oxygen. Almost all living organisms on earth directly or indirectly depend on food energy derived from organic compounds formed during the photosynthesis process.

Agriculture is the managed production of food, feed, biofuels, fibre and other products for human purposes by cultivation of crops and the raising of domesticated animals. Pre-industrial agriculture was largely subsistence agriculture in which farmers grew most of their crops for their own consumption, although trade of agricultural commodities did occur. Hence, the production, processing and consumption of food and feed were closely connected in space and time, and wastes, if regarded as that at all, were recycled. Productivity of agricultural lands was sustained by techniques such as fallowing, biological fixation, flooding, shifting cultivation or application of manure from livestock grazing on 'wastelands'.

With improvement of farming techniques over the centuries, the farm surplus gradually increased, allowing or obliging some people to do something else for a living. Knowledge and technologies emerging from 'early engineers' helped to increase the land area under agriculture and increase yields per hectare. Major shifts in agricultural practices have occurred in response to new technologies and the development of world markets. One of the fundamental breakthroughs in the early 20th century has been the Haber-Bosch method for synthesizing ammonium nitrate, which made the traditional practice of recycling nutrients with crop rotation and animal manures less necessary. The subsequent introduction of mineral fertilisers and pesticides in agriculture, advances in plant breeding and many other technological improvements have greatly increased yields from cultivation. Selective breeding and modern practices in animal husbandry have similarly increased the output of meat. For the past 50 years, this 'green revolution' has enabled global food production to outpace human population growth, despite a doubling of the population [1]. However, it has

* Corresponding author. Jules Bos, P.O. Box 616, NL-6700 AP Wageningen, The Netherlands. Tel.: +31 317 480562; fax: +31 317 423110.
E-mail address: jules.bos@wur.nl (J.F.F.P. Bos).
URL: http://www.pri.wur.nl/ (J.F.F.P. Bos).

1573-5214/$ – see front matter © 2013 Royal Netherlands Society for Agricultural Sciences. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.njas.2013.06.001

also caused significant environmental damage on a global scale at great cost to natural ecosystems and biodiversity [2,3].

With growing population numbers and increasing per capita consumption, agriculture is expected to double its food and feed production once more in the coming decades [4]. Besides food and feed, agriculture is also expected to produce significant amounts of biomass for energy [5] and sequester carbon in soils [6]. These are already huge challenges on their own, but they should be realized under a scenario of a changing climate, without further deteriorating the state of environment and biodiversity, and increasingly based on production methods using renewable or recycled resources only. In the Netherlands, demands on agriculture are sometimes framed as 'Two times more [food], with two times less [environmental impact]' [7]. However, such framing ignores the fact that the products of photosynthesis can either be used as food or fuel for humans, as feed for livestock, as food for wild animals or as stored soil carbon, but not for all purposes at the same time. Indeed, the different claims on agriculture are often competing and may turn out to be unrealistic.

Due to the expected further increase in environmental impact resulting from human activities, the number of studies addressing global sustainability concerns such as food security, biodiversity loss and climate change is increasing [8–11]. Some studies warn that human activities, largely because of a rapidly growing reliance on fossil fuels and intensive agriculture, have reached a level that could damage the systems that keep earth in the stable and desirable state of the Holocene [9,11]. Barnosky et al. [9] recently reviewed the evidence for the plausibility of global-scale 'critical transitions' as a result of human influence, leading to rapid and irreversible state shifts, overriding trends and producing unanticipated biotic effects. Such critical transitions have occurred at the global scale in previous geological eras and have been shown to occur in local ecosystems in the current era. Global-scale mechanisms that could force global-scale transitions today are human population growth and attendant resource consumption, large-scale habitat transformation and fragmentation, energy production and consumption and climate change [9]. To meet the challenge of maintaining the Holocene state, recently a framework based on planetary boundaries was proposed, together defining a safe operating space for humanity [11]. The earth-system processes for which such boundaries were defined are climate change, biodiversity loss rate, human interference with nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, land use changes, chemical pollution and atmospheric aerosol loading. It was suggested that boundaries of three earth system processes have already been transgressed (climate change, biodiversity loss rate, and interference with the nitrogen cycle), while boundaries for four others (global freshwater use, change in land use, ocean acidification and interference with the global phosphorus cycle) may soon be approached [11]. Obviously, in many of the associated processes agriculture plays a major role.

An interpretation of environmental sustainability resembling the planetary boundaries concept was given already much earlier by others [12,13]. These authors argue that environmental, economic and social sustainability cannot be considered equal in rank and define environmental sustainability as a non-negotiable prerequisite for economic and social sustainability. The basic idea behind this hierarchy is the recognition of limits to the carrying capacity of the biosphere, expressed in terms of stocks of finite natural resources and finite capacities to absorb pollution and degradation. Sustainable development in this view is defined as development without growth in throughput of matter and energy beyond regenerative and absorptive capacities of the earth system [13].

While development is of crucial importance for fighting poverty, illiteracy, hunger and disease, it is clear that current consumption levels in western, affluent societies can never be the norm for all world citizens, let alone for future generations, without large scale destruction of the natural capital on which future economic activities depend [13,14]. Yet, the evidence of recent decades indicates continuing growth, often at close to exponential rates in both population and consumption [10,15]. There is thus a growing number of warnings about the current trajectory of human activity, challenging the foundations of western economic models for their dependence on never-ending consumption-driven growth, which, due to biophysical limitations, cannot be sustained [16–19]. However, the school of thought postulating that continued population and consumption growth are the sustainability problems *par excellence*, is still miles away from mainstream thinking in politics and media, in which economic growth, also in already rich and developed nations, is seen as a *conditio sine qua non* for human welfare. We conclude therefore that the core message of the Club of Rome, that there are limits to growth [20], is at least as urgent today as it was forty years ago.

This paper finds its origin in an essay as one of the contributions to a book on 'careful livestock farming' in the Netherlands [21]. Inspired by the global sustainability context sketched above and by scientists expressing concerns about current trends in population, consumption and sustainable development [22,23], our motivation to write this essay was our personal appreciation of the debate in Dutch society about sustainable agriculture. This debate, in our view, is flawed in the sense that it is characterised by a one sided focus on the need to produce more food and increase resource use efficiencies in agriculture. Such an approach of sustainability in already highly intensive Dutch agriculture in our view neglects considerable environmental and social trade-offs. Moreover, solely emphasizing the need to increase food production ignores important sustainability options that exist on the consumption side. As in our essay, the goal of this opinion paper is therefore (1) to contribute to the Dutch debate on sustainable agriculture by significantly broadening its scope, bringing in relevant arguments raised in the literature that in our view are largely ignored and (2) to reflect on the implications for Dutch agriculture, with a special focus on the livestock sectors.

1.1. Sustainable intensification

Recent studies suggest that production would need to roughly double to keep pace with projected demands from population growth, dietary changes and increasing bioenergy use, unless there are dramatic changes in agricultural consumption patterns [4,24]. Quantitative assessments show that the environmental impacts of meeting this demand depend on how global agriculture expands [25]. Foley et al. [4] outline the preferential strategies based on the principles of 'sustainable intensification', which has been described as producing more food from the same area of land, while reducing environmental impacts [1]. One of the main arguments used in favour of sustainable intensification is the sparing of land for nature [26]. Core strategies of a sustainable intensification trajectory are (1) stopping the expansion of agriculture in pristine areas, (2) closing yield gaps on underperforming existing agricultural lands, (3) increasing agricultural resource use efficiencies, and (4) changing human diets and reducing food wastes. According to Foley et al. [4] these four core strategies can–in principle–meet future food production needs and environmental challenges if deployed simultaneously.

Sustainable intensification is often contrasted with 'agro-ecological' or 'wildlife friendly farming', i.e. a land sharing approach, integrating agricultural production and biodiversity conservation on the same land [27–29]. Like sustainable intensification, agro-ecological farming is not clearly defined, but it is commonly associated with smallholder farming, diversification in farm outputs and more extensive farming practices [27,30]. Its defenders argue that a dichotomic view between either land sparing or land sharing approaches is overly simplistic, as social and ecological real world complexities would not allow a stark choice between the two [27,31]. Such complexities include that (1) smallholder farming and not large scale farming is currently the backbone of global food security in the developing world, (2) agricultural yields and biodiversity are not always negatively correlated and (3) increased yields do not necessarily spare land [27,32]. Risks of a singular focus on a land sparing strategy include that damage to biodiversity resulting from intensification is increased, while the further expansion of agriculture is not prevented [33]. Historical patterns showing that land-sparing is a weak process that occurs only under a limited set of circumstances [34] suggest that these risks are real.

According to Garnett & Godfray [30], the controversy about sustainable intensification arises from differing connotations hinging upon three linked assumptions: (1) sustainable intensification would denote a particular type of agriculture, (2) sustainable intensification would inherently be bound up with arguments about the need to produce more food, and (3) the 'intensification' side of the term would be privileged over the 'sustainable' side. Garnett & Godfray [30] denounce these interpretations, arguing that it is still not clear how sustainable intensification will get shape on the ground, and how this might differ amongst production systems, in different places and given different demand trajectories. In their view, the prime goal of sustainable intensification is, simply, to raise productivity (i.e. increasing yields per unit of inputs and per unit of undesirable outputs), and the 'need' for sustainable intensification should be seen as being independent of the 'need' to produce more food. The required 'intensity' of productivity increase to meet an increase in overall demand for food will depend upon progress on improving governance, reducing food wastes, changing dietary patterns and addressing population growth. Sustainable intensification should thus be seen as a complement to, not a substitute for actions on all of these fronts [30].

1.2. Nutrient use

The optimum law of Liebscher, formulated at the end of the 19th century, states that a production factor which is in minimum supply contributes more to production, the closer other production factors are to their optimum. The implication of this law is that use efficiencies of inputs (e.g., water, nitrogen fertiliser, other nutrient inputs) can be maximised by applying the minimum of each production resource that is needed to allow maximum utilization of all other resources [35]. Hence, the gap between actual yield and attainable yield can be closed by optimizing growing conditions, eliminating the production-limiting effect of the resource in minimum supply. Especially in areas where these gaps are still large, bridging yield gaps requires increased input use per unit of land. While this may result in the more efficient use of inputs and agricultural land per unit of product, an increase of inputs per unit of land will also result in higher losses per unit of land. On the regional level the total loss of a nutrient in kilograms is determined by the product of hectares, the nutrient inputs per hectare and the (in)efficiency of their use [36]. If a high efficiency is associated with a high input level, the regional impact of losses can still be substantial, especially if there are many agricultural hectares relative to non-agricultural land use. From an environmental perspective, this confronts us with a major balancing act. On the one hand it is desirable to use scarce resources such as land, nutrients and energy as efficiently as possible, meaning that we should aim for efficient, high-yield agriculture by creating optimal growing conditions for crops and animals. On the other hand it is desirable to limit agriculturally induced emissions per unit of land, requiring a moderate use of inputs and resulting in yields below attainable levels.

In practice the promise of efficient resource use in intensive agriculture may not always be realised. While the totality of resources are utilised most efficiently when their supplies are all close to yield-optimizing levels, all yield response functions reflect, *ceteris paribus*, decreasing returns to increases in the supply of one production factor [37]. Accordingly, the phenomenon of decreasing efficiencies with increasing inputs is demonstrated in several case studies. At the global scale N fertiliser use in cereals increased by sevenfold between 1960 and 1995, cereal yields more than doubled, but N fertiliser efficiency declined from over 70 to around 25 kg grain per kg N [3,37]. At the farming system level, N loss per unit product in European dairy farming systems has been shown to increase significantly with production intensity [38,39]. Excess use of fertilizers has recently been described for China and Mexico, where N fertiliser inputs in wheat systems could be halved without loss of yield or grain quality [40]. Excess use of fertilisers has also been recorded in Dutch dairy farming systems in the early 1980s, with N use efficiencies of no more than 15% and N surpluses of over 450 kg per ha per year [41]. Even today, well-educated arable farmers in the Netherlands apply phosphorus fertilizers in excess of formal recommendations [42]. General causes underlying inefficient input use include uncertainties about responses of crops to inputs, distrust in fertiliser recommendation systems and economic realities such as cheap prices of inputs and one-sided focus on economic yield maximization of single components.

Regional emissions may further increase if similar intensive farm types concentrate for logistic, economic or other reasons, as is common for industrial livestock production around the world [43]. In Figure 1, this is exemplified for Europe, showing N consumption by livestock and N inputs and N surplus of agricultural soils in 1 km^2 grid cells. Regions of high N input can be found in large parts of northwestern Europe, including parts of Denmark, Belgium, the Netherlands, UK, Germany and France. Regions with the highest N inputs and surpluses are also those with highest livestock density, such as Brittany (France), Po valley (Italy) and most of Denmark, Belgium and particularly the Netherlands.

Humans have more than doubled global land-based cycling of nitrogen and phosphorus. The world's N and P cycles are now out of balance, causing a cascade of major environmental, health and economic problems and representing a global challenge [45]. Major problems associated with high levels of nutrient use remain in large parts of Europe, North America, South and East Asia and Latin America. In contrast, insufficient access to nutrients still limits food production in parts of Africa, Latin America and Asia, contributing to land degradation. FAO estimates suggest that there will be a further 50% increase in global NPK fertiliser consumption by 2050 as a result of population increases and changing diets [46]. This will exacerbate nutrient losses, further threatening the quality of water, air and soils and affecting climate and biodiversity. Projections based on scenarios that emphasize population and economic growth suggest that nitrogen losses to the environment could increase by 70% in 2050 (reference year 2000) [46].

1.3. Forgotten costs

Intensive agricultural practices are associated with environmental and other social costs that are unaccounted for in product prices [3,47]. Examples of such costs include recurring costs of knowledge development and transfer, animal disease management and control, land and water management schemes, drinking water purification, exemptions from fuel taxes, mitigation of drainage and eutrophication effects in natural ecosystems, enforcement of rules and regulations and the maintenance of basic facilities in rural areas confronted with agricultural abandonment. Costs in only a few of these categories have been systematically estimated, e.g. related to outbreaks of animal diseases [48] and freshwater

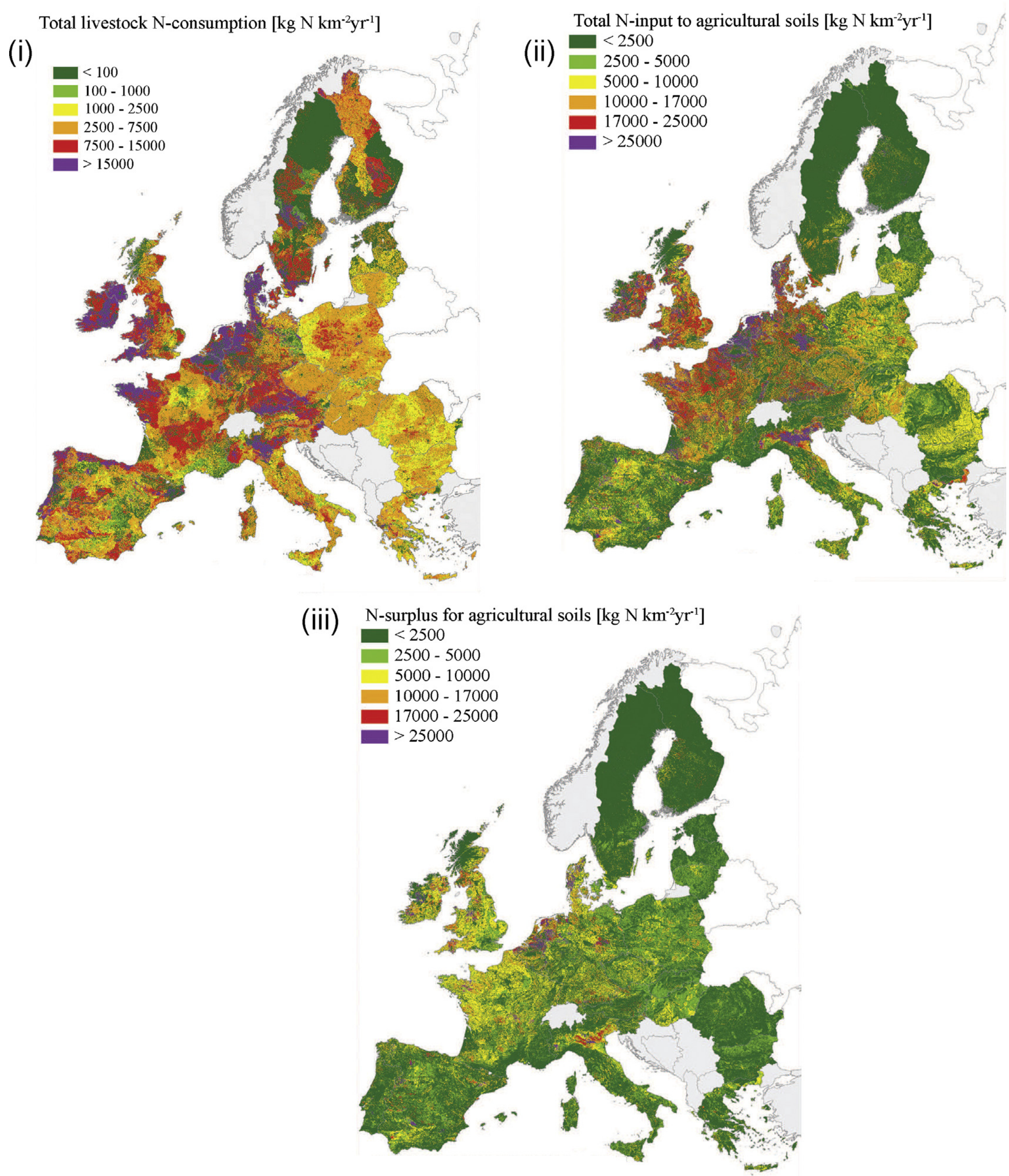

Figure 1. Total livestock N consumption and N input and surplus of agricultural soils in 2002, expressed in kg N per km^2 per year [44]. Total N input to agricultural soils includes mineral and organic fertilisers, manure from grazing livestock, crop residues, biological nitrogen fixation and atmospheric deposition. N surplus is calculated as N inputs minus N outputs in harvested crops, including crop residues and grazed grass.

eutrophication [49]. Integrated assessments have been made for agriculture in the US, UK and Germany, suggesting total external costs in the range of 49-208 UK pounds per ha of agricultural land [50]. In this study significant costs arose from drinking water contamination, gaseous emissions, soil erosion, bovine spongiform encephalopathy and damage to biodiversity and landscape. A more recent study estimated annual social costs inflicted by EU-27 N emissions from agriculture at between 20 and 150 billion euro per year [51]. Expressed in euro per kg N emission, the highest social costs were associated with air pollution effects of NO_x on human health (10-30 euro per kg), effects of various N losses on aquatic ecosystems (5-20 euro per kg) and effects of NH_3 on human health through particulate matter (2-20 euro per kg). Annual social costs of N emissions in the Netherlands are estimated at 3-15 billion euro (200-1000 euro per inhabitant), with about half of these costs caused by emissions from agriculture [52]. Social costs per inhabitant are higher than the European average, related to the high intensity of both agriculture and traffic. Indicative results suggest that accounting for environmental costs of N-intensive agriculture in northwestern Europe would result in economically optimal N application rates that are about 50 kg per ha (30%) lower than the private economic optimum rate for the farmer [51].

Unfortunately, studies estimating external costs of agriculture are fraught with methodological issues and uncertainty. For example, in many cases it is not well known to what extent external costs are linked to current agricultural practices, and how these costs change upon adjustments of management. It is also difficult to attach monetary values to human health and ecosystem services. Rather than offering clues for concrete actions, studies into external costs of agriculture highlight the extent of the damage caused and illustrate the potential benefits of adapting agricultural practices. Obviously, to maximise the net benefits of agriculture to society, an accurate quantification of the total impact of agricultural practices is essential.

1.4. Farmland biodiversity

Unlike many other regions in the world, most of the European landscapes are the result of century-long human activities. This means that the characteristic landscapes, habitats and associated species are generally there because of traditional land management. It has been estimated that 50% of all species in Europe depend on agricultural habitats, including a number of endemic and threatened species. While the green revolution was successful in providing good-quality and cheap food to every European citizen, it has come at a great cost to biodiversity, with severe losses across different taxonomic groups and affecting a high proportion of the land surface [53,54]. Declines of populations of birds [55], butterflies [56], other insects [57] and wild flora [58] by at least several tens of percentage points indicate that large tracts of European farmland currently offer a hostile environment to wildlife. The evidence that these declines are caused by agricultural intensification is overwhelming [59–61]. Agricultural intensification impacts through multivariate and interacting effects, with as universal consequence the loss of ecological heterogeneity and biotic homogenization at multiple spatial and temporal scales [62,63].

While rich farmland biodiversity was natural and self-evident in earlier times, conservation of farmland biodiversity in modern times requires the active choice to reserve space and time for non-target organisms to complete their life cycles [53]. Although this certainly does not equate to a return to the Arcadian landscapes of the old times, it does require the reversing of intensification and sacrificing some of the productivity of farmland. Wildlife friendly farming by implementing conservation actions in farmed landscapes has been criticised for failure to halt declines in farmland biodiversity [64]. While the largely simple and cheap measures of many of the current European agri-environment programs are indeed unlikely to be effective in considerably improving the ecological status of intensified farmland [65], a significant part of farmland biodiversity may be effectively preserved by complying to a number of guiding principles [66]. Crucially, to be effective, conservation measures must be evidence-based, i.e. based on sound knowledge of the ecological requirements of target species. In England, such evidence-based approaches to habitat creation on portions of otherwise intensively managed agricultural land have resulted in large increases in plant, bee and bird species [67].

Wildlife friendly management on portions of agricultural land will not be enough to preserve specific forms of farmland biodiversity. For example, low-lying grassland areas on peaty soils in the north and west of the Netherlands traditionally harbour globally unique meadow bird communities, with internationally important populations of species like Black-tailed Godwit, Lapwing and Common Redshank. Intensification of dairy farming in these areas, involving widespread land consolidation, drainage, fertilisation and mechanisation and allowing increases in stocking densities and earlier, more frequent and faster mowing of structurally uniform monoculture grasslands, has caused severe declines in these populations [68]. Recent evidence suggests that to preserve these populations, it is necessary to reverse intensification altogether, restoring the herb-rich meadows and high water tables as present during the times of thriving meadow bird populations [69]. However, large-scale deployment of such far-reaching measures is unlikely, due to a lack of support and financial resources. The most effective strategy will then be to concentrate conservation efforts in areas with favourable abiotic and biotic conditions and apply the required measures there [68]. Such a strategy would fit in the concept of 'high nature value' farming (HNV farming) used in European policies [70,71]. HNV farming was developed in response to the growing recognition that agricultural habitats support populations of priority species that are dependent on the continuation of low-intensity farming practices.

The future prospects for European farmland biodiversity are strongly influenced by the effects of the EU's Common Agricultural Policy (CAP). Despite successive reforms of this policy in the past, intensification of agriculture in some regions and concurrent abandonment in others remain the major threats to biodiversity [65]. The EU Biodiversity Strategy [72] underlines the need to better integrate biodiversity objectives in other policies and places particular emphasis on the part that the CAP and agricultural sector have to play in halting the loss of biodiversity in the EU by 2020. One target specified in this strategy is to use the current CAP reform to maximise areas under agriculture that are covered by biodiversity-related measures to bring about a measurable improvement in the conservation status of species and habitats that depend on agriculture. As part of the current CAP reform, the European Commission proposed to couple direct income support to farmers with three compulsory 'greening measures': maintenance of permanent grassland, crop diversification and the designation semi-natural habitats ('ecological focus areas') on 7% of arable land. Since their publication in 2011, these greening measures have been the subject of fierce debate among European institutions and stakeholders throughout Europe. The preliminary result of these discussions has been a weakening of the greening measures [73], with agricultural stakeholders generally welcoming the amendments and environmental organizations cynical about the extent to which the greening proposals have been weakened. At the time of writing (April 2013), final decisions on the CAP reform are underway. To what extent these decisions will improve future prospects for farmland biodiversity remains to be seen.

The preservation of 'living' European agricultural landscapes requires the reconciliation of agriculture's production function with biodiversity conservation and the provision of environmental goods and services [66,74]. For this to happen, the idea that agriculture may be about more than efficient food production has to become widely accepted across the EU. This perspective is still far away. Thus, biodiversity conservation in agricultural areas poses not only an ecological challenge, but also a social challenge [75]. There is a need for instruments influencing the individual farmer's motivation and behaviour, to place farmland biodiversity 'in the hearts and minds of farmers'. Although biodiversity in a general sense is indispensable for agriculture [76], current scientific insights learn that Corn flowers, Field crickets or Skylarks, to mention but a few species, do not provide economic benefits and hence are not particularly 'useful' to farmers. For such species, the popular trend in conservation based on economic logic and attaching monetary values to nature's goods and services, will not work [77,78]. Hence, the only rationale for the conservation of such species, and of the landscapes in which they live in, is for their intrinsic value, aesthetic beauty and cultural importance: protecting nature for nature's sake.

1.5. Dutch agriculture

Agriculture and the agri-food sector in the Netherlands have historically occupied a significant economic and cultural position as important drivers of growth and development. Dutch agriculture and rural areas have changed dramatically during the last century. Stimulated by European and national policies that favoured production maximisation, major changes have included the large scale introduction of mineral fertilisers, chemical pesticides, mechanisation and land consolidation schemes [79]. This has been associated with specialisation and scale enlargement, such that by 2008 there

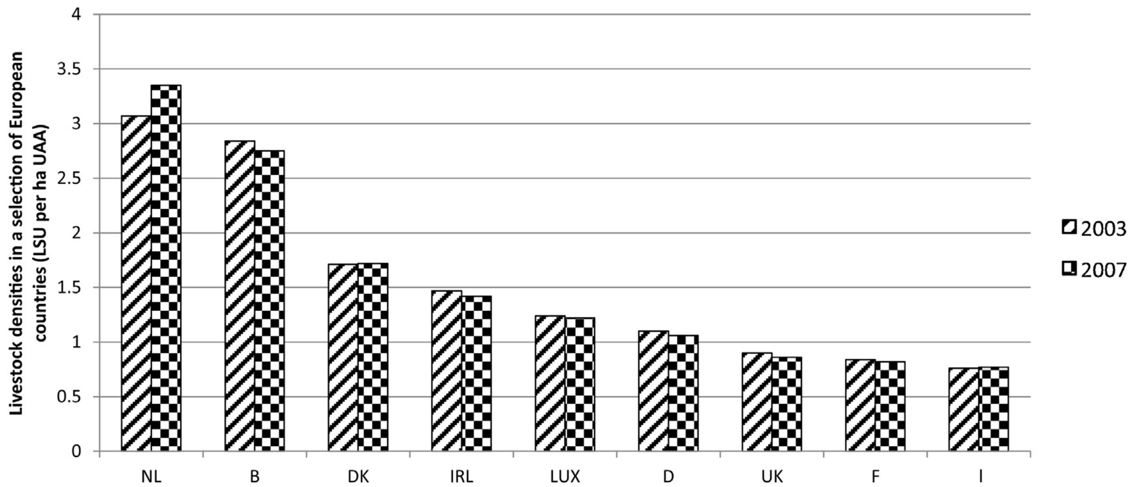

Figure 2. Livestock densities in selected European countries expressed in European livestock units (LSUs) per hectare utilised agricultural area. (Source: Eurostat).

were 70% fewer farms than in 1960. Further expansion of farm size and scale is expected to continue in the future.

Both livestock density (Figure 2) and human population density in the Netherlands are among the highest in the world. This has put biodiversity, environment and landscape under severe pressure [80,81]. High livestock numbers have caused manure surpluses, a problem that by now has featured on the political agenda for almost four decades [82]. To reduce nutrient emissions from agriculture, measures have been introduced since the 1980s. These measures have resulted in strongly reduced farm level surpluses of nitrogen and phosphorus and in reduced nitrate concentrations in groundwater and surface waters [83]. From 2003 onwards nitrate concentrations in groundwater have more or less stabilised due to stagnating nitrogen surpluses on farms. In the southern sandy and loess regions of the Netherlands nitrate concentrations in groundwater still exceed the 50 mg NO_3 standard set in the Nitrates Directive [84]. Also in half of monitoring points in surface waters, nitrate and phosphorus concentrations still exceed levels that will probably be needed to comply with the goals of the Water Framework Directive. Ammonia emissions from agriculture have been more than halved since 1990 so that the ceiling specified in the EU NEC Directive for 2010 (128 kton) has been met. Ammonia emission reduction has been realised mainly because of the introduction of low-emission manure application techniques and the covering of manure storages. Despite the strong decrease in ammonia emission, nitrogen deposition levels in more than half of nature reserves still exceed critical thresholds, so that ecosystems continue to be affected [85]. The European Commission is currently reviewing EU's air policy and is expected to propose a revised NEC Directive with new objectives addressing human health and the environment for 2020 and beyond for relevant air pollutants.

Despite considerable reductions of nutrient surpluses in Dutch agriculture, these still far surpass those in all other European countries (Figure 3). Since environmental quality standards have not yet been met, it is likely that nutrient management issues in agriculture will remain on the policy agenda [86]. The cheap measures have already been taken. New measures focus on adapting feed rations to reduce nutrient excretion in animal manures and on manure processing technologies. The (economic) feasibility of the latter technologies is still unknown.

Focus in Dutch agriculture is strongly on further increasing economic and environmental efficiencies through further farm scale enlargement and adoption of additional capital-intensive technologies. Referring to the resulting efficiency gains, some label this on-going rationalisation as contributing to sustainable development of Dutch agriculture [79,87]. Sustainable development is then viewed as a dynamic and multidimensional 'optimisation' of ecological, economic and societal issues (triple-P: people, planet, prosperity). However, such an approach ignores that Dutch agriculture is not a closed or isolated system, but interconnected with and embedded in much larger global environmental systems by flows of energy and material. An ecological approach to sustainability highlights these interdependencies and recognizes that these flows are governed by physical 'zero sum' conservation laws, implying that global constraints ultimately limit flows at smaller scales [88]. The focus of many sustainability assessments on efforts to reduce environmental impacts on regional or lower scales is therefore problematic, as these efforts will inevitably fail unless the global system is sustainable. This also implies that increasing resource use efficiencies can never be the single item on the sustainability agenda, since that does not guarantee that the carrying capacity of the earth's system is not exceeded.

Efforts of agricultural, governmental and research organizations have been and still are geared towards consolidating and strengthening the Dutch position as second agricultural exporter in a growing world market. In 2010 the government in office identified nine key sectors (so-called 'top sectors') that were considered important to the Dutch economy and are highlighted in current innovation and stimulation policies. One of these key sectors is the agri-food sector [89]. Activities undertaken as part of the top sector policy are inspired by a demand driven, free market growth strategy, based on public-private partnerships of industry, science and government with business in the lead [90]. Such arrangements are likely to primarily serve vested interests, with a narrow focus on productivity and efficiency, based on technologies that fit into existing production systems and lead to private benefits [91]. In the meantime, the increasingly industrial character of especially the livestock sectors has made these the subject of continuous political and societal debate. This debate addresses a wide range of issues related to livestock farming, including the use of antibiotics, the increasing size of farms in people's 'backyards', zoonotic diseases and animal welfare issues. Conflicts between agricultural and public interests in rural areas in the Netherlands are now common, risking agriculture's societal 'licence to produce' [86,87,92]. While industrialisation is already an outstanding and controversial feature of intensive pig and poultry farming, the dairy sector is gradually moving in the same direction. Anticipating the abolition of the European milk quota system by 2015, many Dutch dairy farmers have increased their production capacity, which has been associated with increases in average farm and herd sizes and

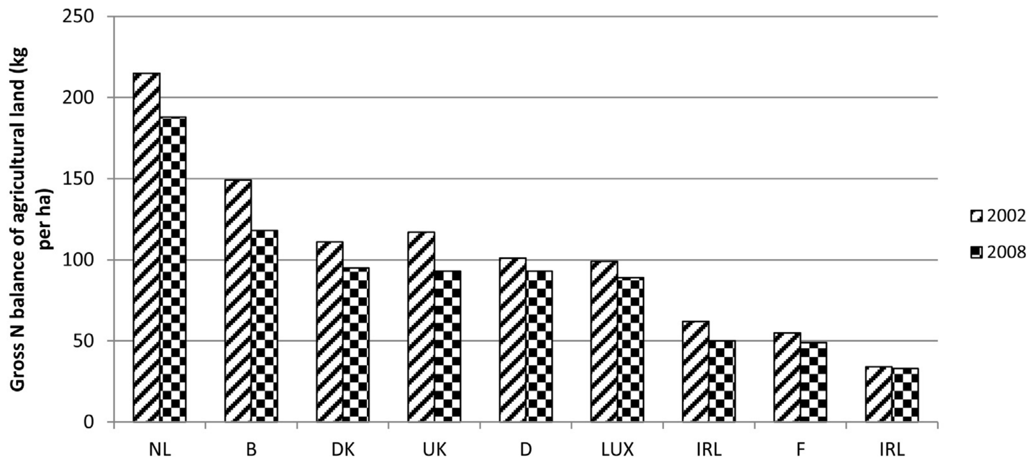

Figure 3. Gross nitrogen balances in selected European countries (kg N per ha of agricultural land). (Source: Eurostat). Gross N balance is calculated as inputs in mineral and organic fertilisers and atmospheric deposition minus outputs in harvested crops and during grazing.

adoption of robotic milking systems [86]. As farmers perceive the grazing of large dairy herds as difficult to manage, this has in turn been associated with a larger proportion of the dairy herd kept indoors year-round. So far, grazing dairy cows have greatly contributed to the positive image of the dairy sector among the general public.

2. Concluding remarks

The goal for agriculture is no longer simply to maximize productivity and profitability, but to optimize across a far more complex range of production, rural development, environmental, social and food consumption outcomes [93,94]. Obviously, the multitude of associated sustainability concerns confront humanity with numerous and great governance challenges. It is beyond the scope of this paper to deal with these challenges here, but it will be crucial that such governance is organised at multiple levels, is adaptive and avoids problem shifting across regions, across environmental themes and over time [95].

Current institutional settings and policies are still mainly directed at economic and environmental efficiencies on the production side, while policies aimed at reducing consumption are practically non-existent. Sound policies, however, start with the acknowledgement of trade-offs between population size, consumption levels and land spared for nature. Therefore, a legitimate, but seldom asked question is which part of the total effort needed to feed the human population should be on more production (with all its possible consequences) and which part on limiting population growth, changing human diets and global redistribution of wealth. Accordingly there are three pressing global challenges [14]. First, to reduce global inequality, the world's 1.3 billion poorest people need to be raised out of extreme poverty. This will require increased per capita consumption for this group, allowing improved nutrition and healthcare, and reduction in family size in countries with high fertility rates. Second, in developed and emerging economies, unsustainable consumption must be reduced. This will entail scaling back or radical transformation of damaging consumption and emissions, and the adoption of sustainable technologies. At present, consumption is closely linked to economic models based on growth. Improving the wellbeing of individuals requires moving from current economic measures to fully valuing natural capital. Third, global population growth needs to be slowed and stabilised, of which voluntary family planning and education is a key part.

Policies addressing consumption could include legislation, encouragement of institutional changes, innovations and behavioural changes and financial instruments aimed at 'getting the price right'. There are many potential change routes, but each route is likely to require the involvement and commitment of many stakeholders in governmental bodies, food industry and civil society. If policies lag behind, consumers and other actors in the food chain could initiate and implement strategies ahead of policy and institutions. However, they will probably only do so if they are well informed by food companies and retailers and if there are real choices to be made.

References

[1] H.C.J. Godfray, J.R. Beddington, I.R. Crute, L. Haddad, et al., Food security; the challenge of feeding 9 billion people, Science 327 (2010) 812–818.
[2] R.E. Green, S.J. Cornell, J.P.W. Scharlemann, A. Balmford, Farming and the fate of wild nature, Science 307 (2005) 550–555.
[3] D. Tilman, K.G. Cassman, P.A. Matson, R. Naylor, S. Polasky, Agricultural sustainability and intensive production practices, Nature 418 (2002) 671–677.
[4] J.A. Foley, N. Ramankutty, K.A. Brauman, E.S. Cassidy, et al., Solutions for a cultivated planet, Nature 478 (2011) 337–342.
[5] P.S. Bindraban, E.H. Bulte, S.G. Conijn, Can large scale biofuels production be sustainable by 2020? Agr. Sys. 101 (2009) 197–199.
[6] R. Lal, Soil carbon sequestration impacts on global climate change and food security, Science 304 (2004) 1623–1626.
[7] M.J. Kropff, J.A.M. van Arendonk, H.J.M. Löffler, Food for all. Sustainable nutrition security; 95 years, Wageningen University, Wageningen UR, 2013.
[8] P.R. Ehrlich, A.H. Ehrlich, Can a collapse of global civilization be avoided? P. Roy. Soc. Lond. B. 280 (2013) 20122845.
[9] A.D. Barnosky, E.A. Hadly, J. Bascompte, E.L. Berlow, J.H. Brown, M. Fortelius, W.M. Getz, J. Harte, A. Hastings, P.A. Marquet, N.D. Martinez, A. Mooers, P. Roopnarine, G. Vermeij, J.W. Williams, R. Gillespie, J. Kitzes, C. Marshall, N. Matzke, D.P. Mindell, E. Revilla, A.B. Smith, Approaching a state shift in Earth's biosphere, Nature 486 (2012) 52–58.
[10] W. Steffen, L. Å Persson, J. Deutsch, Zalasiewicz, et al., The Anthropocene: from global change to planetary stewardship, Ambio 40 (2011) 739–761.
[11] J. Rockström, W. Steffen, K. Noone, Å. Persson, et al., A safe operating space for humanity, Nature 461 (2009) 472–475.
[12] R. Hueting, L. Reijnders, Sustainability is an objective concept, Ecol. Econ. 27 (1998) 139–147.
[13] R. Goodland, H.E. Daly, Environmental sustainability: universal and non-negotiable, Ecol. Appl. 6 (1996) 1002–1017.
[14] The Royal Society, People and the planet, The Royal Society Science Policy Centre report 01/12, 2012.
[15] G.M. Mace, The limits to sustainability science: ecological constraints or endless innovation? PLoS Biol. 10 (2012) e1001343.
[16] T. Jackson, Prosperity without Growth: economics for a finite planet, Earthscan/Routledge, UK, 2011.
[17] C. Nair, Consumptionomics Asia's role in reshaping capitalism and saving the planet, John Wiley & Sons, Singapore, 2010.
[18] R. Heinberg, The end of growth: adapting to our new economic reality, Canada, New Society Publishers, Gabriola Island, 2011.
[19] U. Hoffman, Some reflections on climate change, Green Growth illusions and development space, Discussion Papers No 205, United Nations Conference on Trade and Development, UNCTAD/OSG/DP/2011/5, 2011.
[20] D.H. Meadows, D.L. Meadows, J. Randers, W.W. Beherens III, The limits to growth, Universe Books, 1972.

[21] H. Eijsackers & M. Scholten, Livestock farming with care; summaries from a collection of essays, Wageningen UR, 43 p., 2011.
[22] IAP, IAP Statement on population and consumption, IAP, the global network of science academies, 2012.
[23] L. Brito, M. Stafford Smith, State of the planet declaration, International Council for Science (2012).
[24] T. Kastner, M.J. Ibarrola Rivas, W. Koch, S. Nonhebel, Global changes in diets and the consequences for land requirements of food, P. Natl. Acad. Sci. 109 (2012) 6868–6872.
[25] D. Tilman, C. Balzer, J. Hill, B.L. Befort, Global food demand and the sustainable intensification of agriculture, P. Natl. Acad. Sci. USA 108 (2011) 20260–20264.
[26] B. Phalan, M. Onial, A. Balmford, R. Green, Reconciling food production and biodiversity conservation: land sharing and land sparing compared, Science 333 (2011) 1289–1291.
[27] T. Tscharntke, Y. Clough, T.C. Wanger, L. Jackson, et al., Global food security, biodiversity conservation and the future of agricultural intensification, Biol Cons. 151 (2012) 53–59.
[28] I. Perfecto, J. Vandermeer, The agroecological matrix as alternative to the landsparing/agriculture intensification model, P. Natl. Acad. Sci. 107 (2010) 5786–5791.
[29] J. Fischer, P. Batáry, K.S. Bawa, L. Brussaard, et al., Conservation: limits of land sparing, Science 334 (2011) 593.
[30] T. Garnett, C. Godfray, Sustainable intensification in agriculture. Navigating a course through competing food system priorities. Food Climate Research Network and the Oxford Martin Programme on the Future of Food, University of Oxford, 2012.
[31] J. Fischer, B. Brosi, G.C. Daily, P.R. Ehrlich, et al., Should agricultural policies encourage land sparing or wildlife-friendly farming? Front. Ecol. Environ. 6 (2008) 380–385.
[32] P.A. Matson, P.M. Vitousek, Agricultural intensification: will land spared from farming be land spared for nature, Conserv. Biol. 20 (2006) 709–710.
[33] S.A. Cunningham, S.J. Attwood, K.S. Bawa, T.G. Benton, L.M. Broadhurst, et al., To close the yield-gap while saving biodiversity will require multiple locally relevant strategies, Agr. Ecosyst. Environ. 173 (2013) 20–27.
[34] R.M. Ewers, J.P.W. Scharlemann, A. Balmford, R.E. Green, Do increases in agricultural yield spare land for nature? Global Change Biol. 15 (2009) 1716–1726.
[35] C.T. de Wit, Resource use efficiency in agriculture, Agr. Syst. 40 (1992) 125–151.
[36] J.J. Schröder, A.L. Smit, D. Cordell, A. Rosemarin, Improved phosphorus use efficiency in agriculture: a key requirement for its sustainable use, Chemosphere 84 (2011) 822–831.
[37] B.A. Keating, P.S. Carberry, P.S. Bindraban, S. Asseng, H. Meinke, J. Dixon, Eco-efficient agriculture: concepts, challenges and opportunities, Crop Sci. 50 (2010) S1–S11.
[38] M.A. Bleken, H. Steinshamn, S. Hansen, High nitrogen costs of dairy production in Europe: worsened by intensification, Ambio 34 (2005) 598–606.
[39] J.B. Schiere, H. van Keulen, Rethinking high input systems of livestock production: a case study of nitrogen emissions in Dutch dairy farming (Harry Stobbs Memorial Lecture 1997), Trop. Grasslands 33 (1997) 1–10.
[40] P.M. Vitousek, R. Naylor, T. Crews, M.B. David, et al., Nutrient imbalances in agricultural development, Science 324 (2009) 1519–1520.
[41] H.F.M. Aarts, E.E. Biewinga, H. Van Keulen, Dairy farming systems based on efficient nutrient management, Neth. J. Agr. Sci. 40 (1992) 285–299.
[42] A. Reijneveld, O. Oenema, Developments in soil phosphorus status in a recently reclaimed polder in the Netherlands, Nutr. Cycl. Agroecosyst. 94 (2012) 33–45.
[43] J.N. Galloway, M. Burke, E. Bradford, R.L. Naylor, et al., International trade in meat: the tip of the pork chop, Ambio 36 (2007) 622–629.
[44] A. Leip, et al., Integrating nitrogen fluxes at the European scale, in: M.A. Sutton, et al. (Eds.), The European Nitrogen Assessment, Cambridge University Press, 2011.
[45] M.A. Sutton, A. Bleeker, C.M. Howard, M. Bekunda, et al., Our nutrient world: the challenge to produce more food and energy with less pollution, Centre for Ecology and Hydrology, Edinburgh, 2013.
[46] M.A. Sutton, A. Bleeker, The shape of nitrogen to come, Nature 494 (2013) 435–436.
[47] R. Naylor, H. Steinfeld, W. Falcon, J. Galloway, et al., Losing the links between livestock and land, Science 310 (2005) 1621–1622.
[48] M.P.M. Meuwissen, M. van Boven, T.J. Hagenaars, G.J. Boender, et al., Predicting future costs of High-Pathogenicity Avian Influenza epidemics: large versus small uncertainties, Neth. J. Agr. Sci. 54 (2006) 195–205.
[49] J.N. Pretty, C.F. Mason, D.B. Nedwell, R.E. Hine, et al., Environmental costs of freshwater eutrophication in England and Wales, Environ. Sci. Technol. 37 (2003) 201–208.
[50] J. Pretty, C. Brett, D. Gee, R. Hine, et al., Policy challenges and priorities for internalizing the externalities of modern agriculture, J. Environ. Plann. Man. 44 (2001) 263–283.
[51] C. Brink, H. van Grinsven, Costs and benefits of nitrogen in the environment, in: M.A. Sutton, et al. (Eds.), The European Nitrogen Assessment, Cambridge University Press, 2011.
[52] H. van Grinsven, J.W. Erisman, O. Oenema, L. Bouwman, et al., Conclusions and lessons from the first European Nitrogen Assessment, Milieu 17 (2011) 17–22.
[53] J.D. Wilson, A.D. Evans, P.V. Grice, Bird conservation and agriculture: a pivotal moment? Ibis 152 (2010) 176–179.
[54] J.A. Foley, R. DeFries, G.P. Asner, C. Barford, et al., Global consequences of land use, Science 309 (2005) 570–574.
[55] P.F. Donald, R.E. Green, M.F. Heath, Agricultural intensification and the collapse of Europe's farmland bird populations, P. Roy. Soc. Lond. B. 268 (2001) 25–29.
[56] H. Van Dyck, A.J. van Strien, D. Maes, C.A. van Swaay, Declines in common, widespread butterflies in a landscape under intense human use, Conserv. Biol. 23 (2009) 957–965.
[57] S.G. Potts, J.C. Biesmeijer, C. Kremen, P. Neumann, et al., Global pollinator declines: trends, impacts and drivers, Trends Ecol, Evol. 25 (2010) 345–353.
[58] J. Storkey, S. Meyer, K.S. Still, C. Leuschner, The impact of agricultural intensification and land-use change on the European arable flora, Proc. Natl. Acad. Sci. 279 (2012) 1421–1429.
[59] F. Geiger, J. Bengtsson, F. Berendse, W.W. Weisser, M. Emmerson, et al., Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland, Basic Appl. Ecol. 11 (2010) 97–105.
[60] D. Kleijn, F. Kohler, A. Báldi, P. Batáry, E.D. Concepción, et al., On the relationship between farmland biodiversity and land-use intensity in Europe, P. Roy. Soc. Lond. B. 276 (2009) 903–909.
[61] I. Newton, The recent declines of farmland bird populations in Britain: an appraisal of causal factors and conservation actions, Ibis 146 (2004) 579–600.
[62] T.G. Benton, J.A. Vickery, J.D. Wilson, Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol Evol. 18 (2003) 182–188.
[63] I. Le Viol, F. Jiguet, L. Brotons, S. Herrando, et al., More and more generalists: two decades of changes in the European avifauna, Biol. Lett. 8 (2012) 780–782.
[64] D. Kleijn, M. Rundlöf, J. Scheper, H.G. Smith, T. Tscharntke, Does conservation on farmland contribute to halting the biodiversity decline? Trends Ecol Evol. 26 (2011) 474–481.
[65] C. Stoate, A. Báldi, P. Beja, N.D. Boatman, I. Herzon, A. van Doorn, G.R. de Snoo, L. Rakosy, C. Ramwell, Ecological impacts of early 21st century agricultural change in Europe–A review, J. Environ. Manage 91 (2009) 22–46.
[66] J. Fischer, D.B. Lindenmayer, A.D. Manning, Biodiversity ecosystem function, and resilience: ten guiding principles for commodity production landscapes, Front. Ecol. Environ. 4 (2006) 80–86.
[67] R.F. Pywell, M.S. Heard, R.B. Bradbury, S. Hinsley, et al., Wildlife-friendly farming benefits rare birds, bees and plants, Biol Lett. 8 (2012) 772–775.
[68] H. Schekkerman, Precocial problems; shorebird chick performance in relation to weather, farming, and predation, Alterra Scientific Contributions 24 (2008).
[69] R. Kentie, J.C.E.W. Hooijmeijer, K.B. Trimbos, N.M. Groen, T. Piersma, Intensified agricultural use of grassland reduces chick growth and survical of precocial shorebird chicks, J. Appl. Ecol. 50 (2013) 243–251.
[70] A.M. van Doorn & B. Elbersen, Implementation of High Nature Value farmland in agri-environmental policies: what can be learned from other EU member states?, Alterra Report 2289, Wageningen, 2012.
[71] EEA, High nature value farmland; characteristics, trends and policy challenges, EEA Report No 1/2004, European Environment Agency, 2004.
[72] EC, Our life insurance, our natural capital: an EU biodiversity strategy to 2020, European Commission, Brussels, 2011.
[73] K. Medarova-Bergstrom, D. Baldock, K. Hart, A. Volkery, A greener EU budget in the balance: the 2014-2020 MFF deal, Institute for European Environmental Policy, 2013.
[74] L. Brussaard, P. Caron, B. Campbell, L. Lipper, S. Mainka, R. Rabbinge, D. Babin, M. Pulleman, Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture, Curr. Opin. Environ. Sust. 2 (2010) 34–42.
[75] G.R. de Snoo, I. Herzon, H. Staats, R.J.F. Burton, et al., Towards effective nature conservation on farmland: making farmers matter, Conserv. Lett. 6 (2013) 66–72.
[76] D. Hillel, C. Rosenzweig, The role of biodiversity in agronomy, Adv. Agronomy 88 (2005) 1–34.
[77] E. Turnhout, C., Waterton, K., Neves, M. Buizer, Rethinking biodiversity: from goods and services to living with, Conserv. Lett., 10.1111/j.1755-263X.2012.00307.x.
[78] D.J. McCauley, Selling out on nature, Nature 443 (2006) 27–28.
[79] A. Veldkamp, A.C. Van Altvorst, R. Eweg, E. Jacobsen, et al., Triggering transitions towards sustainable development of the Dutch agricultural sector: TransForum's approach, Agron. Sustain. Dev. 28 (2009) 87–96.
[80] R. Bobbink, M. Hornung, J.G.M. Roelofs, The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation, J. Ecol. 86 (1998) 717–738.
[81] MNP, National Nature Outlook 2, RIVM, Bilthoven, The Netherlands, 2002.
[82] P.L.C.M. Henkens, H. van Keulen, Mineral policy in the Netherlands and nitrate policy within the European Community, Neth. J. Agr. Sci. 49 (2001) 117–134.
[83] J. Willems, M. van Schijndel, Evaluation Nutrient Policy Legislation 2012. Synthesis report, PBL, The Hague, 2012.
[84] F.J.E. van der Bolt, O.F. Schoumans, Trends in soil and water quality; Evaluation of Nutrient Policy Legislation 2012, Final ex-post report, Alterra, Wageningen, 2012.
[85] B.J. de Haan, J. Kros, R. Bobbink, J.A. van Jaarsveld, W. de Vries, H. Noordijk, Ammonia in the Netherlands, PBL, Bilthoven, 2008.
[86] Th.V. Vellinga, A. Bannink, M.C.J. Smits, A. van den Pol-van Dasselaar, I. Pinxterhuis, Intensive dairy production systems in an urban landscape, the Dutch situation, Livest. Sci. 139 (2011) 122–134.
[87] A.R.H. Fischer, P.J. Beers, H. van Latesteijn, K. Andeweg, et al., Transforum system innovation towards sustainable food: a review, Agron. Sustain. Dev. 32 (2012) 595–608.

[88] J.R. Burger, C.D. Allen, J.H. Brown, W.R. Burnside, A.D. Davidson, et al., The Marcoecology of sustainability, PLoS Biol. 10 (2012) 1–7.
[89] Topsector Agro&Food, Agro&Food, the Dutch growth diamond, 2012.
[90] EZ, 2013, http://www.top-sectoren.nl/international, accessed 15 April 2013.
[91] J.P. Renagold, D. Jackson-Smith, S.S. Batie, R.R. Harwood, et al., Transforming U.S. agriculture, Science 332 (2011) 670–671.
[92] M. van Lieshout, A.R.P.J. Dewulf, M.N.C. Aarts, C.J.A.M. Termeer, Do scale frames matter? Scale frame mismatches in the decision making process about a mega farm in a small Dutch village, Ecol. Soc. 16 (2011) 38.
[93] J. Pretty, W.J. Sutherland, J. Ashby, J. Auburn, et al., The top 100 questions of importance to the future of global agriculture, Int. J. Agric. Sustain. 8 (2010) 219–236.
[94] Foresight, The future of food and farming, final project report, The Government Office for Science, London.
[95] V. Galaz, F. Biermann, C. Folke, M. Nilsson, P. Olsson, Global environmental governance and planetary boundaries: an introduction, Ecol. Econ. 81 (2012) 1–3.