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Perspective

Agriculture and biodiversity: a better balance benefits both

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Abstract: Sustainable agriculture is an important component of many of the 17 Sustainable Development Goals agreed upon by the UN in 2015 (https://sustainabledevelopment.un.org/sdgs). However, the trend in agriculture is moving in the opposite, non-sustainable direction. Agriculture is one of the major drivers of biodiversity loss. Next to biodiversity loss due to habitat destruction by conversion of natural lands into agriculture, intensification of agriculture has led to a strong decline of specific farmland biodiversity. Furthermore, many agricultural landscapes face pollution by pesticides and fertilizers, and encounter depleted soils and erosion due to unsustainable farming practices. This is threatening not only biodiversity but also complete ecosystems and the ecosystem services on which agriculture itself depends. Moreover, the pressure of feeding an increasing number of people in combination with a change in diets towards more animal protein puts a lot of additional pressure on the current available agricultural lands and nature areas.

We propose a holistic approach that contributes to the development and implementation of sustainable agricultural practices that both make use and support biodiversity and ecosystem services both in agricultural and in semi-natural areas. An agricultural system based on the full potential of (functional agro) biodiversity provides opportunities to create a resilient system in which both food production and nature can thrive.

Keywords: agriculture; biodiversity; sustainability; ecosystem services; conceptual framework

1. Introduction

Biodiversity can be described as the richness and diversity of all life on earth. Biodiversity is not just about the individual species, but also about the diversity of ecosystems, species and genes, and the relationship between them [1]. Biodiversity is not only relevant in/for (semi-)natural areas, but also for agricultural areas, which often have specific biodiversity which contributes to ecosystem services. Agriculture in turn can contribute to the increase and conservation of biodiversity, for example by smarter management of marginal land, but also by the management of fertile areas.

Agriculture has different functions of which production of food, feed and fibres and sustaining socio-economic structures and management of ecosystem services are the most important. In doing so, agriculture often makes use of and contributes to the services provided by ecosystems such as healthy soils. About 40% of the world's terrestrial surface has been converted into agriculture [2], Thus, in many parts of the world, humankind has intervened tremendously into the natural succession of ecosystems. In a resilient agricultural system, farming practices provide a good balance between the exploitation and use of biodiversity, ecosystems services and the natural surroundings. In these systems, the challenge is to optimize food production while at the same time minimising impacts on the environment and the ecosystem.

The notion that agriculture depends on biodiversity and that many specific species of animals and plants depend on sustainable agricultural landscapes is key in the approach of resilient agricultural systems. Both agriculture and nature can benefit from a holistic approach towards resilient systems. This approach focuses on an optimal use of agro-biodiversity and a reduction of long-term (economic and natural) risks by using ecosystem services rather than external inputs.

1.1. Agriculture benefits from biodiversity

According to Odum (1969) [3] succession is the "increased control of, or homeostasis with, the physical environment in the sense of achieving maximum protection from its perturbations. "... the strategy of *maximum protection* (that is, trying to achieve maximum support of complex biomass structure) often conflicts with man's goal of *maximum production* (trying to obtain the highest possible yield)." Agriculture is in ecological sense an early-successional system which is continually out of (homeostatic) balance and therefore makes stability hard to achieve. In a resilient agricultural system there should be a good balance between protection and production. Holling (1973) [4] discusses the difference between resilience and stability in ecological systems. Resilience is defined as the propensity of a system to retain its organizational structure and functions such as productivity following a perturbation. Stability, on the other hand, is the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is. In this definition stability is the property of the system and the degree of fluctuation around specific states. The goal of producing a maximum sustained yield may result in a more stable system of reduced resilience [4]. Nowadays Holling's definition of resilience is defined as "resistance" and "stability" defined as "resilience". Here, resilience is thus defined as "the ability of a system to return to an equilibrium state after a temporary disturbance". But we go a step further and add to this definition

Agriculture hampers ecosystem succession, as with each cropping cycle, the system is brought back to an early-successional stage. At the same time, agriculture stimulates productivity and manages biodiversity. By converting natural ecosystems into agriculture a new environment was created that allowed for a different biodiversity. A good example is the strong increase in the black-tailed godwit (*Limosa limosa*) population in the Netherlands when forests and peatbogs where converted into meadows and agricultural grasslands [5].

However, today's agriculture generally aims to produce large quantities of food, against the lowest economic costs, in the short term. These short-term goals often lead to conflict with the conservation and management of biodiversity and other long-term ecosystem services (e.g. [6-8]). Moreover, a short term focus on maximizing productivity can endanger the ecosystem services in such a way that dependence on external inputs such as fertilizers and pesticides increases in order to maintain productivity [9-12]. When out of balance, these systems inevitably collapse or need more technical interventions to remain productive, all at great economic, social and ecological costs (e.g. [11,13,14]).

The importance of agricultural biodiversity (agrobiodiversity) is thus large: living organisms are involved in all natural processes used in agriculture to produce food. If only considering soil, many types of bacteria, fungi, nematodes, springtails, earthworms, etc. are active in the soil to provide ecosystem services e.g. digesting manure, crop residues and roots. This digestion process releases nutrients for crops, and at the same time contributes to the carrying capacity of soils, to disease-suppression, water retention and water-supplying capacity of the soil. But also on the level of plant and grassland biodiversity, the diversity of farm animals, the agricultural gene pools, or the on-farm habitat diversity, agriculture basically depends on biodiversity to function well (e.g. [15-18]). Recently more attention has been paid to these services in agriculture (e.g. [19,20]).

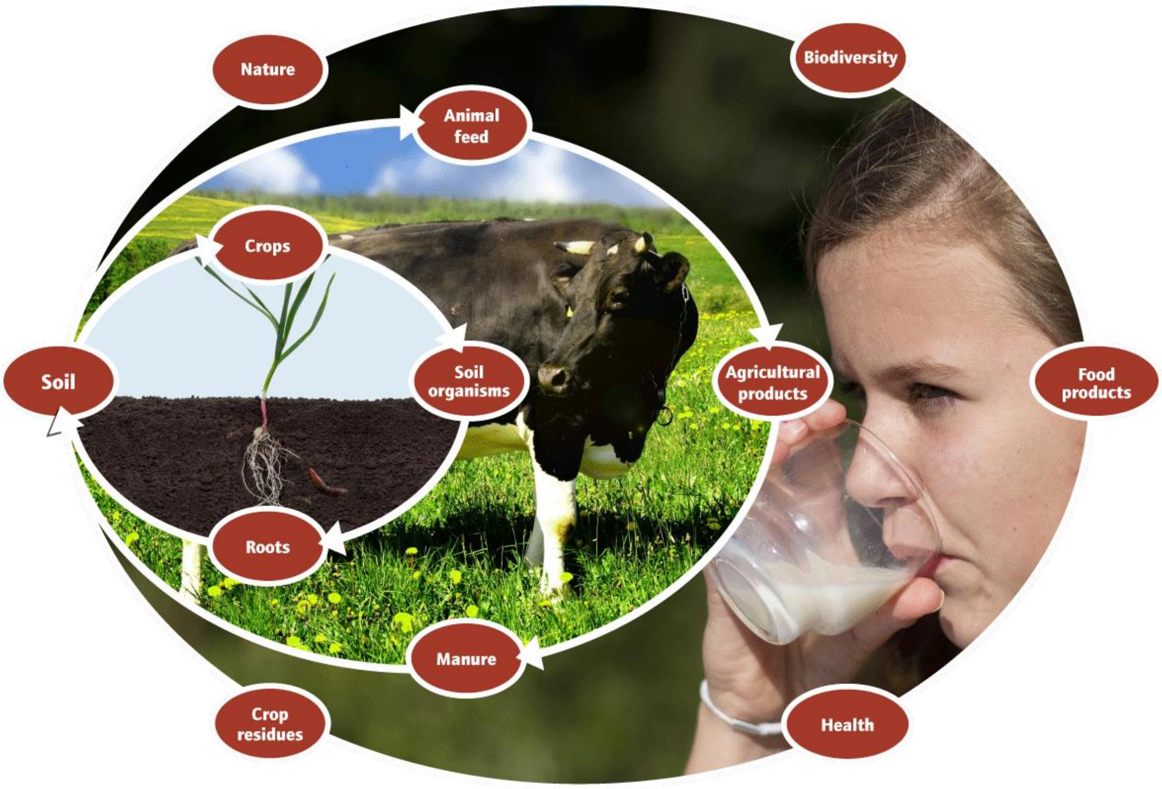

Figure 1. Relationship between sustainable agriculture, nutrition and health. Sustainable agriculture, nutrition and health begins with a healthy soil. The outer cycle represents the main drivers of the agriculture system.

Research shows that the resilience of the (eco)system increases with a larger (functional) biodiversity [21-24]. This also holds for biodiversity in (agro)ecosystems [25,26]. Crops grown in genetically uniform monocultures show a higher vulnerability against diseases, pests and nutrient deficiencies and increase the pressure on environmental resources [27]. When growing mixtures of different crops or varieties, the system becomes more resilient to fungal diseases and pests, yields are stabilized and the sustainability of the system as a whole increases (e.g. [28-30]). Biodiversity increases productivity and biodiversity increases stability of ecosystems. Biodiversity is therefore strongly linked to the resilience of systems and is essential for food security. Maintaining or improving biodiversity means obtaining a true system view and approach. The interaction between the production of food, nature and health is shown in Figure 1: Sustainable agriculture, nutrition and health begins with a healthy soil.

1.2. Biodiversity can benefit from agriculture

Besides the direct function of biodiversity in agriculture, (bio)diversity also provides other values. Due to the presence of hedges, ditches, field margins, hedgerows, etc. the cultural aspects of landscape design is preserved, but these elements also form the specific habitat for insects, birds, plants and other animals. This biodiversity has a high cultural and nature value, but can also support agricultural production e.g. nutrition, animal health (as leaves of shrubs and trees contain health-promoting substances) and welfare of livestock (animal behavior and shade), or the provisioning of insects for pollination or biological plague reduction. When aiming for a durable and robust farming system and thus for sustainable agriculture, it is essential to preserve, support, use and promote biodiversity.

There are many examples where agriculture has a positive (and negative) effect of biodiversity. Here we use examples of grassland management. Recent outbreaks of common voles (*Microtus arvalis*) in the North of the Netherlands (Friesland) caused extensive damage to the grassland and therewith milk production. It was shown that land use changes, management and lowering the groundwater table was the main cause of the outbreaks. Increasing the water table led to better control of the vole population but at the same time increased grassland productivity and the meadow bird population. These unpublished results are confirmed by extensive research on the factors associated with the colonization of agricultural areas by common voles in NW Spain [31]. Increased predator densities over the years have been suggested as an important cause of the trend towards lower nest survival in agricultural grasslands (e.g. [32]). Kentie et al. [33] showed that high-quality habitat in the form of herb-rich meadows provides a degree of protection against predators with higher nest survival on herb-rich meadows compared to monocultures. Therefore, increased predator densities are an increased threat during the egg stage only if habitat quality is low. Several studies show that agriculture landscape heterogeneity contribute to the highest diversity of birds [7,34,35].

At present, we propose to implement this principle of biodiversity-based agriculture in dairy systems in the Netherlands as an example to develop a conceptual framework for biodiversity as the basis for sustainable agriculture. This framework in essence can be applied to other agricultural sectors (e.g. arable cropping, horticulture or mixed farming). Here we will discuss the state of biodiversity in Dutch agriculture and characterise the agricultural model. We propose a resilient model as the basis for the conceptual framework for biodiversity and ecosystem services in agriculture. After explanation of the framework we will provide development paths and clusters of management options to successfully improve biodiversity.

2. Agriculture threat to biodiversity

Occupying 70% of the land area of the Netherlands, the agricultural landscape is the largest habitat for plants and animals. There are more than 45,000 plants, fungi, insects, animals and other organisms known in the Netherlands [36]. A large number of these species depend on the agricultural landscape as their prime habitat. However, in recent years species for which the Netherlands is extremely important, like the black-tailed godwit (*Limosa limosa*), lapwing (*Vanellus vanellus),* partridge (*Perdix perdix)* and the skylark (*Alauda arvensis*), have been in decline. Strikingly, the most significant cause of the decline of meadow birds lies in their breeding grounds in the Netherlands, rather than elsewhere along their migratory route [6,8,37-39]. The dairy sector uses 40% of the terrestrial area of the Netherlands. As such the sector has a large impact on the biodiversity in the agricultural landscape. Moreover, the dairy sector is one of the largest contributors to nitrogen deposition in nature areas, which is considered one of the main causes of ongoing biodiversity loss in open nature areas [8,40].

The average number of species of breeding birds and vascular plants (such as flowers and grasses) has increased in semi-natural areas between 1990–2005 compared to 1975–1989 (see Figure 2, left). In contrast, in the same period the figure shows a continuous decline of all species in the agricultural zone (see Figure 2, right). Butterflies are declining in both areas, but at a faster rate in agricultural areas compared to semi-natural areas [8,36].

Not only species on farmland are in decline; agriculture is an important cause of the stagnant recovery of Dutch nature [38,39]. For example, the critical nitrogen load is exceeded in two thirds of the semi-natural ecosystems. The quality of these areas is thus under pressure through agriculture, which is next to burning of fossil fuels the main source of nitrogen deposition [39,41]. Moreover, both nature and agriculture profits from species that live in both areas, such as pollinators, butterflies, etc. Therefore, decline of these species in nature affects agriculture.

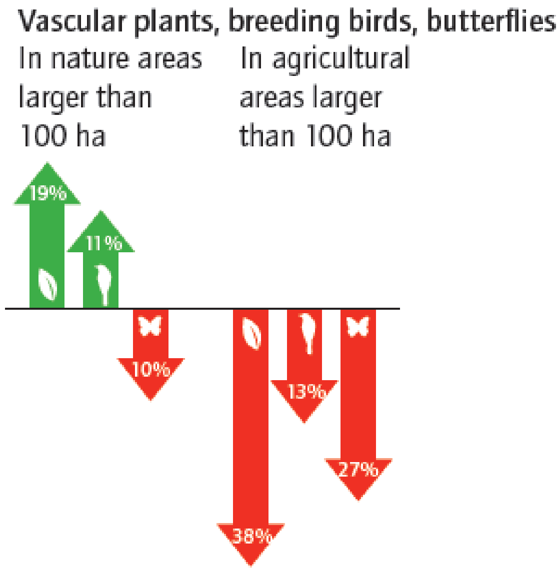

Figure 2. Changes (%) in vascular plants, breeding birds and butterflies in semi-natural areas and in agricultural areas as compared between the periods 1990–2005 and 1975–1989 [8,36].

3. Risk management model versus resilience model

In the Netherlands, the loss of biodiversity is mainly due to intensification of agriculture these past decades. The main characteristic of the intensification of agriculture has been the focus on as much production per hectare or per animal as possible resulting in a simplification of ecosystems: mixed farms have switched to specialization, fields have been stripped from hedges and trees, and ditches were straightened as the result of land consolidation policies [42]. Furthermore, the mowing of grassland was intensified and groundwater levels lowered [14,37]. This was made possible by the availability of techniques and tools, such as machinery, fertilizers, pesticides and irrigation. These services that were previously provided by the ecosystem were gradually unconsciously replaced by these tools.

We call this the so-called “control” or risk management model, where the balance is heavily dependent on external inputs such as seed companies and suppliers, processors, supermarkets, price control, etc. and the focus is on short-term revenues and control actions (Figure 3). In this model, natural processes and associated biodiversity have become under severe pressure and are not optimally utilized. As the plant depends on readily available fertilizers, the soil processes for nutrient supply play only a marginal role. Weeds are controlled with herbicides and no use is made of natural pest control. There is a high risk that soil quality decreases in the long term. Because the natural functions are not used, there is a high degree of dependence on external inputs. Price fluctuations make the system very vulnerable when insufficient buffer is built. This can lead to risks such as the long-term loss of production, and thus additional costs. The “control” to keep the system in balance and minimize risk of production loss leads to increased dependency on external resources [41,43,44].

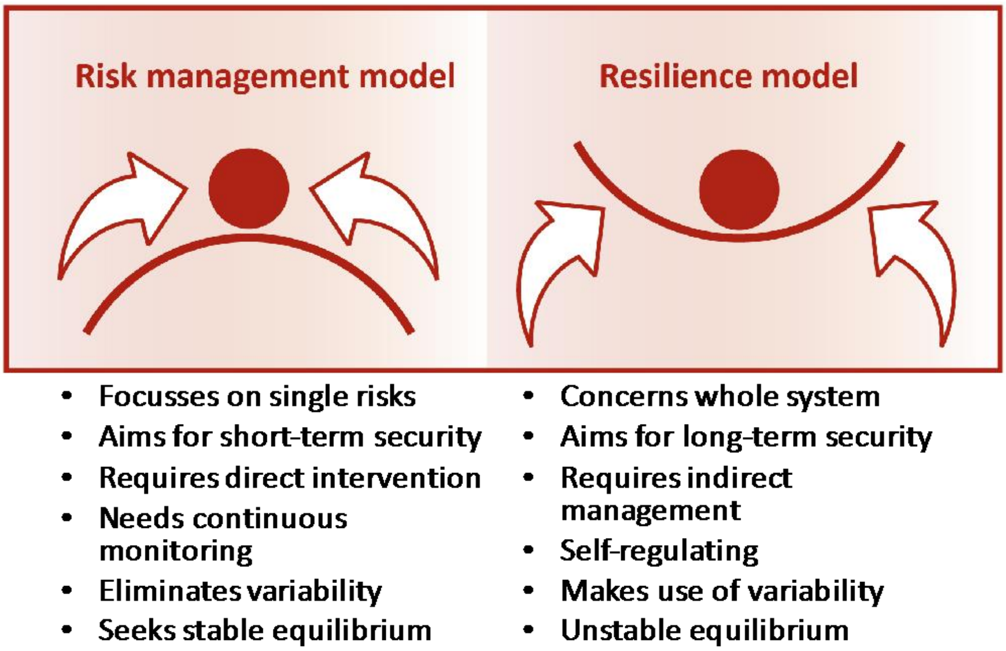

Figure 3. Outline of the current agricultural system that fits into a Risk management model and the characteristics of a resilience model. Robust, resilient systems are less vulnerable [43,44].

This contrasts with the resilience model which optimally uses biodiversity and natural processes in order to increase the resilience and reduce risks [43,45]. By supporting and strengthening the natural processes in agriculture, productive systems can be realized to increase the productivity and stability. Short-term productivity may be equal or lower, but long-term productivity is warranted, through higher resilience and a better ability to cope with disturbances (e.g. [45-47]).

This is a system approach and focuses on the stable equilibrium and usage of the variability as a basis for resilience. As an example, promoting the root system (e.g. by breeding, [48]) increases the resilience of the grassland system. Roots play an important role in reconciling production and environmental goals. By increasing the rooting system, nutrient uptake and yield are improved, while environmental losses (e.g. nitrate leaching) are decreased. It also reduces the risk of the effects of climate change through better water absorption, better soil structure and less erosion. Due to the build-up of organic material more carbon is sequestered, contributing to the mitigation of climate change (e.g. [49]). A resilient system focuses on strengthening the interactions within the system.

The Risk management model has led to a large increase in food production per hectare of farmland, creating a more productive system. Side effects, such as environmental impacts and reduced animal welfare are now increasingly recognized which has led to more focus on sustainability and "precision" agriculture. These side effects have led to additional costs for society of which the estimates by Van Grinsven et al. [50] for nitrogen pollution in Europe are a clear example. The intensification of agriculture has negative effects on soil quality and on the above- and belowground biodiversity. For sustainable production good management of soil and biodiversity is essential. Another characteristic of the risk management model is that it is focused on short term economic revenues and a large dependency of individual farmers on large companies that mainly profit from the farmer's activities. These companies include banks, retail, insurance companies, machinery producers, seed companies, etc., who all have limited incentives to change this system from their own economic interest.

The resilience model is put into practice through e.g. organic farming permaculture, agroforestry, agro-ecology, etc. [7,51]. These are proven systems, but do not deliver the same production levels as conventional farming systems. The difference is on average between 20 to 30% less yield as measured on the short-term [52,53], but there are also production systems that achieve similar levels of production, see e.g., [54]. Furthermore, at the long-term, especially when climate extremes are experienced, these systems appear to be much more resilient. Yield losses are expected to be much smaller than in case of conventional, low-resilience farming systems (e.g. [55-57]). In the resilience model soil quality and biodiversity are essential. A healthy soil can much better cope with external stress such as drought and heavy rainfall, disease, plagues, etc. In this model, therefore the long-term risks are much lower than in the Risk management model. Eventually, on the long term, the lower costs will compensate for the lower production level, yielding a better margin for the farmer and less social (external) costs for society due to lower pollution levels, more carbon sequestration and higher levels of biodiversity.

4. The value of landscape elements

Landscape elements are essential to support the functional (agro)biodiversity on the farm [7,35,58-60]. If these habitat elements are not present, the overall effect of (agro)biodiversity at farm level remains limited, regardless whether the management focused on the functional biodiversity, according to a recent international study [61]. The importance of these elements for biodiversity and species is illustrated by Kretschmer et al. [62] and Hoffmann et al. [63] who used observations to show that species richness increases with an increasing proportion of landscape elements. Benton et al. [64] show the effect of the disappearance of mosaic structures on the decrease of farmland biodiversity.

There is a large amount of different landscape elements: roadsides, groves, springs, ditches, hedges, sunken roads, orchards, land vegetation, ditches, thickets, ponds, and livestock drinking pools and watercourses [60]. Landscape elements are part of functional agro-biodiversity and may consist of species or ecological communities (e.g. trees, hedges, ditches or land vegetation) that are also part of biodiversity. Landscape elements often also have a cultural and historical value. A large proportion of landscape elements, however, is no guarantee of high biodiversity value. Their quality and the connections made between individual elements, are of great importance. By fragmentation of the area some species cannot thrive.

5. Biodiversity versus intensity of a farm

The intensity of a farm is interpreted in different ways and is not a unique term. Intensity, for example can be related to land-based systems, defined as the amount of food that can be produced on agricultural land in relation to the production of milk/meat without affecting soil quality and within the environmental standards. The intensity also determines how the nutrient cycles are closed at the farm. The intensity is higher when nutrients (or feed) need to be imported from elsewhere.

Allan et al. [65] characterized intensity as a measure composed of: the level of fertilization, the grazing and mowing regime. They show higher loss of farm scale biodiversity at higher levels of fertilization, less grazing and higher cutting regime (intensive agriculture). Fertilization has a big impact on biodiversity, as has been shown by changes in plant species composition (e.g. [40,66]), but also plagues of Common Vole *Microtis arvalis* are associated with increased fertilization [67]. At higher levels of fertilization the aboveground biodiversity decreases rapidly. Also probably the function of the underground biodiversity is reduced at higher levels of fertilization, although there seems to be an optimum in functionality at a given level of fertilization [68]. The positive effect of earthworms disappears when fertilization increases: the higher the fertilization, the lower the efficiency of nitrogen. Van Groeningen et al. [69] showed that the positive effect of earthworms can be demonstrated and leads to 25% more production especially when organic material is returned to the soil. The positive effect of earthworms disappears when fertilization increases: the higher the fertilization, the lower the efficiency of earthworms to efficiently use nitrogen.

Geiger et al. [10,70] examined 13 variables that have an effect on biodiversity in European agriculture. They discovered that fungicides had the greatest influence. In practice on dairy farms the parameters affecting biodiversity are perhaps more complex and next to fertilization, grazing and mowing regime also turning grassland into continuous maize production, tillage, use of pesticides and antibiotics, concentrates and indirect the percentage of grass in the feed ration play a significant role.

It is important to derive an unequivocal indicator of the intensity of a farm, because within classes of intensity biodiversity varies considerably and that gives opportunities to achieve improvement in biodiversity at farm level. Besides an indicator of intensity also indicators for biodiversity are essential. This is illustrated for fertilization as one of the factors of intensity. Much is known about the relationship between nitrogen and yields and (above ground) biodiversity. While above ground biodiversity rapidly decreases with increasing intensity, resilience decreases and the risks increase. Not only short-term, direct risks for the farmer, e.g. the risk of damage due to climate or weather conditions such as drought or excessive rainfall; but also social risks, e.g. the probability of increasing the social costs by increasing the environmental pressures; and finally farmers are confronted with long-term risks of higher production costs and loss of production, due to soil degradation and the loss of the functioning of soil life. Recently, the environmental and social costs of loss of nitrogen to the environment were quantified on the basis of the "willingness to pay method". The method estimates what people are willing to pay, or the cost of actions they are willing to take, to avoid the adverse effects of nitrogen pollution [50,71]. The costs due to nitrogen losses to the environment are quantified by PBL for Europe and EPA for the US and increase as the fertilization and associated losses increase to the environment [50,71,72]. These costs are indirectly paid by society.

Intensification has been historically linked with "uniformisation" and "simplification" of agricultural systems. The negative correlation between intensification and biodiversity reflects the loss of diversity within and among agro-ecosystems If (bio)diversity would be restored and/or properly managed it could be possible to have intensive agricultural systems with relatively high biodiversity [73,74]. Furthermore, it has been proven that management of biodiversity creates benefits for agriculture in terms of productivity (e.g. [44,45,73,75]) and overall sustainability (e.g. [51,55,56,73,74]). Even intensive agriculture can benefit from biodiversity management to increase species and at the same time maintain or increase productivity [70]. Genetic diversity may be deliberately "engineered" to increase crop yield further, which has come to a standstill with the breeding for uniformity in e.g. wheat.

6. Conceptual framework as developed for dairy farming

To promote resilience (as described in the resilience model) on dairy farms an integrated approach is required [9]. The starting point of the conceptual framework is the desire to reverse the decline of biodiversity, and on the other hand to better use and enhance biodiversity at the farm. This at the same time increases the efficiency in the cycles at the farm and reduced stress factors causing biodiversity loss in (semi)natural areas (Figure 4).

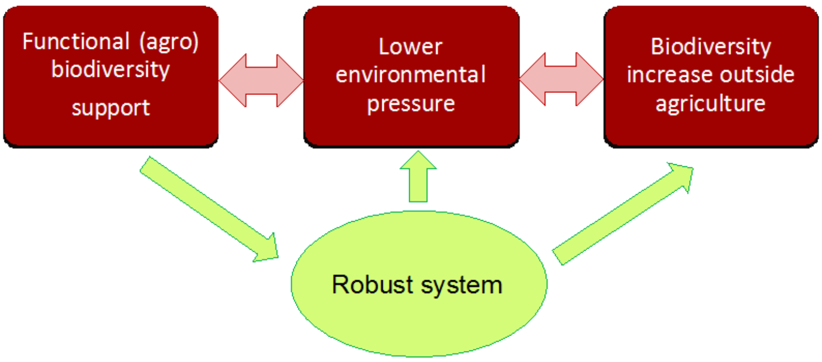

Figure 4. Functional agrobiodiversity strengthens a robust system, lowering environmental pressure and therewith increasing biodiversity outside the agricultural system.

Considering the importance and function (promoting resilience and reducing risks) of biodiversity on dairy farms it is important to enhance the functional (agro)biodiversity. Functional (agro)biodiversity enhancement however is not enough and should be supported by landscape elements and diversity and the connections of biodiversity source areas in an area including several other farms and land uses. Therefore, we distinguish four interconnected pillars for biodiversity (Figure 5):

1. Functional (agro)biodiversity at the farm. This encompasses management of soil biodiversity, including rooting systems, grass- and cropland biodiversity, and the diversity of farm animals,

and the cycles of nutrients, water and energy at the farm (soil, crop, cow, business); optimized by using the functional agro-biodiversity and to serve as a basis for underground and aboveground biodiversity, water management, carbon sequestration, nutrient use, etc. The intensity of a farm largely determines whether cycles are closed at the farm level.

2. Landscape diversity at the farm: influence of the landscape elements (hedges, ditches, flower zones, trees and forests, etc.) to support the functional agro-biodiversity.
3. Specific species management (mowing, fertilization timing, water management, etc.) at the farm for maintaining and increasing specific species (e.g. farmland/meadow birds).
4. Source areas and connection zones (landscape): management within an area (ecological corridors, exchange and connection of dry and wet zones, regional biodiversity, etc.).

Biodiversity is enhanced when clusters of measures are taken within these four levels of biodiversity.

These four interconnected pillars form the basis of the conceptual model and helps the farmer to manage the farm sustainably. It builds on the force of nature, which is determined by the potential of the land, region and climatic circumstances by focussing on soil, roots, grass and mineral cycles (pillar 1), supported by the region specific landscape elements (pillar 2) in connection with biodiversity sources areas, hydrological and landscape features (pillar 4). Except for the third pillar, the farmer benefits from focussing on the improvement of the other 3. The third pillar is mainly for promoting the biodiversity value of agriculture and to preserve vulnerable species which depend on the agricultural land for breeding and food.

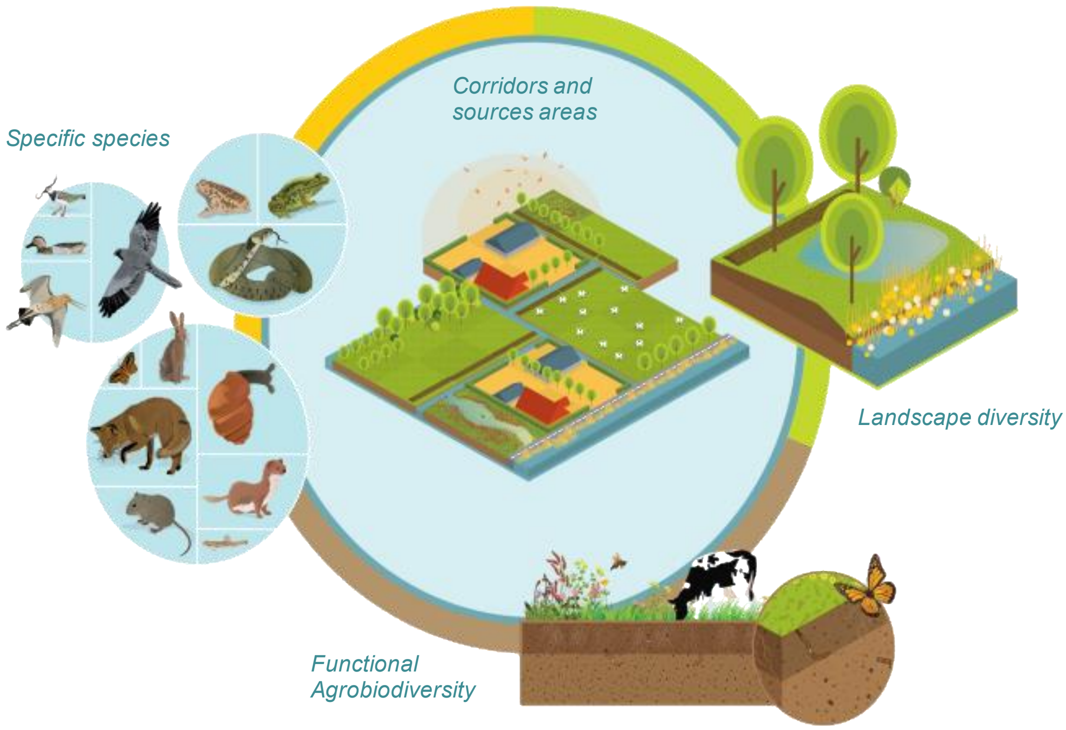

Figure 5. Four interconnected pillars for biodiversity in and around agriculture. It starts with optimizing the functional Agrobiodiversity (pillar 1), supported by landscape diversity (pillar 2) and corridors and source areas for biodiversity (pillar 4). When desired, measures for maintaining specific species can be taken (pillar 3).

7. Clusters of measures depending on the dairy farmer's ambition

Within the four pillars of biodiversity, it is possible to identify levels of ambition that lead to an in- or decrease and an optimal use of functional (agro)biodiversity. Within the levels of ambitions clusters of integrated measures contribute to biodiversity enhancement and functioning. The clusters form a logical sequence of actions: they start with soil and grassland management, and then expand towards measures in the area of grass and crop diversity, animal health and welfare, and farm level measures. The exact content of the action is open and depends on the farmer's ambition. The below-mentioned levels of ambition serve as examples. The four proposed ambition levels are shown in Figure 6 and explained below. Figure 6 shows a score of farms (the individual dots) in relation to intensity and biodiversity score. The maximum biodiversity per intensity class is determined by connecting the best farms in terms of biodiversity for each intensity class.

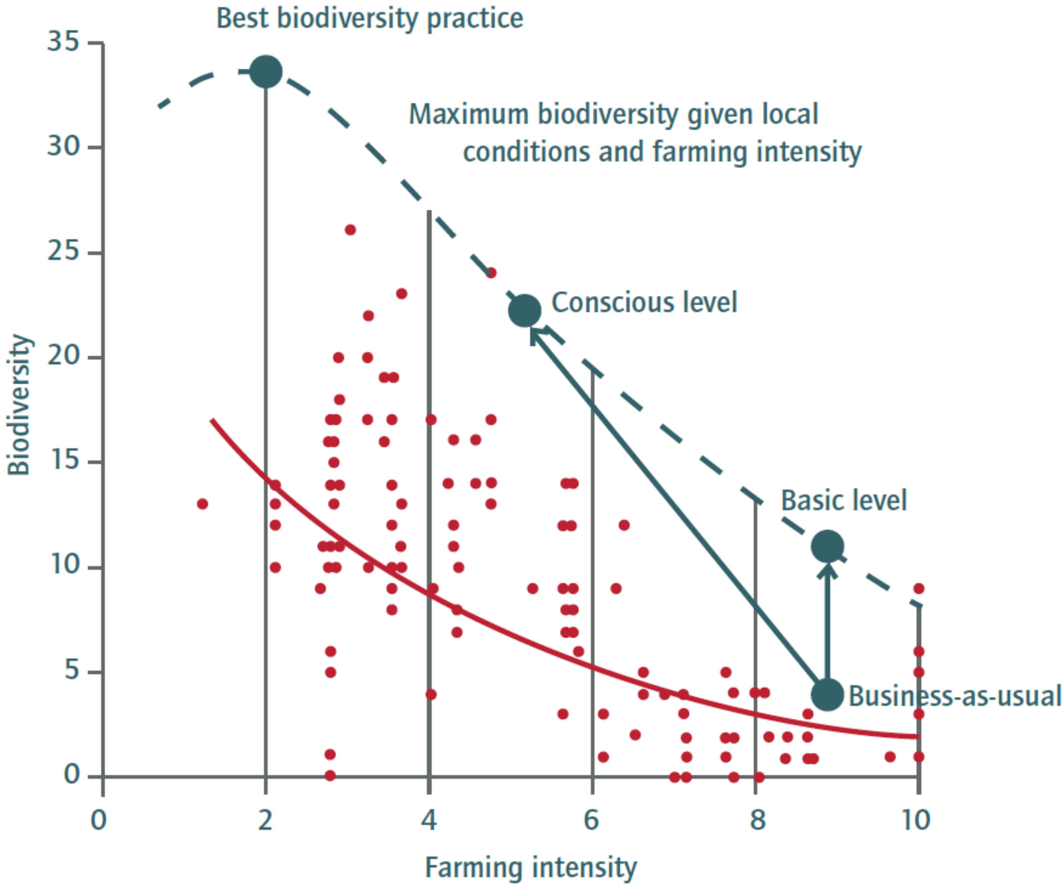

Figure 6. Different farms scored on intensity level and biodiversity adopted from [10,65]. The maximum biodiversity line is the line connecting the farms scoring the highest biodiversity per intensity. The four ambition levels are explained in the text.

7.1. Business as usual

The business as usual level makes little or no use of stimulating functional biodiversity on the farm. The focus is mainly on optimizing or maximizing the various production levels and their control. In addition, the production is highly dependent on external inputs, which both ensure a constant quality (concentrate, genetic material, fertilizers, pesticides), but on the other hand also entail risks regarding the (international) market. In addition, a lack of basic care of biodiversity (starting with management of the soil) in the long run undermine the production system, and to weaken the resilience that is needed to cope with changes in climate, for example.

7.2. Basis

The basic level is current practice of agricultural nature conservation and essentially only focusses on pillar 3: no changes are made regarding the on-farm intensity and management strategy of the farm, but specific biodiversity is stimulated on the farm itself. This can be done by setting aside a piece of (marginal) land or using considerate mowing. This ambition is not enough to sustain agriculture on the long term and a more conscious ambition is needed.

7.3. Conscious

The next level of ambition goes towards an adaptive, resilient system. The basis of soil and grassland management has been laid by a focus on careful management of the most important production factor: the soil. Attention is paid to the organic matter supply to the soil, feeding the soil, and there is a good base of grassland care, which includes a greater diversity in the grassland (herbs, clover), minimisation of (land-based) arable land (and feed import), the use of cereals in rotation with maize, and less externally imported concentrates. Not only the level of soil, grass and crop management is optimal, but also the animal breeding strategy can play a role as an important aspect of resilience. At this level there is much focus on the landscape elements to support the functional biodiversity at the farm. The elements that are chosen depend on the specific location of the farm in a region.

7.4. Best of biodiversity practice

The last level of ambition essentially is a switch from a control system to an adaptive or resilient system, taking the full advantage of the conceptual framework. It makes maximum use of functional biodiversity at farm level, and a transition has been made to a resilient system. At all levels: from soil to grass and crop, animal and plant, the landscape elements and the integration within the region, the farmer makes maximum use of the functional aspects of biodiversity. This ensures less dependence on external inputs, greater internal resilience and robustness. However, these measures sometimes lead to production reduction and / or increase the cost price of products. The advantages of a greater resilience and more stable production levels become visible only in the long term (4–6 years).

8. Indicators

The conceptual framework focusses on the improvement of agrobiodiversity on different levels and by doing that it implicitly assumes that this leads to an increase in resilience and biodiversity elsewhere (Figure 4). This is supported by literature, but the extent of improvement has yet to be determined. This requires the development of simple indicators of biodiversity and of farm performance (for production and economics) for the four pillars above. There are several studies on biodiversity indicators, or even wider sustainability in agriculture. A survey of the literature indicates 500 indicators for sustainability in agriculture that occur one or more times in different systems (certification, etc.; [9]). This indicates that as yet there is no single set of indicators available that can easily be used in practice. Our conceptual framework might provide a basis to derive verifiable indicators at the four pillars and therewith form a basis for measures of biodiversity enhancement and building farm resilience. It should be realized that these are region specific because regional circumstances, environments and ecosystems determine the potential biodiversity.

The conceptual framework requires a limited set of integral key performance indicators (KPIs) that can be used for management purposes and for monitoring progress. In a recent assessment [76] a set of 17 KPI's were identified for dairy farming which should all be followed and then could be used to integrally optimize the system and to monitor progress and results. We propose to reduce these to a limited set of primary KPI's which are needed to integrally manage the system in such a way that it induces measures that lead to improvement of different other parameters. An example is the % protein from and % manure to own land. If the aim is to set this % very high (from currently 60 to 90%), the farmer has to optimize the nutrient cycles, manage the grasslands in such a way that it yields highest productivity (type and age of grassland, rooting, water management, etc.), resulting in improved soil, organic matter content, biodiversity, water quality and emissions. These KPI's are now tested in practice.

9. How to apply and use the conceptual framework?

How a concrete development plan for (functional) biodiversity looks at an individual farm depends on several factors? First, it is important to clarify what is already realized in terms of management and where there is room for improvement for the farmer and for biodiversity. The personal ambition and inspiration of the dairy farmer plays a major role. Additionally, a checklist can make clear where current utilization of functional biodiversity is strong or weak (see e.g. www.biodiversiteitsadvies.nl).

The Development plan for biodiversity can be prepared by the farmer with other interested parties. In the Development plan, the farmer determines the concrete measures leading to improved biodiversity. The choice of measures depends on the eventual fees or other incentives available for the preservation and promotion of biodiversity.

It is important to know where the farm is located geographically, which provides the maximum possible level of biodiversity given the region, soil type, source areas, etc. Then the farmer determines his or her level of ambition (partly dependent on financial capacity and incentives or rewards for biodiversity promotion). This level of ambition must be in agreement with the goals of other stakeholders in the region (water managers, ecological zones, tourism/recreation, etc. [77]. The level of ambition then determines which clusters of measures are applicable.

Management of biodiversity in agriculture is all about the knowledge and experience of the farmer [78]. A shift back from sensor, monitoring tools and indicator management (control) to knowledge intensive management together with technological support is essential (e.g. [77-79]). Farmers have to regain the knowledge about the ecological processes and drivers that enable production of enough and healthy food. This can be done in two ways, both based on agronomic knowledge: reducing the external input (and the dependency on these inputs) to as low as possible requirements for the system to optimal function and be resilient (precision agriculture). The second option is to start optimizing the system without external inputs and gradually increasing the production using agronomic knowledge and necessary external inputs. When the optimum is reached it can be decided to add external inputs to further increase its productivity searching for the resilient limits.

10. Conclusion

A paradigm shift is needed in agriculture to stop the large-scale loss of biodiversity in the agricultural landscape and soil, but even more than that to rethink the use of the role of soil life, landscape elements and biodiversity in sustainable agriculture. In Europe, where long-term data are available it is shown that most species are in decline. For some species as birds, butterflies and insects the speed and extend of decline is alarming. In hotspot intensive agricultural areas such as the Netherlands for some years policies have been implemented that should help improve the situation (manure policy, nitrate directive, air quality, nature protection...). While in the semi-natural areas this has led to some success stories and species decline is stopped or reversed, this is not the case in agricultural areas. Here a steady decline is still observed. The agricultural intensification which focuses on increasing productivity per hectare or per unit input (such as feed) is the main cause of the decline. Apparently we reached a tipping point where rethinking our agricultural practices is needed in the face of sustainability and production of food. There are different successful initiatives, but a large scale change is not observed.

At present, the risks in intensive agriculture are managed by a so-called (risk) control model based on externalities, with important side effects such as risks of social costs and decreased function of natural processes. In a resilient system risks are lower, reducing costs and increasing biodiversity. Adaptive risk management is most successful when a portfolio of measures is taken. This can be achieved by focusing on four interconnected levels of biodiversity for sustainable management of ecosystem services (Functional (agro)biodiversity; Landscape diversity; Specific species management; and Source areas and connection zones).

The conceptual framework provides a basis to derive strong indicators at the four levels and therewith forms a basis for measures of biodiversity enhancement and building farm resilience. These levels provide also the basis for a system of reward or other incentives. Such incentives could be based on the relative size between maximum achievable and current biodiversity in an intensity class of the farm and taking into account the current level of biodiversity.

The framework focusses on the use and management of biodiversity to improve productivity in agricultural system along with sustainability and therewith on lowering the long term risk of production loss. By managing (bio)diversity in agriculture, sustainable agriculture can contribute to reaching several Sustainable Development Goals.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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