VERBINDUNGSSTELLE VLI LANDWIRTSCHAFT-INDUSTRIE E.V.

Ecological Sustainability of German arable farming

Scientific study on order of VLI
prepared by

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Abbreviations

USLE	Universal soil loss equation
AL	Arable land
BBodSchG	German Soil Protection Law
BMELV	Federal Ministry of Food, Agriculture and Consumer Protection
BMEL	Federal Ministry of Food and Agriculture
f. e.	For example
EO	Economic orientation
o. r.	or rather
CF	Carbon footprint
CO	Carbon dioxide
C_{org}	Organic carbon
DirektZahlVerpflV	Regulation on the Principles of Conservation of Agricultural Land in a Good Agricultural and Ecological Condition
DtM	Digital Terrain Model
dt	Deciton
eq	Equivalent
e.V.	Registered Association
CHC	Chlorinated hydrocarbons
GU	Grain unit
Gpp	Good professional practice
if applicable	if applicable
GIS	Geoinformation system
GJ	Gigajoule
GU ha^{-1}	Livestock units per hectare
GW	Groundwater
GWP	Global warming potential
Heq	Humus equivalents
ha	Hectare
HU	Humus units
FHC	Fluorinated hydrocarbons
INL	Private Institute for Sustainable Land Management GmbH
incl.	including
JKI	Julius Kühn Institute Braunschweig
kg	Kilogram
km	Kilometre
km^2	Square kilometre
KTBL	Association for Technology and Structures in Agriculture
LCA	Life-cycle assessment
AL	Agricultural land
LfULG	Saxon Regional Institute for Environment, Agriculture and Geology
LLH	Hess Department of Agriculture
MJ	Megajoule
N	Nitrogen
NAP	National Action Plan on Plant Protection
NH_3	Ammonia
NH_4	Ammonium

NIR	National Inventory Report (Nationaler Inventarbericht)
N_2O	Nitrous oxide
N_{org}	Organically bonded nitrogen
NO_3	Nitrate
P	Phosphorus
PIX	German Plant Protection Index
P_2O_5	Diphosphorus pentoxide
REPRO	Model for analyzing ecological sustainability
SF_6	Sulphur hexafluoride
GHG	Greenhouse gases
TM	Dry mass
t	Ton
TI/vTI	Thünen Institute
TLL	Thuringian Regional Office for Agriculture
UBA	Federal Environment Agency
a.m.m.	and many more
VDLUFA	Association of German Agricultural Investigation and Research Center
cf.	compare (confer)
SS	Supply stage
WRRL	Water Framework Directive
WF	Weighting factors
VLI	Liaison Office for Agriculture and Industry inc.
f. e.	For example
part.	Partly

Summary

In the last years, sustainability became a relevant issue in all areas of society. As a user of finite resources and exploiter of usable areas in this country, agriculture is particularly required to demonstrate performances in terms of sustainability.
To evaluate the sustainability of agricultural production at individual farms from a scientific point of view, the Verbindungsstelle Landwirtschaft-Industrie e.V. (Liaison Office for Agriculture and Industry inc.) (VLI) initiated a project for „Analysis of ecological sustainability of German farms“ in 2014. The aim of this project was the analysis of farms in terms of environmental impacts of raw materials production. For this purpose, 32 farms were analyzed with regard to their agricultural practices in four regions (North, East, South, West). To compile a transparent sustainability profile, nine agri-environmental indicators were calculated and evaluated. The calculation of these indicators was made by Privates Institut für Nachhaltige Landbewirtschaftung GmbH (Private Institute for Sustainable Land Management) Halle/Saale (INL) with the aid of the model REPRO.

In the first part of the project, statistical data were initially investigated with regard to the farm structures specific for the federal state in order to fundamentally aggregate the planned project regions North, East, South and West. Then, the regional project farms were canvassed on the basis of defined selection criteria (main occupation, conventional run of business, good data maintenance). As the participation was voluntary, hot-spot-regions might have been underrepresented.

After the survey of the cultivation data for three whole cultivation years, the following agri-environmental indicators could be calculated and evaluated at each farm:

- extended nitrogen balance in kg N ha^{-1}
- corrected phosphorus balance in kg P_2O_5 ha^{-1}
- dynamic humus balance in kg C ha^{-1}
- plant protection intensity as a treatment index
- energy balance in MJ GE^{-1}
- erosion by water in t ha^{-1} a^{-1}
- harmful soil compaction as a load index
- and bio-diversity consisting of 11 partial indicators.

After that, the results were aggregated: for the defined regions on the one hand and as a total average result for the project farms with regard to each calculated indicator on the other hand. In order to be able to make a statement on the sustainability of production, the results of indicators were valuated at the end of the research. For this purpose, the actual values of the farms were transferred into scores between 0 and 1 by using valuation functions. In this system, the score 1 stands for an optimum state and the 0 for a non-tolerable one. The score 0.75 was specified as a threshold for sustainable agricultural practice. This means that all results from 0.75 and above it have to be regarded as sustainable.
This procedure took place for each indicator separately, whereby the applied valuation functions are scientifically well-founded and socially discussed.
In the last work stage, the evaluated results of the indicators were compressed into a single value in order to be able to illustrate the sustainability profile of the project farms.

Nitrogen

The extended nitrogen balance balances all nitrogen amounts supplied to or taken away from the plots (subplots). Apart from the N-amounts from fertilization, N-immissions from the air and symbiotic nitrogen fixation were taken into consideration. Nitrogen balance gives a possibility to make statements on the supply of soil with nitrogen on the one hand and on appearing potential losses and thus potential environmental impacts on the other hand. The *average* balance identified at the project farms was *71 kg N* ha^{-1}. The comparison of the regions shows the following N-balances: 92 kg N ha^{-1} for the region North, 63 kg N ha^{-1} for the region East, 64 kg N ha^{-1} for the region South and 59 kg N ha^{-1} for the region West. The N-balance value of *0.78* was reached for *all farms* by using valuation function. The present results refer explicitly to the project farms, so that certain problematic regions cannot be differentiated.

Phosphorus

The nutrient balancing for phosphorus is also (sub)plot-related. Additionally, a correction by plot-specific soil categories (nutrient supply stages) is made after the calculation of P-balance. The calculation of the corrected phosphorus balance resulted for *the project farms in an average of -15 kg* P_2O_5 ha^{-1} and in the following balances for each region: North 31 kg P_2O_5 ha^{-1}, East -29 kg P_2O_5 ha^{-1}, South -25 kg P_2O_5 ha^{-1} and West -45 kg P_2O_5 ha^{-1}. Subsequent valuation of balances leads to the conclusion that soils are sustainably supplied with phosphorus at *all project farms* with a value of *0.80*.

Humus

Assessment of soil fertility is difficult merely on the basis of humus content and requires a comprehensive consideration of agricultural practices. For this reason, dynamic humus balancing was applied in this research. A balance of *-124 kg C* ha^{-1} was obtained for *all project farms*. The balance results for the regions are: North -106 kg C ha^{-1}, East -79 kg C ha^{-1}, South -179 kg C ha^{-1} and West -152 kg C ha^{-1}. The valuation of the total result with a value of *0.58* shows that the supply of soil with humus is in sum improvable at *all project farms*. Over a long period, the soil fertility will be reduced by this agricultural practice. Furthermore, soil structure is likely to be damaged due to the lower humus contents. Combined with extreme weather events, this can lead to erosion. Load-bearing capacity of soils will be affected as well, thus harmful compaction can increasingly appear.

Crop protection

The indicator of the intensity of crop protection aggregates different key figures for application of pesticides. This includes the number of applications controllable by the farmer, applications on subplots and concentration of application. A grain-specific treatment index was shown and compared with the data from the Neptun-surveys of the Julius Kühn Institute. Then, the indices were valuated. The average value of the project farms was 0.66, whereby the results of the individual farms were between 0.33 and 0.88. The regional grain-specific average value is 0.80. Consequently, it is important to point out the principle of integrated crop protection to the farms with a lower value than this one. In addition, it could be concluded that crop protection strategies of the individual project farms have not yet been optimized regarding nitrogen utilization related to yield formation.

Energy

Energetic efficiency of production is calculated as energy intensity, whereby the energy required (directly and indirectly) is compared with realized gains, shown as a grain unit. The following results were obtained for all project farms and regions: *all project farms 162 MJ* GE^{-1}, North 165 MJ GE^{-1}, East 187 MJ GE^{-1}, South 142 MJ GE^{-1} and West 144 MJ GE^{-1}. Subsequent valuation results in a score of *0.98* for *all farms* and shows high energy efficiency at the investigated farms. This valuation also shows that operating materials are applied in a way that resources are conserved at the investigated farms.

Greenhouse gases

All relevant nitrogen, carbon and energy flows are involved in the balancing of greenhouse gases depending on site and cultivation conditions. All climate relevant emissions are recalculated by means of Global Warming Potentials (GWP) into CO_2- equivalents and balanced. Referring to the produced grain unit, greenhouse gas emissions in kg CO_2 for all project farms and for the regions are as follows: *all project farms 29 kg* CO_2 GE^{-1}, North 27 kg CO_2 GE^{-1}, East 32 kg CO_2 GE^{-1}, South 30 kg CO_2 GE^{-1} and West 28 kg CO_2 GE^{-1}. According to the valuation function, these results have been valuated for all farms as sustainable (*all project farms 0.76*), even though increased CO_2 emissions can occasionally arise.

Harmful soil compaction

The load index calculated at farm level is composed of various influence factors. At first, the potential compaction risk and trafficability are determined by stability of soil structure and by up-to-date water contents in soil. In addition, the pressure generated on the ground during the applications of machinery (vehicle crossings) has considerable influence. Here, the weights of the vehicles, the tire sizes and the tire inflation pressure play a decisive role. The risk of aggregated compaction is expressed as a stress index throughout all stages of cultivation process. For *the project farms,* an *average* index of *0.09* was calculated, broken down by region as follows: North 0.10, East 0.10, South 0,06 and West 0.10. In the end, the valuation of the results provides information about the risk of compaction. An *average* value of *0.77* was obtained for *the project farms.* This result shows that the methods are sufficiently adapted to real soil conditions and that compaction is hardly to be expected.

Erosion by water

At a farm, erosion risk of the soils was calculated as an average annual soil loss in t ha^{-1} a^{-1} by means of Universal Soil Loss Equation (USLE). The major influencing factors are: slope length and inclination of surface, soil coverage ratio as well as the location-specific parameters such as daily precipitation amount and soil type. The *average* potential soil loss *at the project farms* is *0.67 t* ha^{-1} a^{-1}. The values for the regions are as follows: North 0.43 t ha^{-1} a^{-1}, East 0.56 t ha^{-1} a^{-1}, South 0.83 t ha^{-1} a^{-1} and West 0.98 t ha^{-1} a^{-1}. The subsequent valuation shows that all *project farms (average score 0.98)* are optimally protected against water erosion. Despite the obtained result of 0.98 and the corresponding optimal protection of soils against erosion by water, small-scaled erosion effects (discharge paths, steep slopes etc.) cannot be excluded.

Biodiversity

The valuation approach for biodiversity is a qualitative approach which considers eleven indirect indicators. In the process of calculation, there was no recording of species of plants and animals on the areas; the potential of the farm in the use and maintenance of biodiversity was rather estimated on the basis of the cultivation data. Three influenceable areas of activity – structures, input and measurements – were mapped. The eleven differently weighted partial indicators show the farm´s biodiversity potential. For *the project farms, an average* estimated value of *0.64* was calculated. This suggests partial deficits in biodiversity performance.

Sustainability is to be understood as a comprehensive overall concept. Statements on sustainable or un-sustainable agricultural practices can be made both for the average of the project farms and for individual project regions only after all individual indicators are calculated. Taking into account all examined individual indicators, the *average factor for all project farms* results in *0.77*. The defined sustainability threshold of 0.75 is not undershot, so that ecologically sustainable way of farming can be attested. This is also true for the individual regions, as their scores of 0.75 (North), 0.80 (East), 0.77 (South), 0.75 (West) are all above the sustainability threshold.

1. Introduction

The term „sustainability“ is omnipresent and of overall social importance in the 21st century. Sustainability is considered as an overall concept that combines ecological, economic and social basic ideas, which shape general orientation. As an elementary component of transparent economic approach, sustainability needs also to be considered in the agricultural sector. In social perception, relevant environmental impacts come from the land management. Therefore, they need to be recorded, analyzed and then valuated by means of recognized and transparent methods. There arises a question, how sustainability can be measured and valuated on the one hand and which data of production are required or available for this purpose on the other hand.

To illustrate the sustainability of German agriculture by way of example, this project was initiated by the Verbindungsstelle Landwirtschaft-Industrie e. V. (Liaison Office for Agriculture and Industry inc.). The objective was to analyze typical farms in four different regions (North, South, East, West) with regard to the environmental impacts of agricultural production, particularly of crop cultivation. Some farms also produce livestock products, but livestock farming is rather below average in 32 farms. Further studies of ecological sustainability in the livestock hot-spot regions should be carried out.

The analysis period is three cultivation years.

To select the farms, statistical data were evaluated in advance in order to obtain a realistic picture of the agricultural regions. The parameters considered were the size of the farm, the scope of crop cultivation, region-specific yields and livestock if practiced. Alongside with soil climatic conditions of natural areas, these parameters also considerably influence the sustainability profile of the farms.

The available cultivation data of the project farms were processed and valuated with the help of the model REPRO on the basis of relevant ecological sustainability indicators. The valuations of the environmental indicators adopted for the individual farms permit a comparison between the agricultural enterprises within and between the regions.

Finally, the average results of all project farms can be used to provide a statement on sustainability performance of German agriculture in arable farming.

2. Planning sustainability analysis

In order to provide a scientific basis for the analysis of sustainability, a research of statistical data was initially carried out with regard to the federal land-specific farm structures with the aim of establishing four model regions. For this purpose, the internet platform of the Federal Statistical Office DESTATIS was used. For the following aggregation of the federal states (excluding city states), the key figures for cultivation structure and livestock numbers were applied. The regions are represented by the following provinces:

- North: Schleswig-Holstein, Lower Saxony, North Rhine-Westphalia
- East: Mecklenburg-Vorpommern, Brandenburg, Saxony-Anhalt, Saxony, Thuringia
- South: Bavaria, Baden-Wurttemberg
- West: Hesse, Rhineland-Palatinate, Saarland

After the pre-selection of the individual model regions, the 32 project farms were canvassed. There are eight farms in each region, representing the existing operating structures there. Based on the project framework, the following selection criteria have been set for participation in the project:

- Main business
- Conventional cultivation
- No specialized permanent cultivation and horticulture
- Good data keeping and quality in agricultural enterprises (retroactively for three years from 2014).

Both the ministries and state offices or the agricultural chambers as well as the German Farmers‘ Association and the federal state farmers’ associations were involved in canvassing. In the end, the operational pool consisted of around 50 potential practice farms, operating all over Germany, which also had, in addition to voluntary participation, the necessary prerequisites with regard to the cultivation data.
Based on the statistical data and technical discussions, 32 farms were selected from this comprehensive operating tool.

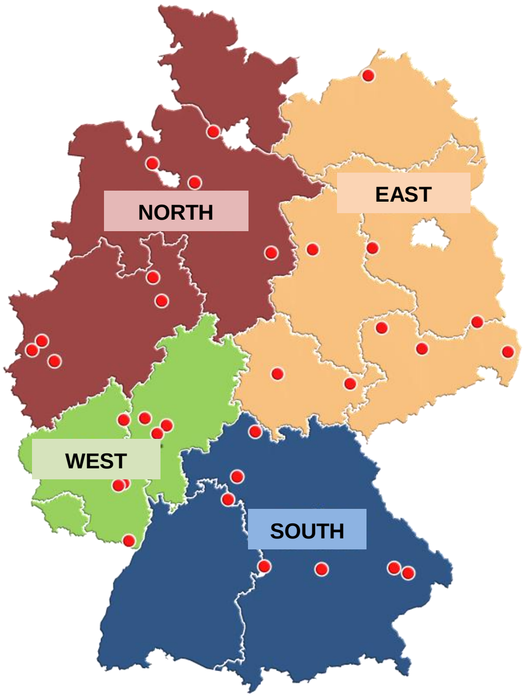


Fig. 1: Distribution of 32 project farms in the regions

3. Model REPRO

The REPRO model is a computer-based accounting model, designed for scientific and practical application. It enables the complex analysis and valuation of sustainability of agricultural operational systems by means of comprehensible methods and informative indicators (HÜLSBERGEN and DIEPENBROCK 1997; HÜLSBERGEN 2003). The networked description of material and energy flows as well as the presentation of the environmental effects resulting from this are the central ideas of the model REPRO. All operating branches are connected to each other via the cycle of materials soil-plant-animal-soil (Fig. 2). Farms are represented in the model REPRO as a whole system by defining and linking the single sections of the farm (site, plant production, livestock farming) as sub-systems. The complete documentation of the production processes at the farms, detailed site data and the model-internal master data form the basis for all evaluations. With the help of these data, a flexible adaptation of the model to real cultivation conditions is possible in the various menu items.

Fig. 2 illustrates the structure of the model REPRO (HÜLSBERGEN 2003).

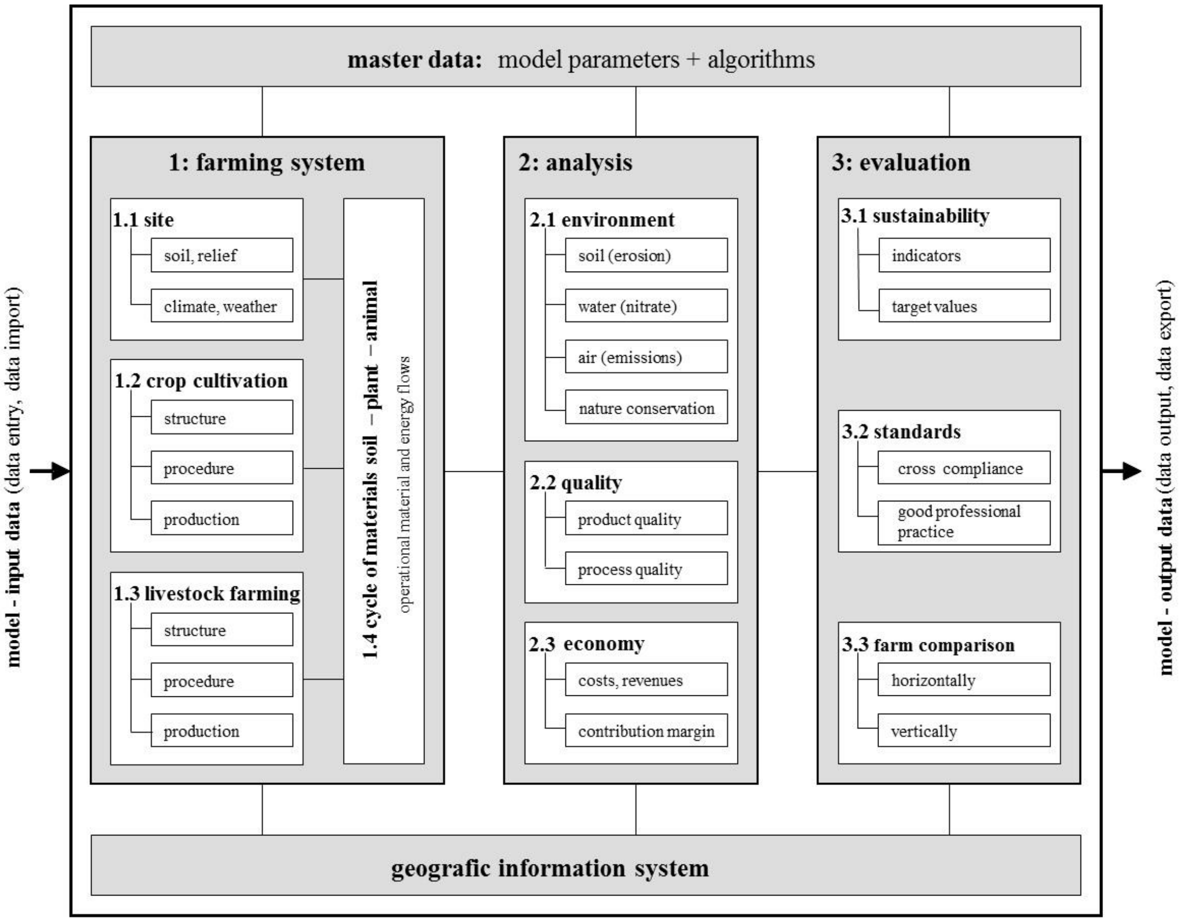


Fig. 2: Structure of the model REPRO (HÜLSBERGEN 2003)

The clear spatial hierarchy in the REPRO model ensures the formation of fully coherent operational systems. The main agricultural activities are recorded at corresponding level. For example, the smallest investigation levels are plot and subplot in the crop cultivation and stable area and herd in the livestock farming. Depending on the research question, cultivation data can be aggregated within the model at a higher level of consideration, such as plot, crop, product, crop rotation and farm level.

The coupling of the modules ensures that all evaluations are corresponding because the same data pool is accessed.

Fig. 2 shows three important work areas. The master data are superimposed on all areas. They comprise model parameters, algorithms and basic data (f. e. composition of fertilizers, active substances of plant protection products etc.). These data are extensible and can be edited by authorized users.

Essential information on the farm is stored in the **work area 1 – farming system,** where the structure, cultivation measures and intensities as well as the location data are managed. It is the central component of the model on which all further analyses are based. To simplify the data input, the program is additionally equipped with the functions for data exchange. The partial work area 1.1 -site- contains plot management with interfaces to GIS and graphical display functions. Information on soil, size of plots and their distance from the farm is recorded by plot (subplot) and year. Site data are required for nearly all model calculations. However, individual models require specific input data.

In crop cultivation, the smallest investigation level is subplot (work area 1.2) with the type of crop and variety cultivated on it and the products produced. For livestock (work area 1.3) this is stable or herd. Data on livestock are sophisticatedly recorded and managed by animal species and production directions, age classes and performance groups. Fodder needs are calculated depending on performance according to grazing or stabling. Depending on feeding, the quantities and the contents of organic fertilizers are calculated. The nutrient losses are determined on the basis of the stable system (solid, liquid dung) and fertilization management. In the menu item 1.4 (cycle of materials soil-plant-animal), the cycles of materials can be aggregated and balanced at different levels (farm, crop, plot etc.). Currently, the analyses for main nutrients (N, P, K), dry mass, grain units and carbon can be carried out.

In the **work area 2**, the effects on abiotic and biotic environment arising from the farm are analyzed. Furthermore, statements are made on economy and quality of the products manufactured based on the information collected. In addition, different methods and indicators are used in the area of environmental impacts.

The overall assessment of the farm is carried out in the **work area 3**. For this purpose, it is necessary to take a comparative look at the indicators obtained in different ways and in different measurement units. The so-called valuation functions are used thereto, which allow conversion of the indicator values with different measurement units into dimensionless scores between 0 and 1. The normalized score 0 means the most unfavorable and the 1 the most favorable situation (=sustainable cultivation). Then the indicators can be weighted and summarized to a total index. The advantages of this method are as follows: different key figures can principally be aggregated, a high degree of transparency with regard to valuation is ensured and the valuation of the results can be displayed as a network diagram. In addition, the comparisons of the farms and temporal consideration of the farm’s development are given as valuation possibilities. However, such an approach does not release from the content-related logical verification with regard to different interactions between the various individual indicators.

DLG Sustainability Certificate

The analysis of ecological sustainability with the use of the REPRO model has already been applied in the certification process of the DLG Sustainability Certificate since 2009. The close cooperation between different scientific institutions and financial support from the German Federal Foundation for the Environment (DBU) enabled the development of this process. In addition to the ecological pillar, the economic and social pillar of sustainability is also being comprehensively analyzed. For being granted the certificate, three years of farming are taken into consideration in order to relativize the single-year effects on the basis of specific weather constellations.

4. Description of sustainability indicators

The project farms of the respective regions were analyzed using the REPRO model. Nine environmental indicators which have a significant influence on different environmental areas were considered in the analysis. This relationship is shown in Table 1.

Table 1: Overview of ecological indicators of sustainability and their impact on various environmental areas (+= close relationship ++= very close relationship)

Indicator	Environmental area				
	Resources	Soil	Water	Air	Biodiversity
Nitrogen balance		+	++	++	+
Corrected phosphorus balance	++	++	++		+
Humus balance		++	+	+	
Plant protection intensity			+		++
Energy intensity	++			+	
Greenhouse gas emissions				++	
Soil erosion by water		++	+		
Harmful soil compaction		++			
Biodiversity potential		+			++

The single indicators were calculated on the basis of the cultivation data from the last three years. Thus, annual fluctuations (f. e. in the nutrient management; weather events) and inaccuracies can be offset.

4.1 Nitrogen balancing

A sufficient supply of plants with nitrogen is an essential prerequisite for high yields with good quality. Besides, nitrogen has more impact on various environmental spheres than any other nutrient. On the global scale, eutrophication is seen as a major environmental problem in addition to the loss of biodiversity and climate change (ROCKSTRÖM et al. 2009, STEFFEN et al. 2015).

Due to its high reactivity, nitrogen is involved in numerous conversion processes in the soil. These processes are significantly influenced by the agricultural use of soils, in particular by mineral and organic fertilization. Whether these fertilizer measures have a negative effect on adjacent environmental areas is dependent on the cultivated type of crop, fertilization intensity and specific N-withdrawal in terms of yield. To minimize the loss paths within the agricultural practice system, farms are obliged to fertilize according to good professional practice (gpp) and to limit the nitrogen surplus to a maximum of 60 kg ha^{-1} (§6 DüV 2006) on a three-year average.

Figure 3 shows the N-balance surpluses for the Federal Republic of the last 23 years, according to which the current surplus (2013) is estimated to be around 63 kg N ha^{-1} a^{-1} (BMEL 2015b).

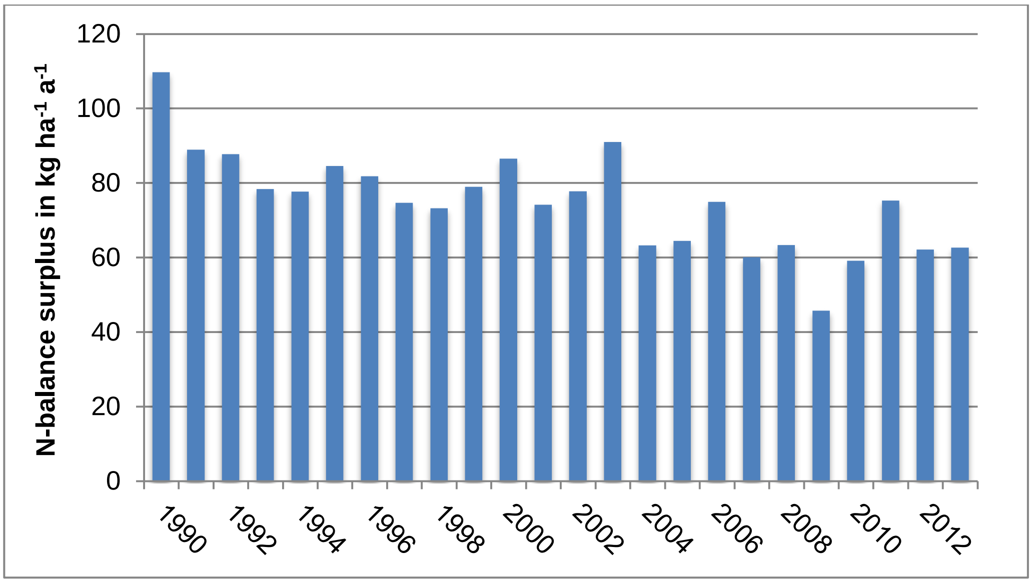


Figure 3: N-balance surplus from 1990 to 2013 in kg N ha^{-1} a^{-1} (BMEL 2015b)

For the analyses of nitrogen balance, various methods and indicators are combined in the model REPRO at different system levels. The aim is to describe coherent operational nitrogen cycles. N-balances, N-utilization rates and N-loss paths are determined on the area-specific basis in order to be able to identify the weak points of the system and stress potentials.

Yard gate balance

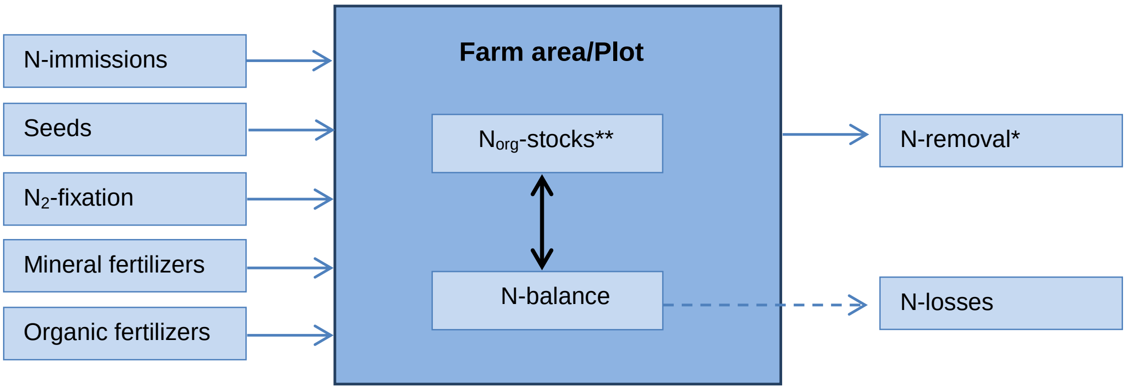
The individual N-supplies from the purchased products and the N-exports via sales products, that go through the yard gate, are balanced in the yard gate balance.

Stable balance

In the stable balance, the N- supplies in the feedingstuffs, straw and purchases of livestock are compared with N-binding in animal products, livestock sales as well as NH_3-losses, rotting and storage losses.

Extended area-related N-balance

In the soil balance (also referred to as area-related N-balance), the N-quantities supplied to and removed from the soil are balanced. The reference area can be a single plot (= plot balance), a crop rotation (= crop rotation balance) or a farm (= farm balance). The area-related N-balance allows to make statements on utilization and efficiency of the fertilizer N as well as on environmental risk caused by N-losses (BIERMANN 1995). The area-related N-balance describes the overall loss potential of reactive N-compounds (NO_3, NH_4, N_2O, NH_3) from the soil. The higher the N-balance, the greater is the risk of environmentally relevant N-emissions into the different environmental areas (water, atmosphere, near-natural biotopes). The area-related N-balance (equation 1) considers the N-flows and N-pools shown in Figure 4.



* N-removal of harvested main products and by-products

** Change in N-stocks in soil (net-mineralisation/-immobilisation)

Figure 4: N-flows taken into account for calculation of area-related N-balance

N-balance is calculated according to the equation 1.

$$S_N = N_I + N_{SYM} + N_{SG} + N_{SD} + N_{OD} + N_{MD} - \Delta N_t - N_E \qquad \textbf{Equation 1}$$

Symbol	Measurement unit	Definition
S_N	kg ha^{-1} a^{-1}	N-balance
N_I	kg ha^{-1} a^{-1}	N-immissions
N_{SYM}	kg ha^{-1} a^{-1}	Symbiotic N-fixation
N_{SG}	kg ha^{-1} a^{-1}	N-supply with seeds
N_{SD}	kg ha^{-1} a^{-1}	N-supply with straw and basic fertilizing
N_{OD}	kg ha^{-1} a^{-1}	N-supply with organic fertilizers from livestock farming
N_{MD}	kg ha^{-1} a^{-1}	Mineral-N-application
ΔN_t	kg ha^{-1} a^{-1}	Change in N-stocks in soil (mineralization, immobilization)
N_E	kg ha^{-1} a^{-1}	N-removal

For better understanding of this kind of balance, the individual elements of N-balance are described below.

4.1.1 N-input

N-immission

N-immissions are explicitly taken into account in the model REPRO. These yield- and environmentally relevant N-supplies are necessary for the most precise balancing, since otherwise the N-losses would be underestimated by this amount. The detailed N-deposition values are based on the survey published by the Federal Environment Office (UBA) in 2002. In this study, the N-deposition values of between 8 and 35 kg N ha^{-1} could be proven for Germany for the investigation period from 1990 to 1999. Within the scope of the continuative UBA-research project PINETI (Pollutant Input and EcosysTem Impact), 9 to 33 kg N ha^{-1} can be calculated on average with the help of the relevant reference data from the year 2009. In continuative literature references, SCHEFFER and SCHACHTSCHABEL (2010) quantify the average N-deposition for Germany at 28 kg ha^{-1}. Due to the wide span between the N-depositions in the literature and in the UBA-mapping, 20 kg N ha^{-1} were calculated for N-immissions in this work paper. This term is particularly important in the calculation of N-balances because administratively used methods do not take it into consideration.

Symbiotic N-fixation

When determining symbiotic N-fixation, a distinction is made in the REPRO model between the different fixed amounts of N_2 contained in the harvested products and those which get into the soil bound in straw and in green manure substance as well as in the crop and roots residues. N_2-binding varies depending on weather factors, soil conditions as well as crop and plant development measures (fertilization, seed inoculation, crop rotation) which have an influence on the development and photosynthesis performance of the legume plants, the survival of rhizobium bacteria in the soil and the effectiveness of the symbiosis (HÖFLICH 1986). Due to the numerous influencing factors, there are also large fluctuations in the data on the fixing capacity of the legume species (cf. SCHILLING 1987, FREYER 2005).

Seeds

In the model REPRO, seeds are calculated from the seed quantity used and the respective seed contents. The necessary information is contained in the master data module „crop types”.

Mineral fertilizer

In the conventional farming, the mineral nitrogen fertilizer represents a decisive input value. The components of the applied mineral fertilizers are stored in the master data, which means that the actual application quantity of the farms is used as the input value.

Organic fertilizer

This balance value takes into account N-supplies from straw and green manure, fertilization with dung, muck, animal slurry and N-input by supply of other organic fertilizers, such as vinasse or compost. The individual components are stored in the master data pool. They are based on the generally represented literature data or are individually adapted to the single farms, when analysis reports on applied organic fertilizers are available.

4.1.2 Change in N-stocks in soil

This factor measures the changes in N-stocks through net mineralization and immobilization taking into account the humus balance. This creates a prerequisite for realistic estimation of N-losses (HÜLSBERGEN 2003).

4.1.3 N-removal

N-removals are shown in each case for the main product and the by-product. The nitrogen removal varies according to the actual harvest quantity and specific N-content in the harvested products.

4.2 Phosphorus balancing

In addition to nitrogen, phosphorus is also an important main nutrient which determines the growth of the plant. Due to its important metabolic functions and highly variable P contents in highly developed soils (SCHEFFER and SCHACHTSCHABEL 1998), it is now also referred to as an essential element (cf. FISCHINGER et al. 2014).

According to the literature, a P-enrichment in topsoils is caused by return of crop residues and fertilization. WERNER (2006) also shows a percentage distribution of the supply stages A to E for arable land in Germany (Table 2). It can be concluded from these values that 41 % of arable land are over-supplied with phosphorus. Therefore, high to very high supply stages have been partly achieved (cf. BMEL 2009).

Table 2: Percentage of individual supply stages of German arable soils (WERNER 2006)

	SUPPLY STAGE				
	A	B	C	D	E
2006	3	18	38	29	12

On the other hand, there are practice data of different federal states, which refer to decreasing P-contents in arable land. Table 3 shows, for example, that there has been a shift in P-supply of Saxonian soils from the supply stage C to B between 1986 and 2011.

Table 3: Percentage distribution and development of P-supply in Saxony/arable soils (LfULG 2013)

	SUPPLY STAGE				
	A	B	C	D	E
1986-1989	3	26	33	30	8
1997-2006	8	32	30	20	9
2007-2011	10	38	30	15	7

The Thuringian Regional Office for Agriculture (2014) points out, too, that 30 to 50 % of arable land have to be classified as the supply stages A and B in the research period 2007-2012 (Table 4).

Table 4: Percentage distribution of P-supply in Thuringia/arable soils (TLL 2014)

	SUPPLY STAGE				
	A	B	C	D	E
2007-2012	13	35	25	15	12

The analyses of the Hess Department of Agriculture (2014) revealed a doubling of the area percentages in the supply stages B with a parallel reduction of the percentages in the supply stages D and E (Table 5).

Table 5: Percentage distribution of P-supply in Hesse/arable soils (LLH 2014)

	SUPPLY STAGE				
	A	B	C	D	E
1998	3	11	33	36	17
2013	7	24	37	23	9

However, the phosphorus contents in agricultural soils are not only influenced by fertilization and retention of the plant organic mass in soil. A significant influence of the agricultural management system (ecological / conventional, dairy cattle farming / cash crop cultivation) could also be shown on the basis of continuous observation experiments (2002-2012) at the location of Trenthorst (Schleswig-Holstein) (PAULSEN et al. 2013).

In the light of these investigation data from the state authorities, it can be concluded that the P-supply of arable soils decreases regionally on the one hand, and there is over-supply with phosphorus in hot-spot regions with livestock farming on the other hand. For these reasons, area-specific balancing is necessary.

In the model REPRO, the phosphorus balance is depicted by entering the plot-related measurement values for the contents of phosphorus in the soil available to plants and by calculating corresponding nutrient balances. The calculation of P-balances includes easy-to-collect cultivation data: cultivated crops, yields of main products and by-products, nutrient removals, mineral and organic fertilization (differentiated by fertilizer type and quality parameters). Finally, a correction is made on the basis of the plot-specific supply class. Equation 2 shows the calculation of the area-related P-balance.

$$\boldsymbol{S_P = P_{SG} + P_{SD} + P_{OD} + P_{MD} - P_E + Correction} \qquad \textbf{Equation 2}$$

Symbol	**Measurement unit**	**Description**
S_P	kg ha^{-1} a^{-1}	P-balance
P_{SG}	kg ha^{-1} a^{-1}	P-supply with seeds
P_{SD}	kg ha^{-1} a^{-1}	P-supply with straw and green manure
P_{OD}	kg ha^{-1} a^{-1}	P-supply with organic fertilizers from livestock farming
P_{MD}	kg ha^{-1} a^{-1}	Mineral-P-application
P_E	kg ha^{-1} a^{-1}	P-removal

4.3 Humus balancing

Soil is the most important production factor in the agricultural management system. It is a finite resource which can be newly formed only very slowly. Currently, 11.9 million hectares (AID 2015) are used for crop farming in Germany, and the farmers are facing high demands. The objective should be preservation of soil fertility for the long term through efficient, sustainable and environmentally friendly land use. These objectives were drafted in the Federal Soil Protection Act (BbodSchG) already in 1996. Since then, they are valid for all land owners and holders of actual authority.

Furthermore, soil is of outstanding importance with regard to national and international climate protection conventions. According to this it is available as a CO_2-sink in order to achieve stable greenhouse gas emissions (BMUB 2015) and to stop climate change. In this respect, a project was initiated by Thünen Institute (TI) in 2011 in order to determine the carbon stocks in German soils on the basis of 3,000 sites. At present, still pending samplings in the southern and eastern federal states as well as laboratory analyses are being carried out. The first results are expected to be available from 2018 onwards.

According to KOLBE and ZIMMER (2016), 45 to 135 t of humus per hectare are contained in topsoil (up to 30 cm) at a humus content of 1 to 3 %. Converted into Humus-C, this corresponds to total carbon stocks of between 26,000 and 78,000 kg C_{org} per hectare.

The principle of humus balancing is based on the fact that the crop-specific humus demand is compared with the humus supply from organic materials. In the model REPRO, this can be done according to four different approaches:

- in the standard mode with fixed coefficients according to LEITHOLD et al. (1997)
- in the extended mode with dynamic coefficients according to HÜLSBERGEN et al. (2000)
- in the LUFA mode according to VDLUFA-STANDPUNKT (2004) for humus balancing; converted into humus equivalents (Heq), where 1 Heq corresponds to 1 kg C in the humidified organic mass of the soil
- with the coefficients within the Cross Compliance Guidelines (Heq).

In the present study, the humus balance was based on the humus units- (HE)-method according to HÜLSBERGEN et al. (2000). The metering scale is the „humus unity“, defined as 1 t humus with 50 kg N and 580 kg C.

The calculation of the humus balance (equations 3 to 8) involves various cultivation data: cultivated types of crops, yields from main products and by-products, nitrogen withdrawals, mineral N fertilization and organic fertilization (differentiated by fertilizer types and quality parameters).

$$H_{BS} = H_{BB} + H_{HM} + H_{SD} + H_{OD}$$ **Equation 3**

$$H_{BB} = \sum_{i=1}^{n} \left(\frac{\mathrm{AF}_{HZi} * \mathrm{k}_{HZi}}{AF} \right)$$ **Equation 4**

$$H_{HM} = \sum_{i=1}^{n} \left(\frac{\mathrm{AF}_{HMi} * \mathrm{k}_{HMi}}{AF} \right)$$ **Equation 5**

$$H_{NB} = H_{BB} + H_{HM}$$ **Equation 6**

$$H_{SD} = \sum_{i=1}^{n} \left(\frac{\mathrm{AF}_{SDi} * \mathrm{SD}_{i} * \mathrm{k}_{SDi}}{AF} \right)$$ **Equation 7**

$$H_{OD} = \sum_{i=1}^{n} \left(\frac{\mathrm{AF}_{ODi} * OD_{i} * \mathrm{k}_{ODi}}{AF} \right)$$ **Equation 8**

Symbol	Measurement unit	Description
H_{BB}	HE ha^{-1} AF^{-1}	Gross need for humus
H_{HM}	HE ha^{-1} AF^{-1}	Humus compensation from humus-producing crops
H_{NB}	HE ha^{-1} AF^{-1}	Net need for humus
H_{SD}	HE ha^{-1} AF^{-1}	Humus compensation from straw and green manure
H_{OD}	HE ha^{-1} AF^{-1}	Humus compensation from organic fertilizers
H_{BS}	HE ha^{-1} AF^{-1}	Humus balance
AF_{HZ}	ha	Arable land with humus-consuming crops
AF_{HM}	ha	Arable land with humus-producing crops
AF_{SD}	ha	Arable land with straw or green manure
AF_{OD}	ha	Arable land with organic fertilization
AF	ha	Arable land (total)
SD	dt FM ha^{-1}	Amount of straw and green manure applied per unit area
OD	dt FM ha^{-1}	Amount of organic fertilizers applied per unit area
k_{HZ}	HE ha^{-1}	Balance coefficient for humus-consuming crop
k_{HZ}	HE ha^{-1}	Balance coefficient for humus-producing crop
k_{SD}	HE dt^{-1} FM^{-1}	Balance coefficient for straw and green manure
k_{OD}	HE dt^{-1} FM^{-1}	Balance coefficient for organic fertilizers

4.4 Intensity of plant protection

Plant protection is one of the most important measures for exploiting and safeguarding the yield potential of cultivated plants. The average yields of our most important cultivated plants have tripled since 1950; and the current annual growth in grain yields is between 0.5 and 0.9 dt ha^{-1}. The proper use of plant protection products is a key factor in this development. Aside from the safeguarding of plant growth by plant protection measures, the fluctuations of yields were reduced between the cultivation years, according to the INL analyses. Comparing the findings of the previous years (before 1990) with the current data, the spread of the annual yield dates decreased for winter wheat from about 21 % to about 13 % and for maize from about 40 % to 19 % (HEYER 2013).

The desired effects of plant protection are achieved through the measures in the cultivated landscape. They are intended to control the appearance of harmful organisms or to achieve a better adaptation of the crop to risky environmental conditions (cold, wind, water deficiency). By optimizing the growth conditions for the crop and exploiting the crop yield potential given in breeding term, the crop protection measures have also impact on the nutrients balance and contribute to the efficient use of plant nutrients. Latterly, the CO_2-binding of the crop is also influenced by safeguarding of yield (HEYER et al. 2010).

However, the aforesaid positive effects of plant protection can be overlapped by rather negative effects, when the application of plant protection products is not carried out properly or is not adapted to yield expectations. The latter indicates that both too little and too much use of plant protection products has to be seen as negative.

Thus, the optimization of the use of plant protection products and the prevention of negative effects on environmentally protected goods is an important objective, when looking at the sustainability of agricultural production.

Optimization of use of plant protection products was in particular highlighted with the reorganization of Plant Protection Act on the basis of Directive 2009/128/EG in February 2012 by reintroducing the administrative and professional framework of good professional practice and integrated plant protection in Section 2 of the Act. To implement and control these targets, an action plan for a sustainable use of plant protection products was initiated. At the same time, the responsibilities for the implementation of the „National Action Plan on Plant Protection (NAP)“ (BMEL 2013) have been defined.

In addition to the registration of the current situation in various areas (f. e. user protection, water protection or land productivity) and to the formulation of priority targets (f. e. water protection, consumer protection, food safety and ecosystem) the action plan contains the defined parameters – the so-called indicators. They are used to check regularly whether the formulated objectives have been achieved. All 28 indicators are summarized in the German Plant Protection Index (PIX). Plant protection products in ground water (GW), SYNOPS risk index for non-target organisms (aquatic and terrestrial) or the share of areas/farms with ecological agriculture are just examples here. The selection of individual examples shows that many of the listed indicators are not directly related to the plant protection measures carried out at the farm. They do not give any reference points for the assessment or optimization of plant protection. However, they are important for valuation of European objectives in connection with the Water Framework Directive (WRRL) or the network Natura 2000.

The NAP framework also provides indicators for the monitoring of plant protection at farms, f. e. yield securing through plant protection, land efficiency and treatment index.

The indicators <yield securing> and <land efficiency> retrospectively cover the performances of plant protection by comparing production systems (or experimental areas) with and without securing plant protection measures as well as given yield performances per hectare. As a rule, direct yield growth through plant protection cannot be derived on the individual farm basis, because crop comparisons with or without plant protection or the comparison of different plant protection strategies are not possible. Neither seems the provision of such data to be possible for most farms.

Therefore, the treatment index was used in the present project. This indicator has some advantages for the assessment of plant protection which are characterized as follows:

The indicator aggregates various parameters for the use of plant protection products, such as the number of applications carried out, applications on subplots and the actual application concentration. These parameters can be controlled by the farmer, and the indicator can be determined for all types of crops and plant protection product groups according to the uniform mathematical formula (HEYER et al. 2005; HEYER and CHRISTEN 2009) (Equation 9). At this level, it is possible to identify possible weak points in the implementation of plant protection. The indicator alone does not yet allow to make an valuation.

$$\boldsymbol{BI} = \frac{\boldsymbol{Application\ amount * treated\ area}}{\boldsymbol{permitted\ quantity\ of\ plant\ protection\ products * \ total\ area}} \qquad \textbf{Equation 9}$$

4.5 Energy balancing

Almost all agricultural activities are connected with the use of fossil energy. Its efficient use plays a key role in terms of climate protection by conserving natural resources and reducing greenhouse gas emissions. Historically, increases in yields have been accompanied by increase in the use of energy. Yields rose by 70 % between 1927 and 1977. At the same time, the use of energy increased by 54 % (KTBL 2008). The reason for this was the improved availability of operating resources such as fertilizers and plant protection products as well as the increase in work productivity through more powerful machines. At that time, the efficiency of machines was limited. Now, the limiting factor is the cost of energy. For this reason, it is important to make the production process more efficient, in order to minimize the operation costs and to reduce negative impacts on the environment (VDLUFA 2012).
For the analyses and valuation of energy efficiency in the model REPRO, the yield-specific use of energy was calculated as energy intensity according to HÜLSBERGEN 2000, 2003.
All production processes at the plot level are included in the balancing, as exemplary illustrated in Figure 5.

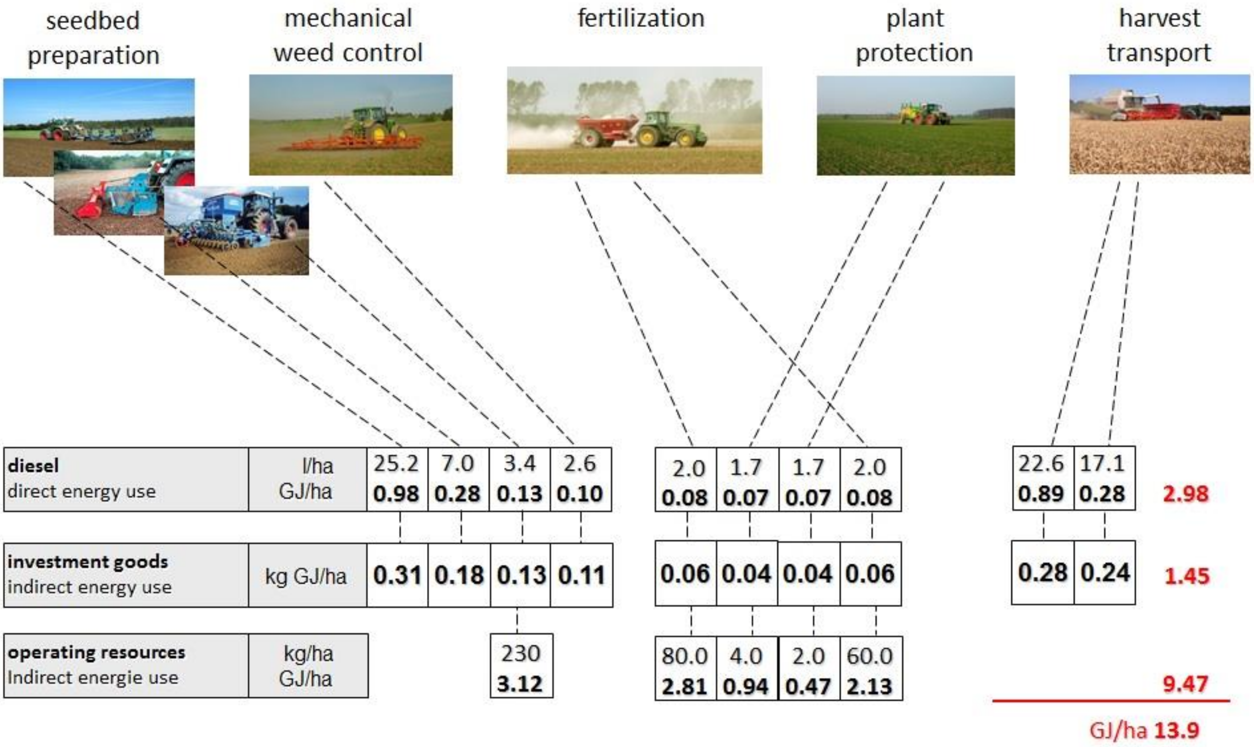


Figure 5: Calculation of energy balance based on direct and indirect energy use (presentation according to Hülsbergen 2003)

The specific machine data, which are individual for each farm, are from the KTBL data collection. They are stored as master data in the program REPRO. The energy intensity can be calculated in relation to the produced grain unit from the equations 10 to 15. Here, the direct use of energy in form of fuel and the indirect use through the production of operating resources (seeds, fertilizers and plant protection products) and investment goods (machines) is taken into account. The input values are converted over the energy equivalents into the primary energy input in Megajoules (MJ) according to Table 6.

The energy performance indicators can be evaluated by the types of crops, crop rotations, arable land and grass land. Energetic expenses for drying, storage, further transport from the farm are not included, just like solar energy and human labor power are not taken into account.

At this point, the grain unit is taken as a measured value according to WOERMANN (1944). It describes the nutritional physiological value of a product unit and ensures the comparability of different types of crops and crop rotations among each other.

Table 6: Energy equivalents of selected operating materials and investment goods

Input value			MU	Energy equivalent	Reference
directly	Fuel	Diesel fuel	MJ l^{-1}	47.8	GEMIS (2002)
indirectly	Operating resources	Mineral fertilizers			
		N (calcium ammonium nitrate)	MJ kg^{-1}	49.10	PATYK & REINHARDT (1997)
		P (superphosphate)	MJ kg^{-1}	40.50	
		K	MJ kg^{-1}	12.70	
		Ca	MJ kg^{-1}	3.35	
		Plant protection products	MJ kg^{-1}	331.80	GEMIS (2002)
		Seeds			
		Potatoes	MJ kg^{-1}	1.30	KALK et al. (1995)
		Winter wheat	MJ kg^{-1}	5.50	
		Winter barley	MJ kg^{-1}	5.50	
		Sugar beet	MJ kg^{-1}	98.00	
	Investment goods	Machinery and equipment	MJ kg^{-1}	108.00	KTBL
		Intra-farm transport	MJ t^{-1} km^{-1}	6.30	KTBL

$$E_i = E_S + E_{MD} + E_{OD} + E_{PSM} + E_M$$ **Equation 10**

$$E = E_d + E_i$$ **Equation 11**

$$EO = EB - EB_S$$ **Equation 12**

$$EOn = EO - E$$ **Equation 13**

$$EI = E / GE$$ **Equation 14**

$$OI = EO / E$$ **Equation 15**

Symbol	Measurement unit	Description
E	GJ ha^{-1}	Energy input
E_d	GJ ha^{-1}	Direct energy use
E_i	GJ ha^{-1}	Indirect energy use
E_S	GJ ha^{-1}	Energy use for seed production
E_{MD}	GJ ha^{-1}	Energy use for production of mineral fertilizers
E_{OD}	GJ ha^{-1}	Energy use with organic fertilizer, substitution value
E_{PSM}	GJ ha^{-1}	Energy use for production of plant protection products
E_M	GJ ha^{-1}	Energy use for production of machinery
EO	GJ ha^{-1}	Energy output
EB	GJ ha^{-1}	Gross energy, physical calorific value of the harvested biomass
EB_S	GJ ha^{-1}	Gross energy of the seed used
EO_n	GJ ha^{-1}	Net energy output
EI	MJ GE^{-1}	Energy intensity
GE	GJ ha^{-1}	Grain units-yield
OI		Output/input-relation

4.6 Greenhouse gas balancing

By signing the Kyoto Protocol in the year 1997, the Federal Republic of Germany committed itself to prepare an annual „National Inventory Report“ (NIR) on the sources and sinks of greenhouse gas emissions (GHG) in Germany from 2005 onwards. Compared to the Climate Summit in Rio de Janeiro in 1992, the special feature of the Kyoto Protocol is, that binding climate protection agreements, which equally apply to all contracting states, were reached for the first time. The objective was to sink the GHG in the form of CO_2 by 21 % compared to the base year 1990. Here, all climate relevant gases (CH_4, N_2O, FCKW, FKW, HFKW und SF_6) were converted into CO_2 equivalents. In 2014, an international review of the target fulfillment by individual contracting states took place, with German even surpassing its target with 23.8 % emission reduction (UBA 2014a). According to the current NIR, the share of agriculture in total emissions is 6.7 % (UBA 2014a). As emission sources, the emissions from fermentative digestion of ruminants, from farm manure management and from agricultural soils are given in the NIR.

However, it is not sufficient to determine the total CO_2 emissions or the CO_2 saving potential globally and nationally for the single sectors. Rather, the question arises, how many CO_2 equivalents are needed to manufacture a product in order to be able to assess the efficiency of production processes. In industry and commerce, ecological balance (Life Cycle Assessment-LCA) is currently being used.

Environmental aspects and effects of production systems (DUNKELBERG et al. 2011) can be analyzed on the basis of standardized methods (according to DIN EN ISO 14040 and 14044). Historical background for the development of life cycle assessment was the increasing consumption of fossil energy and, thus, environmental impacts. The most important partial balance is physical balance, which balances the input and output values, i. e. material and energy flows of a product (f. e. bread, milk) during the entire life cycle. The process data of individual products (incl. the upstream chain) can be called up free of charge via the online database ProBas of the UBA. In addition to the inputs and outputs, the following environmental aspects are considered and available: resources, air emissions, water discharges and waste. Eco-balances can be used both for the definition of limit values and for environmental targets.

Besides the holistic consideration of environmental impacts with the help of LCA, precise statements on greenhouse gas emissions can be made through Carbon Footprint. It is „[…] the sum of all GHG emissions associated with this product “ (OSTERBURG et al. 2009). The calculation includes all the gaseous substances classified by IPCC as climate-relevant.

The evidence of Carbon Footprint creates transparency along the value chain, serves to sensitization and shows potentials for optimizing GHG emissions in the production process (BUNDESVERBAND DER DEUTSCHEN INDUSTRIE E.V. 2010).

Another method, exclusively related to climatic efficiency of agricultural production, was developed by HÜLSBERGEN et al. in 2001. The emissions of climate relevant gases are balanced within the operating system, so that all relevant nitrogen, carbon and energy flows are included depending on location and agricultural practice conditions. The farm structure (number of livestock, crop rotation), the management intensity (material and energy inputs) and the working methods (f. e. soil preparation) are considered as important methods of agricultural practices.

The following approaches are used to quantify the GHG emission (converted into $CO_{2\ eq}$) (equation 16):

- The GHG and energy balances are linked; the direct (f. e. fuel) and indirect (f. e. fertilizers and plant protection products, investment goods) use of fossil energy and the associated GHG emissions are taken into consideration.
- The C storage or release in humus is determined with the humus balance (dynamic approach).

- The N_2O emissions are calculated using the IPCC-approach (IPCC 2006). It is very simply assumed that 1 % of nitrogen supplied to soils by organic and mineral fertilization, N_2-fixation and N-deposition is emitted as N_2O-N. The gaseous NH_3-losses of the fertilizer application remain unconsidered in this view.

According to IPCC, CO_2 and N_2O emissions are converted into CO_2 equivalents [$CO_{2\ eq}$] according to their Global Warming Potential (GWP).

$$\boldsymbol{GHG = \frac{E_{i+N+\Delta C}}{E_o}} \qquad \textbf{Equation 16}$$

Symbol	**Measurement unit**	**Description**
GHG	kg $CO_{2\ eq}$ GJ^{-1}	Greenhouse gas emissions
E_i	kg $CO_{2\ eq}$ ha^{-1}	Energy input
N	kg $CO_{2\ eq}$ ha^{-1}	Nitrogen input
ΔC	kg $CO_{2\ eq}$ ha^{-1}	CO_2-Sequestration (humus pool)
E_O	GJ ha^{-1}	Energy output

4.7 Harmful soil compaction

For long-term maintenance of soil fertility, an intact soil structure is particularly necessary. Therefore, it should be an integral part of suitably adapted cultivation. Thus the BBSchG from the year 1998 stipulates that harmful soil changes, which lead to impairment of soil functions, are to be prevented and, if necessary, the functional capability is to be restored (BBSchG §1f.). From agricultural point of view, this can be achieved through adapted fertilization on the one hand and suitable procedures in the course of vegetation on the other hand. Adapted means, in this sense, adapted to the prevailing state of soil and adjusted to good professional practice. In order to be able to assess the state of soil in the practice, the spade diagnosis is suitable, f. e. according to the scheme of DIEZ (1991). This diagnosis allows, among others, to draw conclusions about harmful compaction by means of assessment of visually presentable parameters, f. e., the form of aggregates.

Soil preparation has the greatest agricultural influence in this process, since the soil structure is influenced directly or indirectly by loosening and re-compacting. In the further production process, soil is submitted to permanent mechanical load, when agricultural machines repeatedly pass over the plots. The dimension of load is essentially dependent on the machine equipment in the farm, in particular on the tires, the tire inflation pressure, the wheel load of the machines, the soil water content at the time of soil preparation and on the prevailing stability of soil structure.

In the model REPRO, the indicator of harmful soil compaction is determined according to RÜCKNAGEL (2007) and RÜCKNAGEL et al. (2015) by means of a stress index for 20 cm and 35 cm soil depth at the farm´s level and presented as compaction risk.

The essential calculation steps are performed in the model REPRO as follows:

- *Stability of soil structure:*
  To assess the stability of soil structure, the standard values for dry bulk density and aggregate density in the lower layer (20 cm) and in the upper subsoil (35 cm) are taken and calculated according to the main soil type. There is a distinction between ploughing and conservative soil tillage. As a correction factor for soil structure stability, the actual soil water content (differentiated by 3 groups of crop types) at the time of the application of machinery was included.
- *Calculation of ground pressure*
  The vertical ground pressure is calculated according to the approach of KOOLEN et al. (1992), i. e., ground pressure is determined as wheel load and tire inflation pressure at the corresponding depth. Analogous to the calculation of structure stability, the actual soil water content at the time of the application of machinery serves as a correction factor for soil pressure calculation.
- *Calculation of load index*
  A dimensionless load index is calculated for each individual application of machinery from the difference between the ground pressure and the stability of soil structure. The value range of the index is ≥ 0 to 1 and indicates the breach of the structure stability with increasing indices. This means that there is a growing load risk per application. In the further process, the individual index values are aggregated up to the farm level.

4.8 Soil erosion by water

Beside the maintenance of soil fertility, the reduction of soil erosion by wind and water is one of the most important cornestones of soil protection.

Due to prognosticated changes in weather conditions and reduced soil coverage ratios on the agricultural sites, a rising erosion risk is prognosticated not only on a global scale but also for Germany according to STEININGER and WURBS (2011). Often, erosion events are a potential source of danger for public life because of heavy rainfalls or strong winds. The starting point is mostly agricultural land due to the constant and partly intensive agricultural practices (FAO 2015). For this reason, erosion protection is of particular importance at the farm. However, in order to be able to undertake the proper preventive measures in the production process, potential soil erosion should be calculated in tons per year. Since 2004, this principle has already been stipulated in the Direct Payments Obligation Ordinance (DirektZahlVerpflV) in § 2. Since then, it has been a criterion for obtaining agricultural direct payments. The calculation basis indicated therein according to DIN 19708: „Soil properties – Determination of erosion risk for soils by water with the help of ABAG“ is reflected in the calculation algorithm of the model REPRO. The application of the Universal Soil Loss Equation (USLE) according to SCHWERTMANN et al. 1990 serves the „[…] realistic [and] quantitative estimation of erosion risk […]“ at a particular location with well-known location characteristics and under consideration of important influencing factors.

$$\boldsymbol{A = R * K * C * L * S} \qquad \textbf{Equation 17}$$

Symbol	Unit	Description
A	t ha^{-1} a^{-1}	Soil loss
R		Rainfall erosivity (heavy rainfall vulnerability)
K		Soil erodibility
C		Factor for soil covering and preparation
L		Factor for slope length
S		Factor for slope inclination

By entering the plot and crop-specific data into the model REPRO, the C factor is determined during the calculation, which is influenced by the type of crop, catch crop and soil preparation (conservation/plough). The allocation of weather stations along with the recording of the daily precipitation data can be used to determine the R factor in the model REPRO. The calculation of the factors L, S and K requires a three-dimensional transformation, which is carried out with the help of the digital terrain model (DTM). As a result, the digital plot profiles in the (GIS data, shape format) terrain model, which are present at the farm, are blended with the present relief, so that both the inclination and the length of the slope can be calculated at a distance of five meters.

Finally, the linkage of the factors determines the average soil loss for each individual plot, which is presented as a weighted average value for the whole farm.

The calculated potential soil loss is then compared with the defined target value and assessed with regard to its risk.

4.9 Biodiversity

Biodiversity plays an important role in discussions about the sustainability of land use systems. In the Convention on Biological Diversity (CBD), the term <biodiversity> includes:

- diversity of species and habitants
- genetic diversity and
- diversity of existing interactions between the organisms and their relation to the environment.

This makes it clear that biodiversity is comprehensively defined and that significantly different methodological approaches are pursued for recording „biodiversity“ depending on the respectively considered area of „biodiversity“ and the respective research objectives.

The model REPRO takes into account the interactions between the cultivation measures and biodiversity (HEYER und CHRISTEN 2009). It is a qualitative approach according to SIEBRECHT and HÜLSBERGEN (2008), which is described by eleven indirect indicators (ROEDENBECK 2004). Under this approach, no types are recorded or counted on the plots, but the potential of the farm is estimated by way of these interactions for benefit and maintenance of biodiversity. The division of the eleven partial indicators into three effective spheres – structures, inputs (intensity) and measures – and their weighting among each other is shown in Table 7.

Table 7: Indirect indicators and weighting factors for calculating biodiversity potential

Biodiversity potential					
Structures (0.5)	**WF**	**Inputs (0.25)**	**WF**	**Measures (0.25)**	**WF**
Use and cultivation diversity (*Use diversity* *Diversity of crop groups* *Diversity of crop types* *Diversity of varieties)*	0.3	Share of arable land without plant protection products	0.125	Soil preparation	0.025
				Harvest	0.1
		Plant protection products-treatment index	0.0625	Greenland use frequency	0.0625
				Frequency of the applications of machinery	0.0625
		Fertilization intensity	0.0625		
Plot size	0.05				
Av. length of the edge	0.1				
Variation coefficient	0.05				

The complexity of an indicator makes it necessary to subdivide the procedure into sub-steps for overall assessment. Each cultivation year is treated according to the following scheme:

1. Determination of the material value for the respective partial indicator at the respective analysis level.
2. Valuation of the material value at the respective valuation level with a specific valuation function.
3. Aggregation of partial indicators based on their weighting to the indicator <biodiversity>.

To calculate the indicator, a weighted arithmetic average is formed from the single cultivation years. Input values are valuation results (normalized values) of the partial indicators with the respective weighting factors. The reference level of the result is the whole farm. The temporal and spatial reference is determined by the partial indicators and the components considered.

Structure

The partial indicators give characteristics for the range of vegetation crops and thus information on biotopes on the cultivated areas. The utilization structure provides information on the offer of different habitats within the farm (niche range). The cultivation structure characterizes the cultivation spectrum (diversity) and the influences of crop types. The size and formation of cultivation areas are described on the basis of the area structure. Increasing area sizes reduce the occurrence of the „remaining areas“ and eco-tones and lead to unification and concentration of use, whereby an increase in environmental pollution is to be expected (cf. HABER 2002).

A) Use and cultivation diversity

For the analyses of use and cultivation diversity, the real values of the applied partial indicators (diversity of use, crop groups, types of crops and varieties) and the corresponding weightings are added to the overall diversity. Then, the aggregated real value is valuated.

The basis for determining the real value of individual partial indicators is the Shannon index (H), which considers not only the number of unities (f. e. types of crops) but also their abundance (share in the totality). For example, the types of use (arable land, grassland, fallow) are considered for the use diversity. For the diversity of the crop groups, the types of use (f. e. arable land) are then split into corresponding subunits (f. e. root crops, grain, …).

B) Area structures

Indicators for the area structure are, apart from the plot size, the edge length and the variation coefficient of the plot size. The partial indicators are based on the data from the digital plot profiles (GIS data). A plot is a documented unit of area. A subplot is a part of the plot managed uniformly as the smallest cultivation unit. The mean plot size corresponds to the average value from all subplots.

The edge length is evaluated at the subplot level. In this case, the plot-specific edge length (UR) is related to the circumference of a circle (U_K) and a square (U_Q) with the same size of area as the plot (Equation 18, 19).

$$U_Q = 4 * \sqrt{A}$$ **Equation 18**

$$U_K = 2 * \pi * \sqrt{A/\pi}$$ **Equation 19**

Symbol	Unit	Description
U_Q	m	Circumference square
U_K	m	Circumference circle
A	m²	Subplot size

The variation coefficient is calculated as a further partial indicator according to Equation 20.

$$\mathit{Variation\ coefficient} = \mathit{Standard\ deviation} / \mathit{Mean\ value}$$ **Equation 20**

Inputs

Inputs characterize the environmental impacts of the farms, which act in the form of material components and influence the quality of biotopes or niches. Potential effects are eutrophication and stress caused by plant protection products (cf. GEIER & KÖPKE 2000; BASTIAN & SCHREIBER 1999). The partial indicators are essentially determined by the intensity of the cultivation system and show therefore high sensitivity to agricultural measures.

A) Share of utilized agricultural land without plant protection products

In order to determine the share of agricultural land without plant protection measures, the subplots of the farm are surveyed according to the implemented plant protection methods. The sizes of the subplots without plant protection measures are added; and the share of the total utilized agricultural area is determined.

B) Overall treatment index

Apart from the recording of the number of applications, the identification of plant protection intensity requires also consideration of application concentrations and of the area treated. The partial indicator <overall treatment index> is determined analogously to the procedure for the standardized treatment index. However, valuation is carried out at the subplot level by means of a uniform valuation curve, which was especially developed with regard to biodiversity. Finally, the weighted average of the valuations is calculated for the whole farm.

C) Fertilization intensity

Changes in the nutrient balance and the intensity of agricultural practices can be estimated by supply of mineral and organic fertilizers. For analyses of the partial indicator <fertilization intensity>, the subplot-specific amounts of the overall supply of mineral N are calculated. The mineral-acting nitrogen of the farm manures is added on the basis of the master data of REPRO to the overall supply after the deduction of application losses.

Measures

The partial indicators from the group <measures> register the effects which have direct or indirect impacts on biodiversity. Direct impacts are those which have an effect on the organism during or immediately after the application of the measure. They are the result of physical-mechanical, chemical effects (contact with the organism) or disturbances (perception). However, the indirect impacts are determined by the fact, that they arise by changing resources (food chain), changing site/habitat or by interaction with other organisms. In contrast to the direct effects, they do not have direct temporal relation (cf. PROCHNOW & MEIERHÖFER 2003, BENTON et al. 2003).

A) Process diversity soil preparation resp. harvesting

Harvesting and soil preparation particularly lead to drastic changes in the development status and vegetation structures of the areas. This can lead to a lack of retreats, particularly in the case of large farming units or synchronization of agricultural practices on several operating areas, which limits the habitats of organisms (see HEYER & CHRISTEN 2005; BENTON et al. 2003). The more areas are in the same development status, or the more areas, on which measures are carried out at the same time, the lower is the niche offer.

B) Frequency of use and application of machinery

The analysis of these partial indicators is also based on the processes recorded at subplot level. In order to determine the frequency of use, all agricultural areas with multi-cut crops are surveyed (grassland, field fodder). This area forms the reference quantity. The number of harvests (cuts) is determined, weighted and averaged over the reference area on all subplots considered.

To determine the frequency of the application of machinery, all relevant measures, which require the crossing of the surface by machines, are summed up on the subplots. The subplot-related values are averaged and assessed over the entire arable land.

5. Results

In this Chapter, the results of the indicators will be explained. Firstly, they will be presented for the average of the project farms. Then, they will be divided into the project regions North, East, South and West. The indicators will partly be considered together, since ecological sustainability is a combination of all indicators.

5.1 Operational structures of the average project farm

An average project farm with specific areas and livestock stocking rates could be identified after recording and processing all operating data. These data are summarized as mean values in Table 8 below.

Table 8: Area in ha and livestock stocking rates in LU ha^{-1} of an average project farm (3-year mean of 32 project farms)

Crop groups	**Average of the project farms**	
	ha	%
Grain	217	48
Winter wheat	*117*	*54*
Winter barley	*44*	*20*
Winter rye	*24*	*11*
Triticale	*9*	*4*
Spring barley	*18*	*8*
Oat	*3*	*2*
Others	*2*	*1*
Rape	73	16
Sugar beet	26	6
Potatoes	5	1
Maize	46	10
Forage crops	21	5
Other crops	16	4
Grassland	46	10
Total area	**450**	**100**
Livestock stocking rate	**LU ha^{-1}**	**0.51**

The range of 32 farms varies from 32 ha to 2.610 ha.

In the project network, an average farm has a total area of 450 ha. This area is used to 90 % for cultivation, the other 10 % are available as grassland.

A look at the breakdown by crop group shows the domination of grain cultivation (48 %), followed by rape (16 %), maize (10 %) and the root crops sugar beet and potatoes (7 %). The cultivation of field fodder takes up a further 5 % of the actual cultivation spectrum. The remaining 4 % refer to other cultivated crops, such as pulses and summer wheat and rye.

The average livestock number at the project farms is 0.51 LU ha^{-1}. Since livestock farming was not analyzed for its sustainability performance in the project, this part of production serves as a consumer of plant products for feeding and as a supplier of organic fertilizers for crop production.

5.2 Results of individual indicators – average project farm

The results of the single indicators for the average of the project farms are described below. It is explicitly pointed out that the results presented here are based only on the cultivation data of the project farms selected according to the criteria stated in Chapter 2.

5.2.1 Nutrient and humus balances

The extended nitrogen balance in kg N ha^{-1} and the corrected phosphorus balance in kg P_2O_5 ha^{-1} are presented in the nutrient balance. The results of the humus balance are calculated in kg C ha^{-1} and illustrated, as described, according to the dynamic method of calculation.

Table 9: Extended N-balance in kg N ha^{-1} (3-year mean of 32 project farms, rounded)

Balance element	Unit	Average of the project farms
Nutrient removal, total	kg N ha^{-1}	201
N-immissions	kg N ha^{-1}	20
Seeds/planting material	kg N ha^{-1}	2
Symbiotic nitrogen supply, total	kg N ha^{-1}	4
Organic fertilization, total	kg N ha^{-1}	101
Straw manure	*kg N ha^{-1}*	*24*
Green manure	*kg N ha^{-1}*	*34*
Stable manure	*kg N ha^{-1}*	*4*
Liquid manure	*kg N ha^{-1}*	*33*
Slurry	*kg N ha^{-1}*	*0*
Others	*kg N ha^{-1}*	*7*
Mineral fertilizers, total	kg N ha^{-1}	133
Nutrients supply, total	kg N ha^{-1}	260
Change in nitrogen stocks in soil	kg N ha^{-1}	-12
NUTRIENT BALANCE	**kg N ha^{-1}**	**71**

On the average, the comparison of nitrogen removal and nitrogen supply results in a nitrogen balance of 71 kg N ha^{-1} for the project farms.

A closer look at the nitrogen supply shows that about 51 % of nitrogen comes from the application of mineral fertilizers and a further 39 % from the use of organic fertilizers. The balance value <organic fertilization> includes both straw and green manure as well as applied farm manure. In this respect, the organic nitrogen supply is dominated by incorporation of straw and green matter with about 57 %. A further 33 % is supplied with liquid manure, around 7 % with other organic fertilizers and around 4 % by application of stable manure (solid dung, compost).

In contrast to the simple N-balance calculations (f. e. farm gate balance), N-immissions and symbiotically fixed nitrogen also enter into the balancing in addition to mineral and organic fertilization. Moreover, the mineralization of nitrogen from the humus pool (change in nitrogen stocks in soil) is taken into account in the extended nitrogen balance. By this means, the analysis of all project farms results in an increase of 12 kg N ha^{-1}.

Figure 6 shows how strongly the N-balances of all 32 farms vary from one to another. The lowest extended balance is 27 kg N ha^{-1} and the highest is around 167 kg N ha^{-1} in the 3-year average.

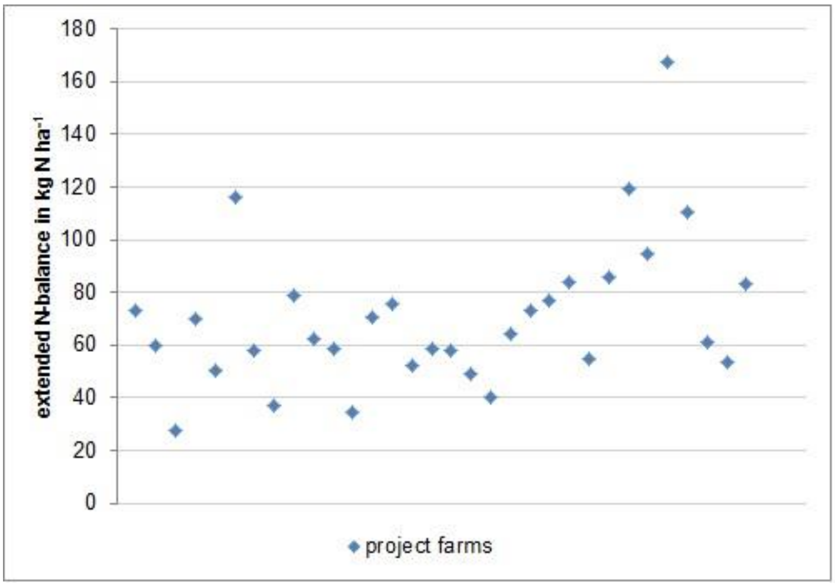


Figure 6: Extended N-balance in kg N ha^{-1} (3-year mean of 32 project farms)

The results of the phosphorus balance presented in Table 10 show that the demand of plants for phosphorus is covered neither by mineral nor by organic fertilization during vegetation. An average balance of -11 kg P_2O_5 ha^{-1} was achieved for 32 farms.

Table 10: P-balance in kg P_2O_5 ha^{-1} (3-year mean of 32 project farms, rounded)

Balance element	**Unit**	**Average of the project farms**
Nutrient removal, total	kg P_2O_5 ha^{-1}	90
Seeds/planting material	kg P_2O_5 ha^{-1}	1
Organic fertilization, total	kg P_2O_5 ha^{-1}	54
Straw manure	*kg P_2O_5 ha^{-1}*	*13*
Green manure	*kg P_2O_5 ha^{-1}*	*11*
Stable manure	*kg P_2O_5 ha^{-1}*	*2*
Liguid manure	*kg P_2O_5 ha^{-1}*	*20*
Slurry	*kg P_2O_5 ha^{-1}*	*0*
Others	*kg P_2O_5 ha^{-1}*	*7*
Mineral fertilizers, total	kg P_2O_5 ha^{-1}	25
Nutrient supply, total	kg P_2O_5 ha^{-1}	79
NUTRIENT BALANCE	**kg P_2O_5 ha^{-1}**	**-11**
Nutrient balance with correction	**kg P_2O_5 ha^{-1}**	**-15**

This existing deficit continues rising with the correction of the balance, explained in Chapter 4, according to the plot-specific supply classes. Thus, the average balance is -15 kg P_2O_5 ha^{-1}.

The realized nutrient supply is covered by organic fertilizers at 68 % and by mineral fertilizers at 32 %. Therefore, more than twice as much phosphorus is supplied with organic than with mineral fertilizers.

In terms of organic fertilization, nutrient supply is determined by 44 % from straw and green fertilization. 37 % are supplied by application of liquid manure and 18 % by spreading stable manure and other organic fertilizers.

On the one hand, the dynamic balance comprises the demand which the farmer can form through cultivation and crop rotation. Furthermore, the plot-specific soil properties and climatic conditions have an influence on the demand of the cultivated crops. These factors cannot be changed by the farmer, because they are location-dependent. However, the farmer can influence the result of the balancing by the supply of organic materials both positively and negatively.

Table 11: Humus balance (dynamic) in kg C ha^{-1} (3-year mean of 32 project farms, rounded)

Balance element	Unit	Average of the project farms
Gross humus demand	kg C ha^{-1}	-667
Increase of humus content	kg C ha^{-1}	25
Seeds/planting material	kg C ha^{-1}	0
Straw manure	kg C ha^{-1}	325
Green manure	kg C ha^{-1}	73
Organic fertilization, total	kg C ha^{-1}	119
Stable manure	*kg C ha^{-1}*	*24*
Liquid manure	*kg C ha^{-1}*	*57*
Others	*kg C ha^{-1}*	*38*
Humus reproduction, total	kg C ha^{-1}	542
HUMUS BALANCE	**kg C ha^{-1}**	**-124**

As far as the humus balance is concerned, humus depletion could be proved on the average for the project farms. It was -124 kg C ha^{-1} on a 3-year average. In addition to organic fertilization, the supply of carbon from straw and green manure is an important component of the balance. The average percentage share of the project farms is about 73 %. Another 22 % of humus-effective carbon compounds come from the application of organic fertilizers, whereby liquid manure and other organic fertilizers are preferably used. The remaining 5 % result from humus increase due to cultivating humus producing plants. In summary, the balance shows that the demand of crops for carbon cannot be fully and sufficiently covered by humus reproduction.

5.2.2 Intensity of plant protection

The calculation of the intensity of plant protection, presented as a treatment index, has already been explained in detail in Chapter 3. In summary, this index value represents a combination of all plant protection measures dependent on the concentration of application and the application area.

Table 12: Treatment indices of the most important main crops (3-year mean of 32 project farms)

Main crop	Treatment index
Winter wheat	5.1
Winter barley	3.6
Winter rye	3.2
Triticale	3.1
Spring barley	3.5
Oat	2.7
Winter rape	6.5
Sugar beet	6.5
Potatoes	12.4
Maize	1.8

In Table 12 the indices of ten most important main crops are summarized.

It can be seen that potatoes are treated most intensively with plant protection products. With a score of 12.4 the treatment index is almost twice as high as for sugar beets and winter rape. At this point, it should be considered of course that the demands of trade and consumers on the product potato are very high. In order to produce high-quality products, intensive plant protection management is indispensable.

Among the grains, winter wheat has the highest treatment index of 5.1. The lowest index is identified for maize.

It can be seen that all crops have different needs for plant protection management, so that valuation between different types of crops is technically not possible.

5.2.3 Energy and greenhouse gas balance

The construction of the energy balance makes it possible to show the energy intensity in MJ GE^{-1}. From this, energetic efficiency of cultivation can be derived with regard to the quantity produced. Table 13 summarizes the results of this calculation and shows individual balance elements.

Table 13: Energy balance in MJ GE^{-1} (3-year mean of 32 project farms, rounded)

Balance element	Unit	Average of the project farms
Binding of energy MP + BP	GJ ha^{-1}	155
Yield MP + BP	GE ha^{-1}	90
Use of fossil energy	GJ ha^{-1}	14
Organic fertilizers, total	*GJ ha^{-1}*	*2*
Mineral fertilizers, total	*GJ ha^{-1}*	*5*
Seeds, total	*GJ ha^{-1}*	*3*
Plant protection products, total	*GJ ha^{-1}*	*1*
Diesel fuel, total	*GJ ha^{-1}*	*3*
Machines and devices, total	*GJ ha^{-1}*	*1*
Energy output	GJ ha^{-1}	154
Energy gain	GJ ha^{-1}	140
Energy intensity	**MJ GU^{-1}**	**162**
Output/Input-relationship		11

The use of fossil energy in the form of direct (diesel) and indirect energy (production of fertilizers, plant protection products, machinery) can be actively influenced by the operational management. Mineral fertilizers have the largest share in the consumption of fossil fuels.
Further offset of the use of fossil energy (converted into MJ ha^{-1}) and the yield in GU ha^{-1} result in energy intensity, which allows to make a statement about the efficiency of production. On average, the project farms have a value of 162 MJ Gu^{-1}.
Another interesting parameter for energy balancing is the relationship between output and input. This shows how much energy is produced per applied GJ. On average, an output/input ratio of 11 was determined for the project farms. This means that 11 times more energy is gained than invested into production.

For the subsequent calculation of the greenhouse gas balance in kg $CO_{2\,eq}$ GU^{-1}, the nitrogen, humus and energy balances provide important balance elements, which are listed in Table 14.

Table 14: Greenhouse gas balance in kg $CO_{2\,eq}$ GU^{-1} (3-year mean of 32 project farms, rounded)

Balance element	Unit	Average of the project farms
C-sequestration*	kg $CO_{2\,eq}$ ha^{-1}	451
CO_2-emissions cultivation	kg $CO_{2\,eq}$ ha^{-1}	990
N_2O-emissions	kg $CO_{2\,eq}$ ha^{-1}	1.161
GHG-emissions (ha)	kg $CO_{2\,eq}$ ha^{-1}	2.602
GHG-emissions (GJ)	kg $CO_{2\,eq}$ GJ^{-1}	17
GHG-emissions (GU)	**kg $CO_{2\,eq}$ GU^{-1}**	**29**

* positive value = C- release from the soil/ negative value = C-storage in the soil

45 % of the total GHG emissions are generated by nitrogen emissions in the form of nitrous oxide (N_2O) from the soil. A further 38 % is emitted by energy usages in the production process. The emissions from the calculated negative humus balance (release of carbon by humus depletion) also correspond to a share of around 17 %. The yield-related conversion of the greenhouse gas emissions results in emissions of 29 kg $CO_{2\,eq}$ per grain unit produced.

5.2.4 Harmful soil compaction and erosion by water

Table 15 shows the results of harmful soil compaction through all process stages in the course of production up to a depth of 35 cm.

Table 15: Threat of harmful compaction to upper subsoil (35 cm) as an index (3-year mean of 32 project farms, rounded)

Balance element or stage of the procedure	Average of the project farms
Soil preparation	0.11
Tillage	0.03
Mineral fertilization	0.11
Organic fertilization	0.10
Plant protection	0.04
Harvest of main crops	0.10
Compaction risk	**0.09**

It can be seen that the stages soil preparation, mineral and organic fertilization as well as the harvest of main crops have a medium compaction risk. Low stress indices were determined for the stages tillage and plant protection on average for the project farms.

In the overall result of the analyses from three cultivation years, the compaction risk of the soils is on average low for the project farms.

An average soil loss of 0.67 t ha^{-1} a^{-1} was calculated for the project farms. Figure 7 shows that the values significantly differ between the project farms. Thus, the lowest soil loss with 0.04 and the highest one with 2.0 t ha^{-1} a^{-1} could be identified during calculation.

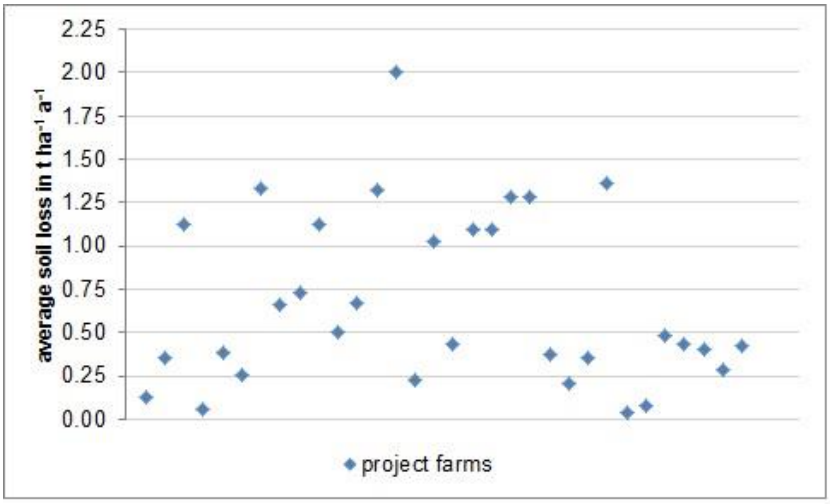


Figure 7: Soil loss in t ha^{-1} a^{-1} (3-year mean of 32 project farms)

5.2.5 Biodiversity

Table 16 summarizes the results of three relevant spheres of influence – structures, inputs and measures – with the respective partial indicators. Since the pure results of the partial indicators cannot give any information about the biodiversity at the farms, the evaluated results are presented in Chapter 5.

Table 16: Results of 11 partial indicators of biodiversity potential (3-year mean of 32 project farms)

Balance element		Unit	Average of the project farms
STRUCTURES	Diversity of varieties		2.68
	Diversity of type of crops		1.45
	Diversity of groups of crops		1.29
	Diversity of use		0.18
	Use-/cultivation diversity		1.02
	Average length of edge	100m	13.92
	Average size of plot	ha	6.42
	Variation coefficient size of subplot	%	100.75
INPUTS	Share of agricult. area without PPT	%	7.18
	Treatment index evaluated		0.30
	Fertilization intensity (nitrogen)	kg ha^{-1}	156.7
MEASURES	Process diversity soil preparation - AL		0.28
	Process diversity harvest		0.17
	Use frequency grassland + field forage	number/$year^{-1}$	1.17
	Frequency of applications of machinery	number/$year^{-1}$	12.14

5.3 Regional farm structures

To be able to discuss the subsequent results, the regional farm structures have been summarized in Table 17 by total area and livestock stocking rate. For this purpose, an average value for each region has been calculated on the basis of the assigned project farms.

In terms of the total size, the largest farms can be identified in the region East and the smallest in the region South. The largest grassland share of 13 % can also be identified for the region East. Regional crop rotations are mainly determined by the cereal crops winter wheat and barley, including both winter and spring barley. In addition to cereal crops, the main cultivated crops are rape, sugar beet, potatoes, maize and forage plants. They have different shares in the crop rotations depending on the region.

The livestock stocking rates in LU ha^{-1} show that the regions North (1.43) and West (0.95) have the highest densities per ha. In this project, the highest livestock density is 5.7 LU ha^{-1}.

At this point, it should be noted that there are certainly districts and regions with much more than 2 LU ha^{-1}. These particular hot-spot regions should be analyzed in further studies with regard to their sustainability performance.

Table 17: Total areas in ha and %; livestock stocking rates in LU ha^{-1} (3-year mean)

	North		**East**		**South**		**West**	
	ha	*%*	ha	*%*	ha	*%*	ha	*%*
Cereal crops	112	*49.5*	507	*45.4*	82	*61.6*	115	*57.8*
Winter wheat	*73*	*32.3*	*250*	*22.4*	*53*	*39.8*	*65*	*32.6*
Winter barley	*8*	*3.5*	*131*	*11.7*	*13*	*9.8*	*11*	*5.6*
Winter rye	*6*	*2.7*	*76*	*6.8*	*1*	*0.8*	*4*	*1.8*
Triticale	*5*	*2.2*	*27*	*2.4*	*0*	*0*	*1*	*0.4*
Spring barley	*15*	*6.6*	*14*	*1.3*	*9*	*6.8*	*34*	*17.3*
Oat	*2*	*0.9*	*7*	*0.6*	*0*	*0*	*0*	*0.1*
Others	*3*	*1.3*	*2*	*0.2*	*6*	*4.5*	*0*	*0.0*
Rape	37	*16.4*	191	*17.1*	14	*10.5*	28	*14.1*
Sugar beet	25	*11.1*	35	*3.1*	23	*17.3*	18	*8.9*
Potatoes	12	*5.3*	3	*0.3*	4	*3.1*	0	*0.0*
Maize	29	*12.8*	116	*10.4*	4	*3.0*	20	*10.0*
Forage plants	1	*0.4*	75	*6.7*	1	*0.8*	0	*0.0*
Other crops	5	*2.2*	43	*3.8*	4	*3.0*	4	*1.9*
Grassland	5	*2.2*	147	*13.2*	1	*0.8*	14	*7.2*
Total area	**226**	***100***	**1.117**	***100***	**133**	***100***	**199**	***100***
Livestock stocking rate in LU ha^{-1}	**1.43**		**0.30**		**0.18**		**0.95**	

5.4 Results of individual indicators – regions

In this section, the results of individual farms for the pre-defined regions (North, East, South, West) are presented in a comparative way. The investigated indicators are summarized analogously to Chapter 5.2.

5.4.1 Nutrient and humus balances

Table 18: Extended N-balance in kg N ha^{-1} (3-year mean of four project regions, rounded)

Balance element	Unit	North	East	South	West
Nutrient removal, total	kg N ha^{-1}	211	171	227	190
N-immissions	kg N ha^{-1}	20	20	20	20
Seeds/plant material	kg N ha^{-1}	2	2	3	2
Symbiotic N-supply, total	kg N ha^{-1}	2	7	3	2
Organic fertilization, total	kg N ha^{-1}	159	72	81	72
Straw fertilization	*kg N ha^{-1}*	*25*	*19*	*28*	*24*
Green manure	*kg N ha^{-1}*	*39*	*15*	*48*	*33*
Stable manure	*kg N ha^{-1}*	*0*	*14*	*0*	*0*
Liquid manure	*kg N ha^{-1}*	*84*	*16*	*2*	*10*
Slurry	*kg N ha^{-1}*	*1*	*0*	*0*	*0*
Others	*kg N ha^{-1}*	*10*	*8*	*3*	*5*
Mineral fertilizers, total	kg N ha^{-1}	111	126	172	138
Nutrient supply, total	kg N ha^{-1}	294	227	278	234
Change in N-stocks in soil	kg N ha^{-1}	-10	-8	-16	-15
NUTRIENT BALANCE	**kg N ha^{-1}**	**92**	**64**	**68**	**59**
Nutrient utilization	%	72	75	81	81

The regional N-balances result in the following order: North > South > East > West.

As it could be seen in the section 5.3, the region North is characterized by a high livestock stocking rate (1.43 LU ha^{-1}), which can reach up to 5,7 GV ha^{-1}. Accordingly, there are more organic fertilizers of animal origin in this region. Just 54 % of nitrogen supply can be provided through organic fertilization. Despite the appropriate use of mineral fertilizers, nitrogen removal is covered more than sufficiently. In comparison, the result of the balancing of nitrogen levels in the regions South and East takes a mean value.

For the regions South and West, a comparatively high value of the change in N-stocks in soil can be seen in the balancing. Already at that point mineralized N-quantities can point out a negative humus balance (Table 20).

For the region West, a livestock stocking rate of 0.95 LU ha^{-1} was determined. Table 18 shows, however, that relatively less nitrogen is provided by the use of organic fertilizers. In the project farms, some amounts of farm manures are exported from the farm and transferred to other farms/companies for utilization.

It can be concluded from nutrient utilization that nitrogen is used efficiently. 72 % (North) and 81 % (South, West) of the applied nutrient is converted into yield.

The results of the phosphorus balance for four project regions presented in Table 19 indicate varying degrees of supply of arable land with the nutrient phosphorus.

Table 19: P-balance in kg P_2O_5 ha^{-1} (3-year mean of four project regions, rounded)

Balance element	Unit	North	East	South	West
Nutrient removal, total	kg P_2O_5 ha^{-1}	96	78	101	87
Seeds/plant material	kg P_2O_5 ha^{-1}	1	1	1	1
Organic fertilization, total	kg P_2O_5 ha^{-1}	94	37	37	37
Straw manure	*kg P_2O_5 ha^{-1}*	*14*	*9*	*16*	*14*
Green manure	*kg P_2O_5 ha^{-1}*	*12*	*5*	*16*	*11*
Stable manure	*kg P_2O_5 ha^{-1}*	*0*	*7*	*0*	*0*
Liquid manure	*kg P_2O_5 ha^{-1}*	*55*	*9*	*2*	*5*
Slurry	*kg P_2O_5 ha^{-1}*	*0*	*0*	*0*	*0*
Others	*kg P_2O_5 ha^{-1}*	*13*	*7*	*2*	*7*
Minreal fertilizers, total	kg P_2O_5 ha^{-1}	16	25	43	21
Nutrient supply, total	kg P_2O_5 ha^{-1}	112	64	80	57
NUTRIENT BALANCE	**kg P_2O_5 ha^{-1}**	**16**	**-16**	**-20**	**-35**
Nutrient balance with correction	**kg P_2O_5 ha^{-1}**	**31**	**-29**	**-25**	**-45**

A positive phosphorus balance can be calculated only for the North region. On the one hand, this reflects a good supply of the plots with the nutrient due to good fertilizer management. On the other hand, the fields are better supplied from the ground up due to intensive animal husbandry und thus continuous supply with organic fertilizers. However, a deficit in supply with phosphorus was identified for all other regions. The demand could not be satisfied during the entire vegetation phase, so that the needed phosphorus had to be mobilized from the soil reserves. This fact can also be illustrated with the help of the corrected phosphorus balance by correcting the calculated phosphorus balance plot-specifically on the basis of soils types in terms of their contents. As a result, an even greater deficit is evident not only for the region East but also for South and West. Phosphorus fertilization might not be in the foreground due to economic conditions, so that sustainable nutrient supply falls into the background during the period considered. Finally, the phosphorus balances (with correction) presented here indicate a potential under-supply of areas on average for all project farms in the regions East, South and West.

The results of the dynamic humus balance shown in Table 20 provide information about the quantity and quality of agricultural practices with regard to the important aspect of soil fertility and its sustainable conservation.

Table 20: Humus balance (dynamic) in kg C ha^{-1} (3-year mean of four project regions, rounded)

Balance parameter	**Unit**	**North**	**East**	**South**	**West**
Gross demand for humus	kg C ha^{-1}	-741	-561	-698	-643
Increase in humus content	kg C ha^{-1}	22	30	22	13
Seeds/Plant material	kg C ha^{-1}	0	0	0	0
Straw fertilization	kg C ha^{-1}	344	250	375	359
Green fertilization	kg C ha^{-1}	86	32	101	68
Organic fertilization, total	kg C ha^{-1}	183	169	28	50
Stable manure	*kg C ha^{-1}*	*0*	83	*1*	*2*
Liquid manure	*kg C ha^{-1}*	*120*	47	*5*	*22*
Others	*kg C ha^{-1}*	*63*	38	*21*	*26*
Humus reproduction, total	kg C ha^{-1}	635	481	526	490
HUMUS BALANCE	**kg C ha^{-1}**	**-106**	**-79**	**-173**	**-152**

The final calculations show the following sequence according to the amount of the balance: East > North > West > South. On closer examination, significant differences are in evidence already in gross demands for humus between the project regions. However, the demand alone does not provide any information on the balance. The level of humus balance is much more determined by the amount of carbon supplied. In the East region, 85 % can already be covered by humus reproduction, which mainly occurs through incorporation of straw and green mass (60 %) into the soil and application of humus-effective farm manures (about 35 %). The comparatively small demand results mainly from the less root-crop intensive crop rotations of the region. In this way, the focused use of organic fertilizers not only closes nutrient cycles, but also stimulates soil fertility with a good nutrient-retaining capacity. The region North is characterized by the highest gross humus demand, which is attributable to a high yield potential in the region (Figure 8).

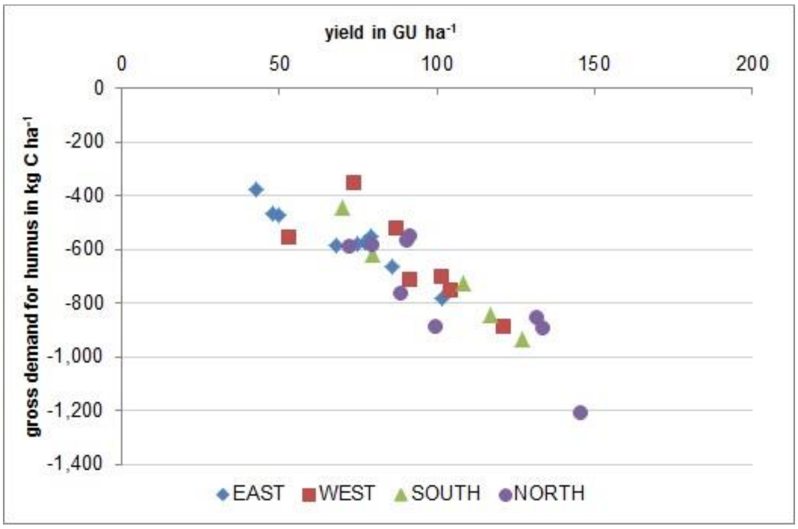


Figure 8: Relationship between gross demand for humus in kg C ha^{-1} and yield in GU ha^{-1}

Along with the nitrogen and phosphorus balance, the share of organic fertilization in the nitrogen balance and humus balance is also high. Due to accumulation and use of animal excrements, mainly from liquid manure, not only nutrients but also carbon compounds, which are humus-effective, are supplied to the soil.

Additionally, high shares of straw and green manure influence the humus balance positively. Despite this, the negative balance indicates strong humus degradation, which can only be compensated inadequately by reproduction.

The strongest negative balance calculated for the region West results from the interaction of many influencing factors. Thus, the comparatively high demand for carbon is determined by the cultivation of high-yielding plants like sugar beet and maize. Their share in the reproduction performance is only about 10 % in spite of cultivation of intermediate crops prior to root crops. Even grain cultivation on 58 % of land can not sufficiently cover the demand for humus by the return of straw. Taking into account the phosphorus balance, animal excrements are used very moderately, so that the comparatively small proportion also provides a small proportion of humus-effective carbon. As already shown in Table 17, the South region is characterized by the lowest livestock stocking rate, compared with the other regions. Thus, the few available organic fertilizers are mainly used as fermentation residues (among other organic fertilizers). They contribute to humus reproduction with almost 30 kg C ha^{-1}. The main part of carbon supply is realized by incorporation of straw and green manure.

5.4.2 Intensity of plant protection

The treatment indices of individual main crops of the four project regions summarized in Table 21 show different plant protection strategies at the agricultural project farms of the regions. This fact can be attributed to different intensities in cultivation, but mainly to climatic conditions. However, the data do not provide indication of quantitative application of plant protection products at the farms.

Table 21: Treatment indices of the most important main crops (3-year mean of four project regions)

Main crop	**Treatment indices**			
	North	**East**	**South**	**West**
Winter wheat	6.6	4.6	4.6	4.3
Winter barley	3.8	3.7	3.6	3.3
Winter rye	4.2	3.0	1.4	4.1
Triticale	4.6	1.9	1.7	2.2
Spring barley	4.2	3.0	4.1	2.9
Oat	6.3	2.1	0.7	3.0
Rape	6.6	5.9	7.6	6.8
Sugar beet	7.9	6.8	5.2	6.1
Potatoes	19.1	10.5	7.1	n. c.*
Maize	2.3	1.6	1.5	1,4

* not cultivated

As plant protection is an important instrument for ensuring yields, the application of plant protection in relation to the yield level is shown in Figure 9. On the one hand, the energy input is representative for the quantity level of active substances; on the other hand, the nutrient removal is taken down as yield-relevant parameter.

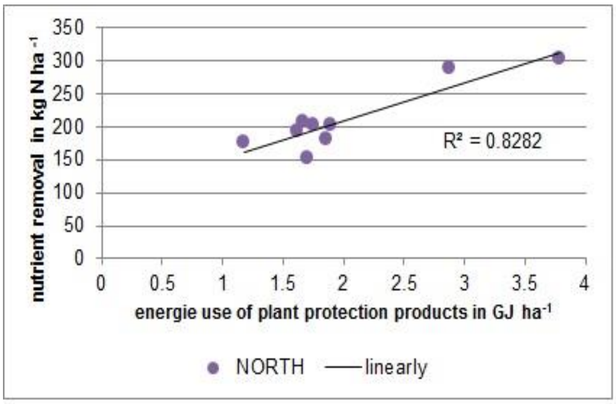


Figure 9: Relationship between nutrient removal in kg N ha^{-1} and energy use for production of plant protection products in GJ ha^{-1} for the project region North

It can be seen that the energy use of plant protection products rises linearly as the nutrient removal increases, i. e. there is a direct dependency between two factors. This is demonstrated by the correlation coefficent 0.8. As a result, an efficient use of plant protection products is evident in the region North, because yields have to be ensured by plant protection.

For other regions, these facts are shown in Figure 10. Due to the lack of statistical dependence (R² ≤ 0.58), it can be concluded that plant protection strategies of the individual project farms have not yet been optimized concerning utilization of nitrogen through yield formation. However, it should be pointed out at this point, that these statements do not imply possible environmental impacts. Plant protection may be reduced, but more plant protection can also lead to better utilization of nitrogen.

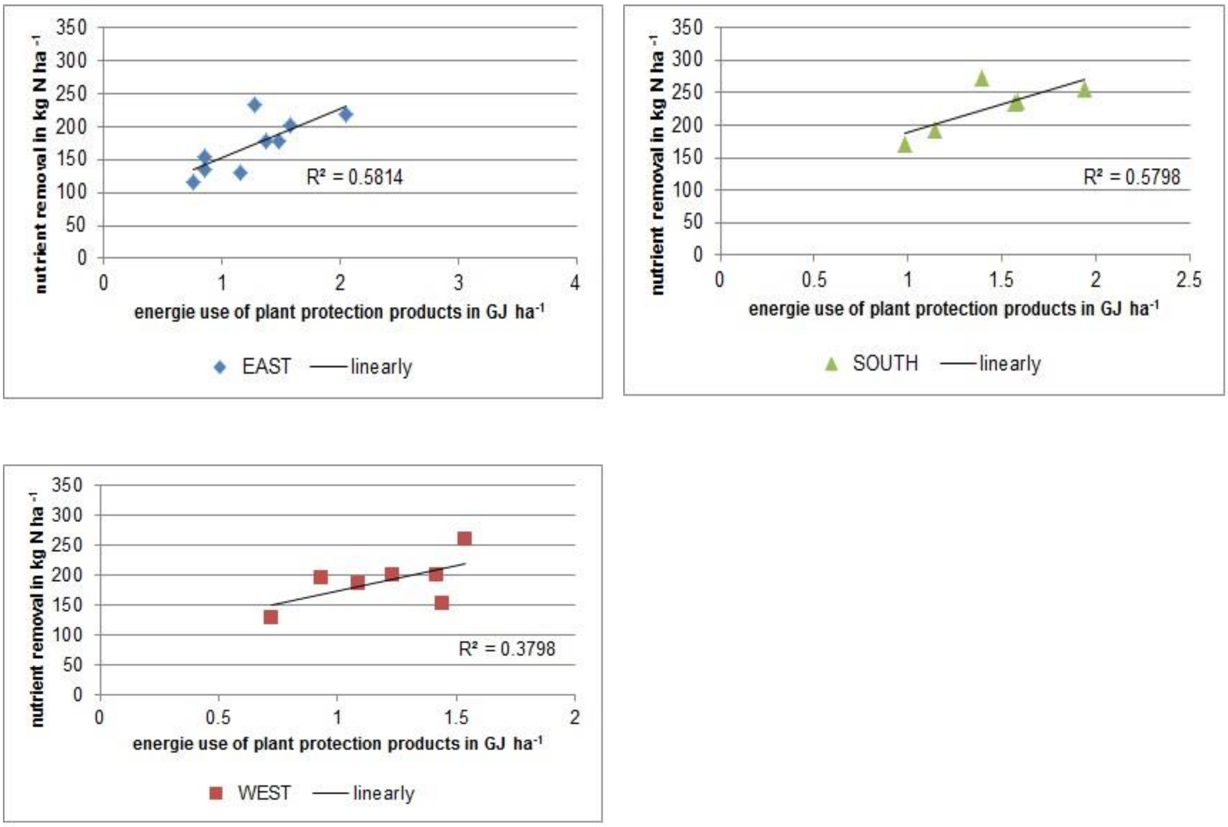


Figure 10: Relationship between nutrient removal in kg N ha^{-1} and energy use for production of plant protection products in GJ ha^{-1} for the project regions East, South, West

5.4.3 Energy and greenhouse gas balance

Table 22: Energy balance in MJ GE^{-1} (3-year mean of four project regions, rounded)

Balance element	Unit	North	East	South	West
Yield MP + BP	GE ha^{-1}	99	70	102	90
Use of fossil energy	GJ ha^{-1}	16	14	16	14
Org. fertilizers, total	*GJ ha^{-1}*	*4*	*1*	*0 (0.2)*	*1*
Mineral fertilizers, total	*GJ ha^{-1}*	*5*	*5*	*7*	*6*
Seeds, total	*GJ ha^{-1}*	*3*	*2*	*3*	*2*
Plant protection products, total	*GJ ha^{-1}*	*2*	*1*	*1*	*1*
Diesel fuel, total	*GJ ha^{-1}*	*3*	*3*	*4*	*3*
Machines and devices, total	*GJ ha^{-1}*	*1*	*1*	*1*	*1*
Energy output	GJ ha^{-1}	160	138	164	148
Energy gain	GJ ha^{-1}	145	126	150	135
Energy intensity	**MJ GE^{-1}**	**165**	**187**	**147**	**144**
Output/input relationship		10	11	11	12

According to energy intensity, the subsequence of the regions is as follows: West > South > North > East. The lowest use of fossil energy, which is indicative of the region West, leads to the best energy intensity in combination with a high yield level. The use of operating resources, adjusted to the regional expectations, results in energetically efficient production, which is described through the output/input relation. Taking into account the nitrogen and the phosphorus balance, nutrients are rather supplied by application of mineral fertilizers due to poor livestock stocking rates in the region South, which is reflected in the energy balance, or that is to say in the use of fossil energy. The related high level of total use of fossil energy can be balanced by the highest yield level, so that a similarly low intensity could be calculated for the South region.

Higher intensities have been calculated both for the region North and East. Despite the high yield level in the region North, the energy used, particularly the energy of mineral fertilizers, which were applied additionally, could not be exploited optimally. For this reason, the output-input relation is accordingly bad. Furthermore, more intensive plant protection is reflected in a higher energetic proportion of plant protection products. In contrast, higher energy intensity, reported for the region East, is predominantly based on the lower yield level, so that the fossil energy used could not be utilized efficiently in the formation of yields. This facts are confirmed by the output-input relationship.

Table 23: Greenhouse gas balance in kg $CO_{2\,eq}$ GE^{-1} (3-year mean of four project regions, rounded)

Balance element	Unit	North	East	South	West
C sequestration*	kg $CO_{2\,eq}$ ha^{-1}	384	292	634	541
CO_2 emissions, cultivation	kg $CO_{2\,eq}$ ha^{-1}	990	897	1,161	963
N_2O emissions	kg $CO_{2\,eq}$ ha^{-1}	1,299	1,014	1,260	1,049
GHG emissions (ha)	kg $CO_{2\,eq}$ ha^{-1}	2,673	2,203	3,055	2,553
GHG emissions (GJ)	kg $CO_{2\,eq}$ GJ^{-1}	16	18	18	17
GHG emissions (GE)	**kg $CO_{2\,eq}$ GE^{-1}**	**27**	**32**	**30**	**28**

* positive value = C release from the soil / negative value = C storage in the soil

Different results were obtained for each region in terms of climate effects. According to the level of production-related emissions, the regions are grouped as follows: East > South > West > North. The highest GHG emissions per production unit are identified for the region East. Here, the regional yield level is shown as a substantial influence factor (see Table 22). The higher the yield realized at the same inputs, the better the product-related GHG emissions. Another component of the greenhouse gas balancing is the C sequestration, which establishes the relation to humus balance. The level of CO_2 released from humus degradation is varying.

Furthermore, the emissions resulting from cultivation and the N_2O emissions converted from nitrogen supply are taken into account. The high proportion of these emissions, calculated for the regions North and South, results from the comparatively high use of organic and mineral fertilizers.

5.4.4 Harmful soil compaction and erosion by water

Table 24: Threat of harmful compaction to upper subsoil (35 cm) as an index (3-year mean of four project regions)

Balance element or process stage	North	East	South	West
Tillage	0.10	0.14	0.08	0.12
Sowing	0.02	0.04	0.02	0.03
Min. fertilization	0.12	0.12	0.06	0.11
Org. fertilization	0.14	0.11	0.00	0.07
Plant protection	0.03	0.05	0.04	0.03
Harvest MP	0.10	0.08	0.12	0.13
Compaction risk	**0.10**	**0.10**	**0.07**	**0.10**

With regard to the level of compaction risk, the ranking of the regions is as follows: South > North – East – West. The lowest compaction risk of the region South results from the comparably low index (< 0.10) throughout all process stages. In particular, organic fertilization with an index of 0.00 does not pose a risk. In contrast, harvesting the main product (MP) presents the highest risk of harmful compaction. Due to root crops-intensive crop rotations, specific harvesting techniques with usually high axle loads are used. In addition, beet harvesting is extended f. e. until after the beginning of November. Since this month is characterized by a higher soil moisture due to the weather conditions, the trafficability of the plots is also affected. In a further comparison, the medium risk of compaction can be derived from the high share of organic fertilization for the region North. However, this is determined not only by the number of applications of machinery, but also by the dimensioning of spreading machines. High axle loads resulting from large filling volumes mean higher soil pressure load. For the region East, the same compaction risk has been identified, but it has been determined by other process stages. Consequently, the tillage practice decisively influences the overall risk. Due to the larger farm structures in the region East, more power capacity is needed in order to be able to perform all work on time. For this purpose, larger vehicles are required. Then, the wheel loads are higher. As a result, the pressure in soil increases during the passages by machines across the plot surface. Coupled with high tire inflation pressure of the tractors, it can increase even more. For the region West, the harvest also has a decisive impact on the overall index.

Decisions relating to application of machinery and harvesting in due time seem to be difficult for all regions, which is why the plots were run over by machines also under unfavorable soil conditions.

The annual soil loss is different for individual regions. The highest loss with 0.98 t ha^{-1} a^{-1} was calculated for the region West. For other regions, the soil loss is 0.83 t ha^{-1} a^{-1} (South) > 0.56 t ha^{-1} a^{-1} (East) > 0.43 t ha^{-1} a^{-1} (North). As a rule, the risk of erosion affects not the whole farm, but only the single so-called erosion spots within the plots. Therefore, the annual soil loss of a project region has little meaning. It can only show tendencies between the regions.

The situation described above is once more shown graphically for a project farm in Table 11.

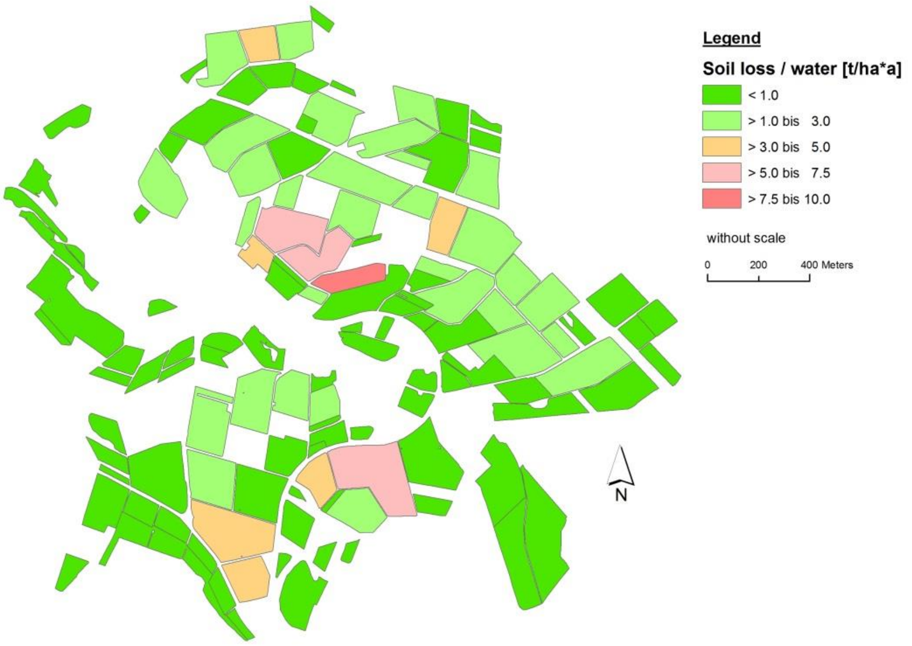


Figure 11: Graphical presentation of soil loss in t ha^{-1} a^{-1} for one project farm

This shows that not all plots of a farm are affected by the risk of erosion. The danger of erosion is possible only on single plots with higher soil losses of ≥ 7.5 t ha^{-1} a^{-1}. As already described in the Chapter 4.8, the level of soil erosion is determined by the combined effect of precipitation, covering degree and the location of the plots on site.

5.4.5 Biodiversity potential

As results from the description of the indicators, the calculation algorithm of biodiversity potential is very complex, which is why only single partial indicators are to be illustrated at this point.

Table 25: Results of 11 partial indicators of biodiversity potential (3-year mean of four project regions)

Balance element		Unit	North	East	South	West
STRUCTURES	Diversity of varieties		2.71	3.79	2.14	2.08
	Diversity of crop types		1.39	2.01	1.35	0.80
	Diversity of crop groups		1.16	1.46	1.29	1.19
	Diversity of use		0.08	0.28	0.09	0.26
	Diversity of use/cultivation		0.93	1.33	0.91	0.83
	Medium length of the edge	100m	13.18	25.15	8.58	8.87
	Medium size of the subplot	ha	7.13	11.12	4.34	2.46
	Variation coefficient/ Size of the subplot	%	88.62	129.41	83.84	90.38
INPUTS	Percentage of agricultural area without PPP	%	2.18	13.98	2.28	9.43
	Treatment index, evaluated		0.12	0.38	0.25	0.41
	Fertilization intensity (nitrogen)	kg ha^{-1}	171.85	142.05	178.03	144.11
MEASURES	Process diversity / Tillage - AL		0.26	0.23	0.28	0.34
	Process diversity / Harvest		0.18	0.12	0.20	0.19
	Use frequency grassland + fodder	number/year^{-1}	0.65	2.15	0.45	1.02
	Frequency of applications of machinery	number/year^{-1}	12.09	12.76	12.80	11.12

Regarding the structures, the region East is characterized by a comparatively high diversity of use/cultivation, which is attributable to a higher diversity of crop types and crop groups.

Along with a larger average size of the subplots in this region, the edge lengths, which are comparatively twice as large, represent the greatest potential within the structures. The inputs are also considered. Resulting from the high share of grassland in the region East, it is shown at this point, that the share of the areas not treated chemically and synthetically is the highest one. The treatment of the remaining areas is entirely included in the calculation, but as valuation which will be described in the following Chapter 6.9. A comparison of the regions with regard to fertilization intensity provides a different picture. Based on the nitrogen balancing (cf. section 0), the highest intensity values of over 170 kg ha^{-1} could also be determined for the regions North and South.

The last group of measures reflects the process diversity within the farms/regions. Decisive differences can be identified as to the frequency of use of grassland and forage in the region East. The higher share of grassland in this region causes a higher use frequency, which can lead to disturbances in the ecosystem. In the end, all measures on the production process are once more summarized as a number per year in the partial indicator <the frequency of applications of machinery>. Fewer applications mean less disturbances of the system, resulting in this partial aspect of biodiversity potential in the following ranking: West > North > East > South.

6. Valuation of results

After calculating the actual values, the values of the farms were assessed with regard to the fulfillment of defined sustainability goals. The assessment whether an indicator value can be classified as sustainable or not requires appropriate valuation functions. All calculated indicators are assigned with the target or rather the limit values. The indicators are converted into dimensionless scores between 0 and 1 through a normalization process; the sustainability status is valuated on the basis of the valuation function. The farm rankings are classified on a scale between 0 and 1, where 0 is the most unfavorable ranking and 1 the most favorable one in terms of sustainability. This makes it possible to aggregate the various individual criteria and to make an overall assessment of the farm using the entire set of the nine indicators.

An optimum range is defined for each indicator to be assessed. These ranges will be specifically presented in the following sections. If this optimum range is reached at the farm level, then, the score will be 1.0. If the indicator value is outside the defined optimum, the score will be lower than 1.0 and goes down up to zeroing. In this work paper, the valuation functions are based on the practice-oriented sustainability standard of DLG.

For the overall assessment of ecological sustainability of the project farms, all individual indicators are averaged equally weighted. This value is used to assess the sustainability performance of the farm. At farm level, this calculated score must be ≥ 0.75, in order to be able to assume a sustainable system of agricultural practices. In this approach, a balance between the single indicators is possible on the principle of weak sustainability.

6.1 Nitrogen balance

The valuation function shown in Figure 12 was used for the assessment of nitrogen balances in the farms. The range between 0 and 50 kg N ha^{-1} a^{-1} has been defined as an optimal condition for sustainable agricultural practices. N-losses can never be totally avoided at this level, because no serious ecological damage is caused by agricultural practices up to the level of 50 kg N ha^{-1} a^{-1}. In the literature, 25 to 50 kg N ha^{-1} a^{-1} are given as the N-balances to be observed (FREDE & DABBERT 1998), although this can only be of indicative nature, since the assumed N-balance methods differ from the REPRO approach used.

Furthermore, it is assumed that non-sustainable agricultural practices happen when the optimum value is both exceeded and not reached. In the case of long-term negative N-balances, a decrease in N-stocks in soils is to be expected, which ultimately leads to decrease in yield ability of soils. With increasing N-balances, the risk of losses of reactive N-compounds increases. The environmental impacts (critical loads), the economic effects (changes in earnings and profits) and the feasibility (initial situation of the farms, N-saving potential) were equally taken into consideration in the determination of the still tolerable N-losses.

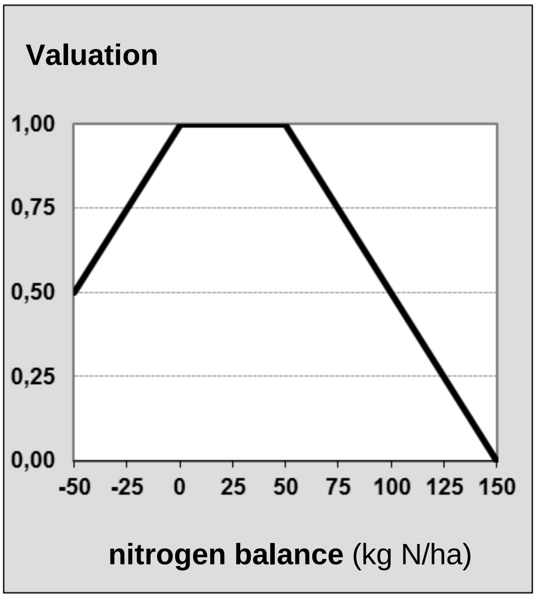


Figure 12: Valuation function <nitrogen balance>

At farm level, the calculated 3-year nitrogen balances result in the scores from 0.00 to 1.00 (Figure 13). A good value of 0.78 was achieved on average in the farms.

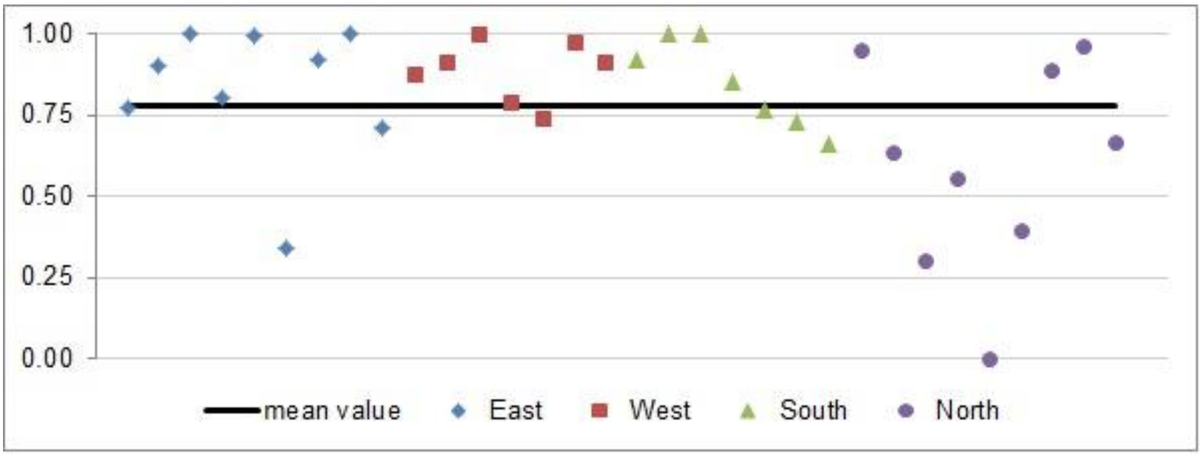


Figure 13: Valuation of nitrogen balances at the farms (32 project farms)

6.2 Phosphorus balance

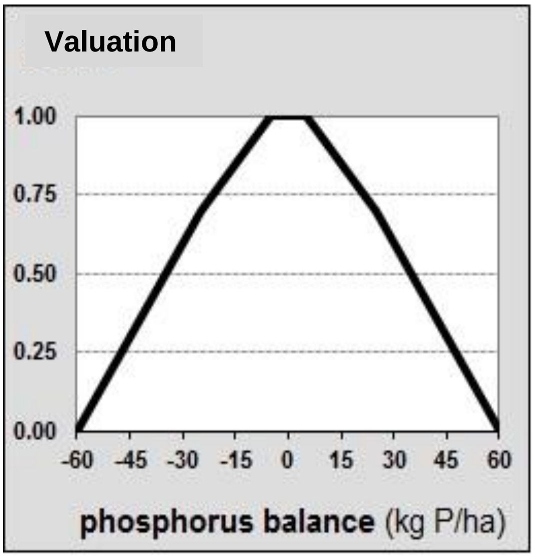


Figure 14: Valuation function <phosphorus balance>

Phosphorus is one of the nutrients that are firmly stored in the soil over the long term. The content of plant-available phosphorus in the soil together with the yield-dependent withdrawal determines the amount of fertilization. The balances calculated for the P-balance are therefore not a suitable basis for valuation of fertilization management without taking into account the contents of plant-available phosphorus in the soil. As presented in Chapter 4.2, the contents of plant-available P in the soil are taken into account as additions or reductions to the P-balance. The linkage of both values leads to the corrected P-balance, which is subject to valuation of the fertilizer management.

The application of the corrected P-balance allows the valuation of P-balance for different classes of soils in terms of their contents using the same valuation curve. Figure 14 shows the valuation function. In contrast to the results, the valuation is based on P and not on P_2O_5. An optimum range from -5 kg P ha^{-1} to 5 kg P ha^{-1} is defined, which obtains the score of 1.00. In this range, the phosphorus balance meets the demands for economic and environmentally friendly nutrient supply. The valuation curve cuts the X-axis at -60 kg P ha^{-1} or rather 60 kg P ha^{-1}. These are the most unfavorable situations. Therefore, they are rated 0.0. In order to come to the overall assessment of the farm, the subplot-related valuations weighted according to the area size are averaged.

The good phosphorus balances of the project farms are also reflected in the valuation. On average, the score is 0.79. The results of the individual farms vary between 0.15 and 1.00 (see Figure 15).

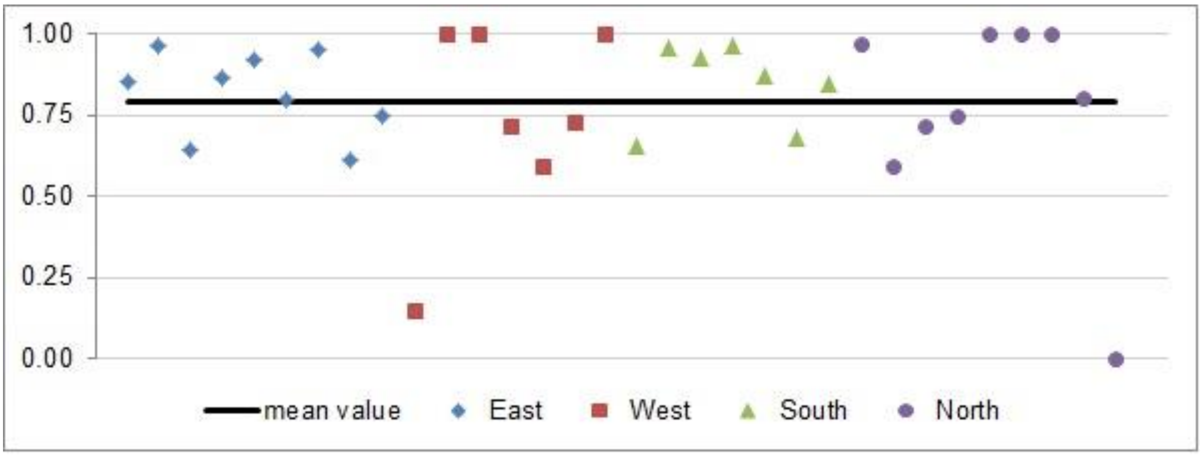


Figure 15: Valuation of phosphorus balances at the farms

6.3 Humus balance

Humus balance results are evaluated on the basis of humus balance groups using the valuation scale of VDLUFA (2004). The group C has to be considered as the optimum range, in which a value between -75 kg C ha^{-1} and 100 kg C ha^{-1} is to be reached on a three-year average of the farm. In this case the score shall be 1.0, because humus contents which suite local conditions will be attained in this group. Compared with this, the unfavorably evaluated groups A and E shall be scored at 0. In the case of undersupply of soils with humus (group A: balance ≤ 200 kg humus-C ha^{-1}), an unfavorable influence on soils function and thus the yield performance is to be expected. On the other hand, strong over-supply (group E: balance ≥300 kg humus-C ha^{-1}) carries a risk of mineralization pushes and thus nitrogen losses. The score between 0.00 and 1.00 is characterized by the groups B and D. In these ranges, the present humus balance should be checked in the medium terms. Based on the described valuation approach according to VDLUFA (2004), the valuation function shown in Figure 16 is used for the valuation of the indicator.

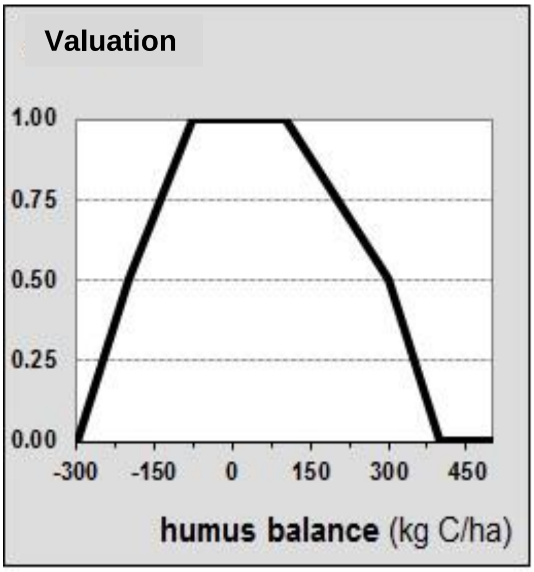


Figure 16: Valuation function <humus balance>

The valuations of humus balance at the individual farms vary analogous to the results, as shown in Figure 17, between 0.00 and 1.00. On average, the valuation of this indicator results in 0.63 for all project farms.

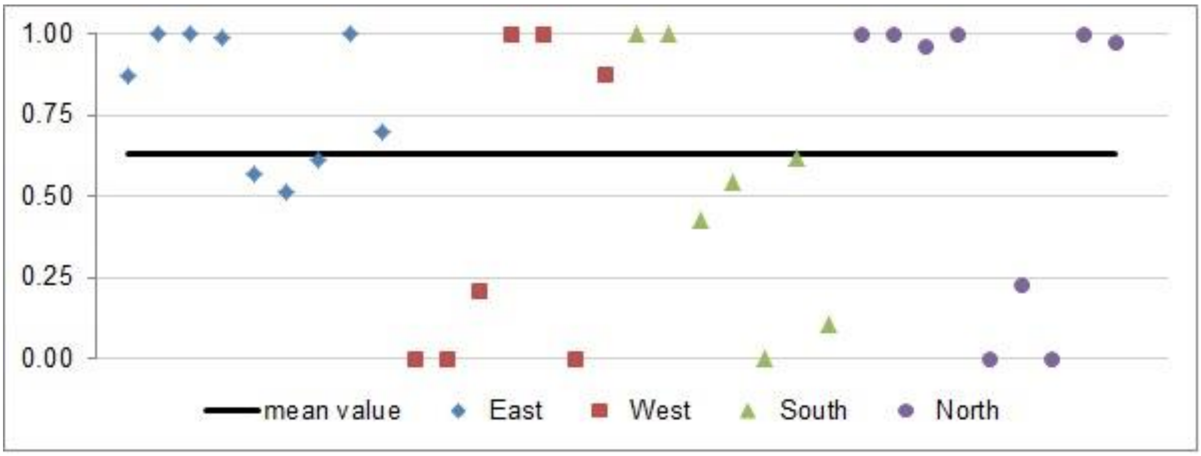


Figure 17: Valuation of humus balances at the farms

6.4 Intensity of plant protection

Plant protection is evaluated at the level of crop types. The target / actual comparison is carried out with the help of the data sets from the network „Reference Farms Plant Protection“ (FREIER et al. 2015) and the PAPA plant protection application data (ROßBERG 2013). The data on the application of plant protection measures are regionally provided to the public as “treatment indices” with further statistical values (f. e. mean, spread) by the JKI and at a high temporal density (annual surveys). This makes it possible to compare the „individual plant protection in the farms“ with the „average behavior of the plants“. Farms which significantly deviate from the average are to be considered as worthy of optimization, if there are no plausible reasons. The function shown in Figure 18 is used for valuation. The regional type of crop-specific mean corresponds to the score of 0.80.

For evaluating and understanding the following results, it should also be mentioned that the treatment indices determined by JKI and used for comparison have slightly increased in the last years. This tendency results from the time-changing framework in practical agriculture, i. e. increases in the yields of the most important crops and the necessity to secure them, increasing proportion of conservation tillage systems, but also other aspects of scientific and technical progress, such as f. e. protection of sugar beet and rape against fungal pathogens, which is better possible at present. Therefore, these factors are taken into account in this valuation approach.

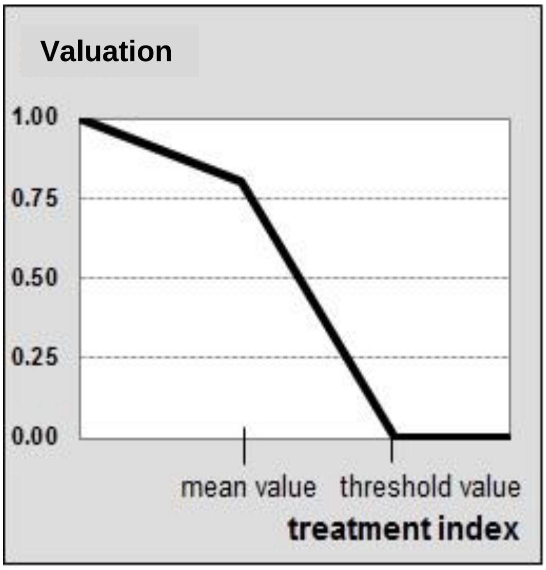


Figure 18: Valuation function <treatment index>

As shown in Figure 19, a score of 0.66 is reached on average at the project farms, and the results of the individual farms vary between 0.33 and 0.88. Consequently, it is important to point out the principle of integrated plant protection to the farms below sustainability threshold.

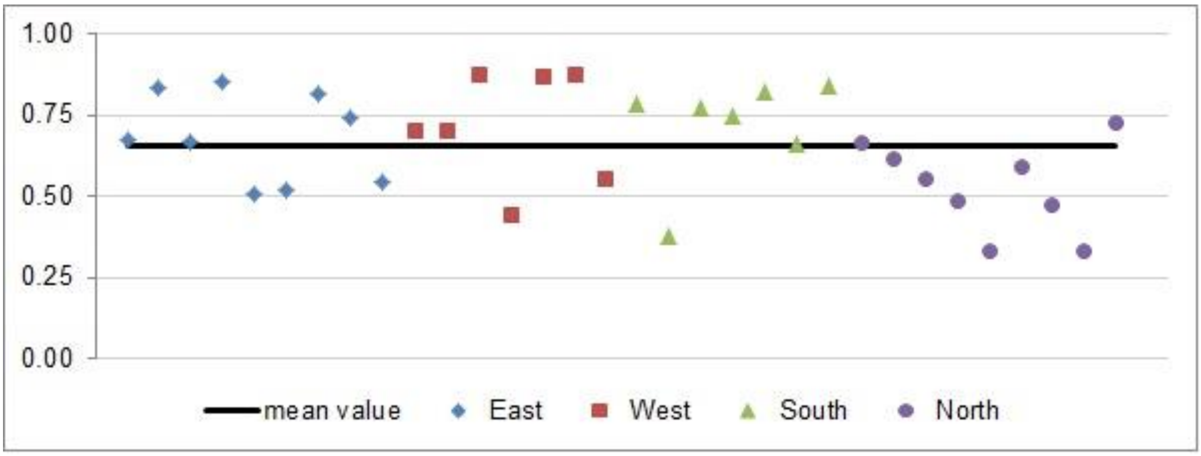


Figure 19: Valuation of the treatment indices at the farms

6.5 Energy intensity

The valuation of energy use of the farm refers to the energy intensity indicator. The entire use of fossil energy, both direct and indirect, is related to the product unit produced, here in grain units (GU). This unit is used to present a comparative overview of all goods manufactured in the agricultural production. The most efficient systems here are those which produce the same amount of products with the lowest use of fossil energy.

The valuation function applied to this indicator is shown in Figure 20. The energy intensity of up to 200 MJ per grain unit is considered as an optimum range. Starting from 350 MJ per grain unit, production is accompanied by undesirably high consumption of resources per unit produced. Insufficient energy efficiency is also reflected in the indicator <greenhouse gas potential>.

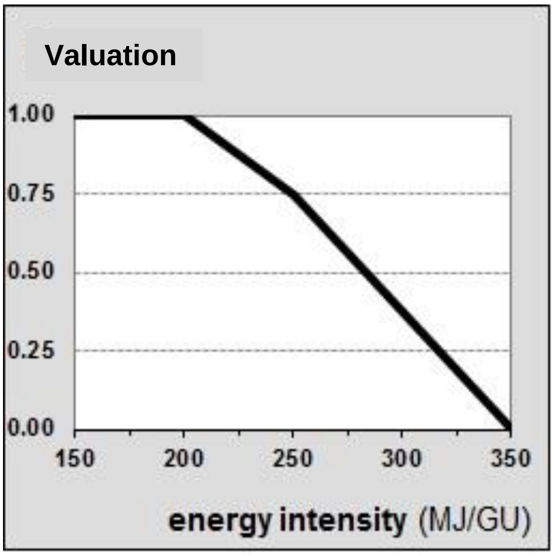


Figure 20: Valuation function <energy intensity>

As shown in Figure 21, an average of 0.98 is achieved in the project farms. This means that production is to be considered as close to the optimum level with regard to the energy input per product produced. The results of the individual farms vary between 0.81 and 1.00. This shows that all project farms have adapted their use of fossil energy to specific yield potential and that sustainable use of this resource can be attested.

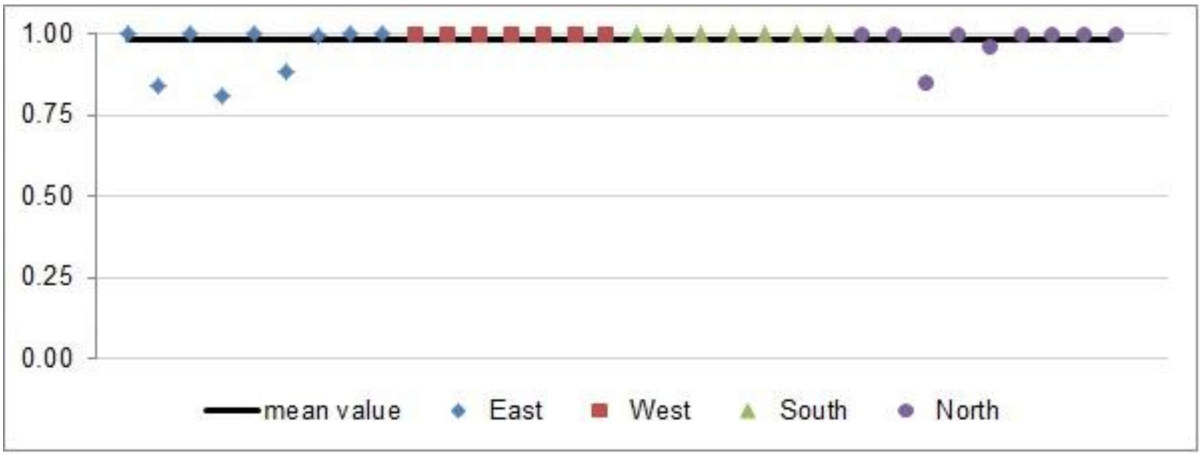


Figure 21: Valuation of energy intensities at the farms

6.6 Greenhouse gas balancing

In this work paper, production-related CO_2 emissions are related to the harvested grain unit in order to be able to represent the nutritional physiological footprint (Carbon Footprint).

For valuation of greenhouse gas emissions, the reference unit GJ was selected which represents the energetic value of the harvested products. The valuation function used is shown in Figure 22. The optimum range of production-related CO_2-emissions was defined from 0.0 up to 12.5 kg CO_2 je GJ. The following range from 12.5 to 25.0 kg CO_2 per GJ is to be regarded as decreasingly acceptable for this indicator in the farm context. High CO_2 emissions of more than 25 kg CO_2 per GJ are not an acceptable value in terms of sustainability.

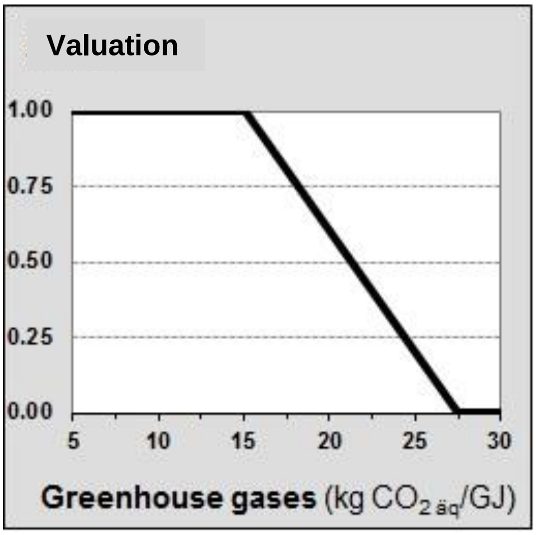


Figure 22: Valuation function <greenhouse gas potential>

The results of the project farms are shown in Figure 23. They vary between 0.00 and 1.00. On average, a good value of 0.80 is achieved.

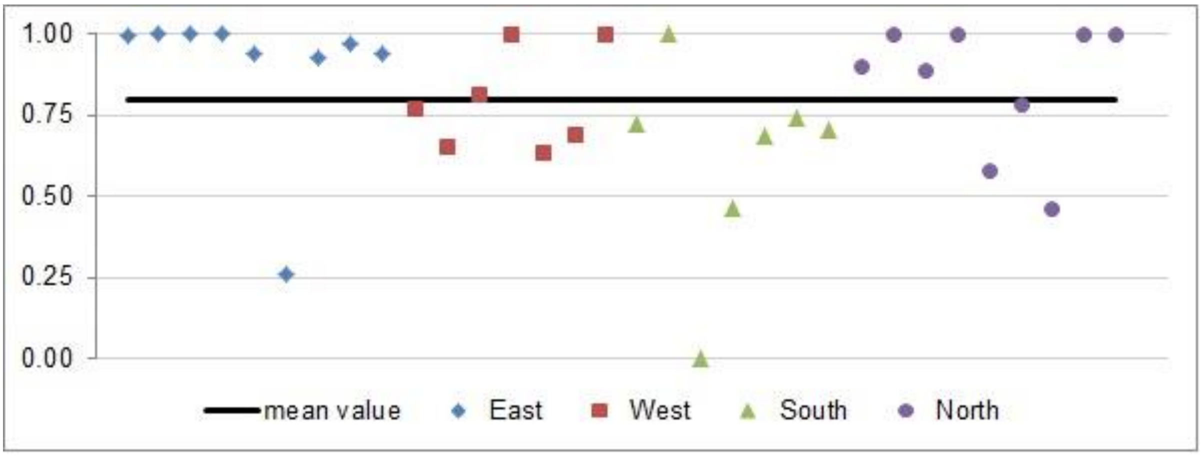


Figure 23: Valuation of greenhouse gas emissions at the farms

6.7 Harmful soil compaction

Harmful soil compaction is calculated as a difference between actual soil pressure and structure stability for each individual application of machinery. For example, the increasing stress indices indicate an increasing breach of structure stability. On the basis of subplot as the smallest operational unit, the summarization of the values at farm level allows to make a complex assessment of the risk of harmful soil compaction under the real conditions of the farm. Figure 24 shows the valuation function. Is the index value 0.0, then no risk of harmful soil compaction is assumed. For this reason, the result is scored at 1.00. The valuation curve decreases linearly up to the index value of 0.4. If this value is reached or exceeded, then, the score is 0.00.

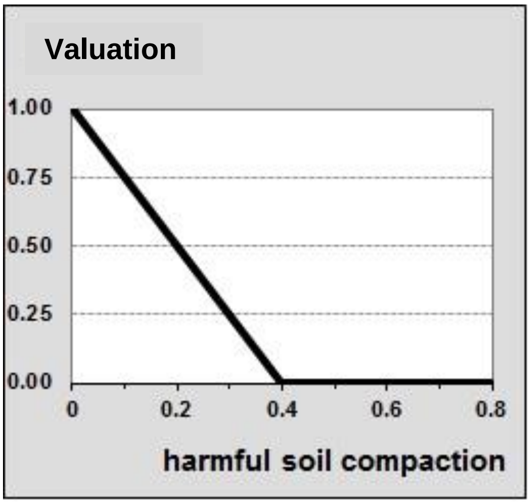


Figure 24: Valuation function <harmful soil compaction>

On average, the analyzed project farms achieve a good index of 0.77, as shown in Figure 25. The scores of individual farms are between 0.30 and 1.00.

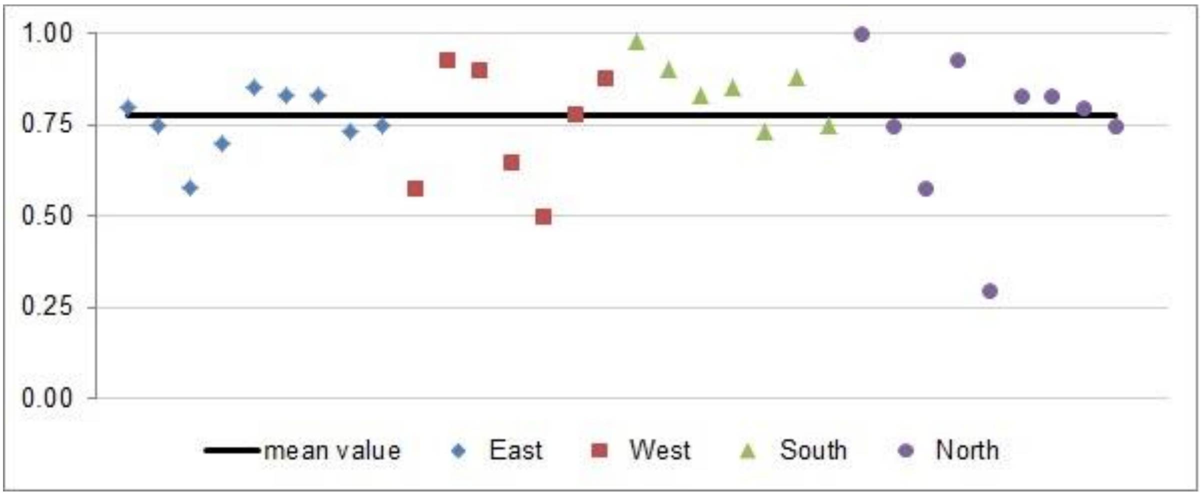


Figure 25: Valuation of harmful soil compaction at the farms

6.8 Soil erosion

The function used for valuation of soil erosion is shown in Figure 26. The optimum range for a farm is defined as an average soil loss of 1 t ha^{-1} a^{-1}. This is based on experience gained from the practice that the soil loss of agricultural land can be reduced to below 1 t ha^{-1} a^{-1} by suitable measures even in areas with high erosion potential (HUBER et al. 2005).

From the point of view of soil protection, a maximum soil removal of up to 12.5 t ha^{-1} a^{-1} for individual plots is considered acceptable (AUERSWALD et al. 1991). On the basis of these findings, the valuation function used for the entire farm decreases linearly from 1 t (optimum) to 12 t ha^{-1} a^{-1} (not acceptable).

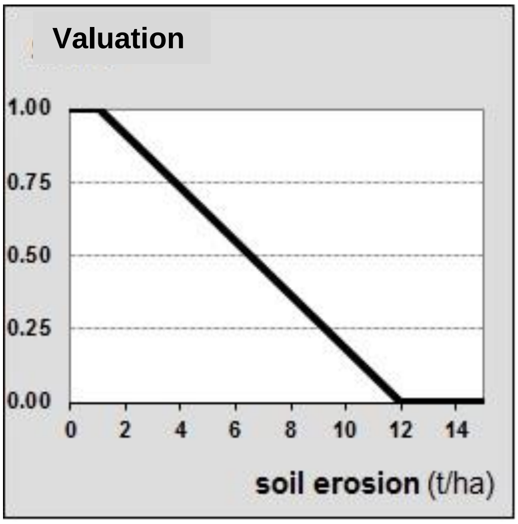


Figure 26: Valuation function <soil erosion>

In the analyzed project farms, the actual calculated average soil erosion was relatively low. The evaluated results are presented in Figure 27. On average, a very good score of 0.99 was reached. The results of the individual farms vary between 0.75 and 1.00.

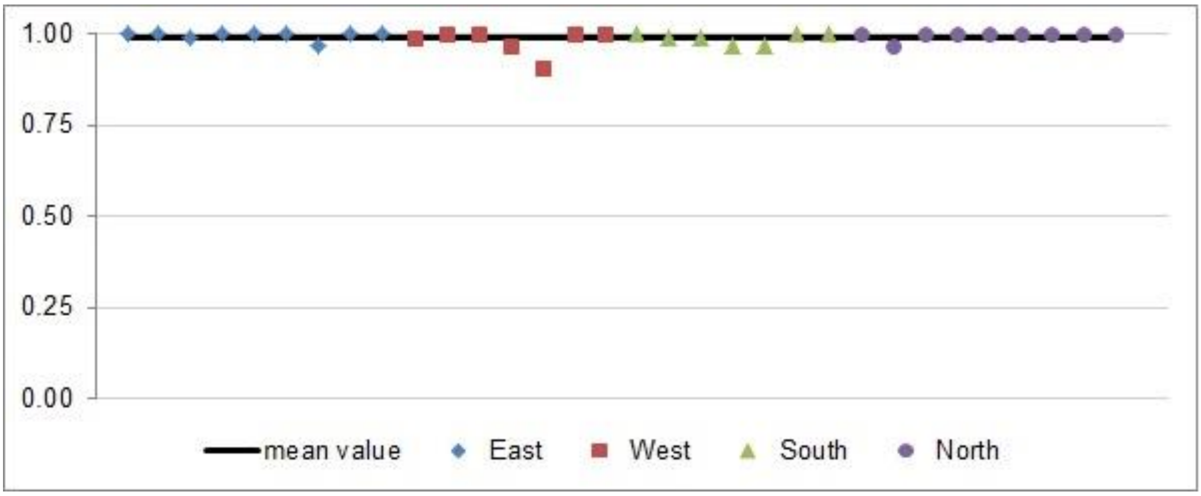


Figure 27: Valuation of soil erosion at the farms

6.9 Biodiversity

The valuation of biodiversity is carried out by means of 11 partial indicators from the fields of action structures-inputs-measures, as described in Chapter 4.9. A score of 0.61 was reached on the average for all project farms, as shown in Figure 28. The scores for biodiversity potential are between 0.26 and 1.00. Thus, there is room for improvement at some farms.

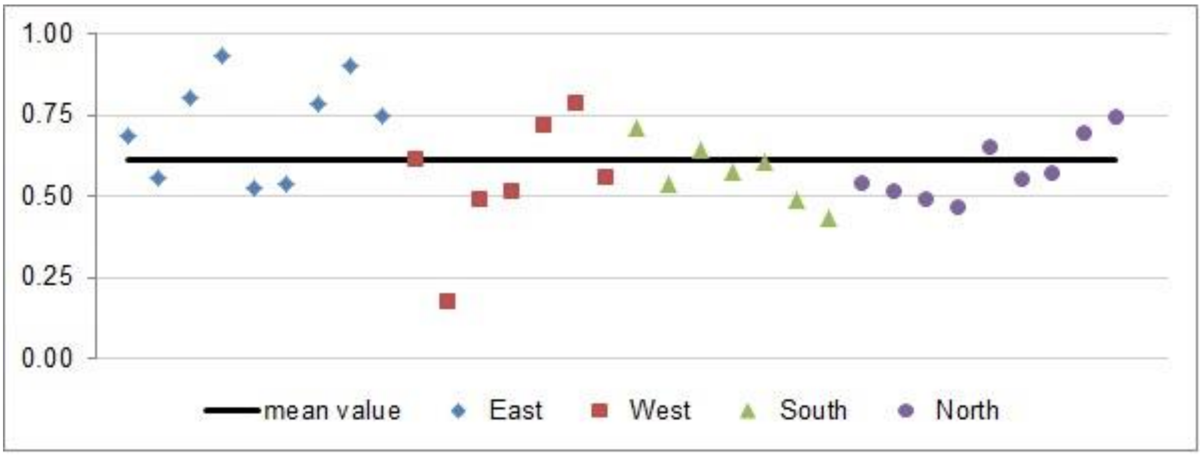


Figure 28: Valuation of biodiversity potential at the farms

6.10 Summarized valuation

For a final overview, a summary valuation has been made for the mean of the 32 analyzed farms, based on the results of the valuation of the examined agri-environmental indicators presented in the last chapters. In order to make a simply communicable statement on sustainability performance of a cultivation system, all the results of the evaluated indicators are compressed to a single value. The single indicators are equally weighted and averaged as described in Chapter 6. This approach provides an objective look at the use of environmental goods in agricultural production.

For a simple representation of the strengths and weaknesses of the land use management, the mean values of all results are shown in Figure 29 with the help of network diagram technique. It is pointed out once again, that the range between 0.75 and 1.00 (light green) is the defined target area for sustainable production in the sense of the presented approach.

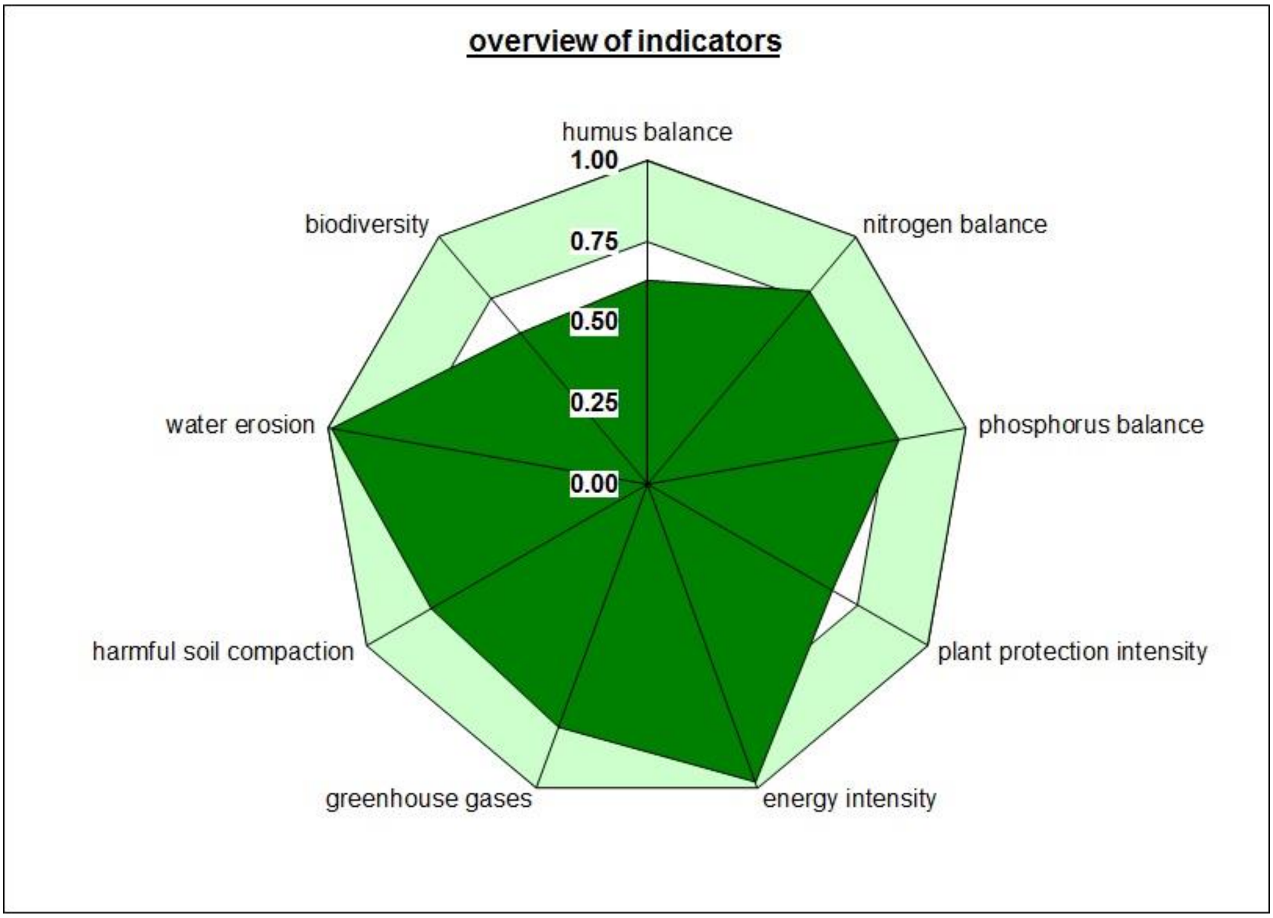


Figure 29: Overview of the valuations of all indicators

As can be seen from the figure, the optimum range for six out of nine indicators is achieved on average for all project farms. It is also recognizable that there are potentials for improvement of ecological sustainability performance in the areas humus, plant protection and biodiversity. The actions required to improve these areas should, if possible, be derived from individual farms in order to achieve improvement in the sum with regard to ecological sustainability.

In this analysis of ecological sustainability of German arable farms, initiated by the VLI, a result of 0.78 was found on the average for all project farms. This total value shows that the 32 investigated farms practice sustainable management in line with the ecological pillar.

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