Role of grassland in phosphorus-flows in mixed organic farms

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List of abbreviations

a^{-1}	Per year
asl	Above sea level
c.f.	Compare
CAL	Calcium ammonium lactate
DM	Dry matter
e.g.	For example
EU15	15 Member States of the European Union as of 2003
FM	Fresh matter
ha	Hectare
IFOAM	International Federation of Organic Agriculture Movements
K	Potassium
L	Liter
LMM	Linear mixed effects models
LTM	Long term monitoring
LU	Livestock unit
Mg	Magnesium
N	Nitrogen
NEL	Net energy lactation
OS	Original substance
P	Phosphorus
SD	Standard deviation
Tg	Teragram
TV	Threshold value

1 General Introduction

This thesis combines the topics of Phosphorus (P) as an essential and finite resource, and the development of P contents in various binding forms in soils under continuous negative soil P balances, with a special view on the role of grassland for P acquisition and P flows on an organic farm. The study is conducted at the experimental station of the Thünen Institute of Organic Farming, Trenthorst, in northern Germany. The goals of this thesis include evaluating measurement methods to quantify grazing intakes and grassland yield, to then use the results to identify farm nutrient balances, and, as a third goal, to assess the role of grassland within the farm nutrient balances. Also, the development of P forms in soil and parameters of biological activity that might influence P supply from soil reserves after twelve years of organic farming and without P-fertilizer import at the study site will be described.

1.1 Phosphorus in soil

Phosphorus is an element essential to all forms of life and thus for plant growth. This nutrient acts, for example, as a structural element of genetic information and has an important role in energy transfer (Grundon et al. 1997, Marschner and Marschner 2012). In a global context, P is often the most limiting nutrient in terrestrial ecosystems (Bünemann et al. 2011). As P is often in short supply for optimal plant and animal development, farmers use P fertilizer and P additives (Schoumans et al. 2015). Crops show dark green foliage and redding or purpling of leaves or petioles as symptoms of nutrient deficits (Bergmann 1988, Grundon et al. 1997). In addition, an adequate P supply plays a special role in the biological nitrogen fixation of legumes, which are cultivated as an essential part of organic crop rotations. For example: P fertilization on organic soils with low P availability results in positive effects on fixing nitrogen, higher yields of red clover and also on the yield of the subsequent crop (Römer et al. 2004).

The lithosphere comprises of meanly 0.1 % P. Therefore soil P contents range from 500 to 2,500 kg ha^{-1} (White 2006). But there is a difference between the existence of P in soils and its availability. Phosphorus occurs in organic and inorganic forms and is subject to many biochemical processes. Thus, P is found in soil biomass, soil organic matter, plant residues and soluble organic P, whereby organic forms in humic topsoils can comprise 20 – 70 % of the P stock in soil (Scheffer and Schachtschabel 2010). From a worldwide perspective, organic P forms make an important contribution to topsoil stocks (Stutter et al. 2012). Instead, soils with an intensive agricultural history contain large proportions of inorganic orthophosphate (Stutter et al. 2012). Inorganic P occurs as primary minerals (Apatites), secondary minerals (formed by precipitation of P with aluminum, calcium and iron) and P adsorbed onto clays, aluminum and iron oxyhydroxides (Sims and Pierzynski 2005).

Nevertheless, of the total amount of existent P, generally less than 0.1 % is present in the soil solution (Scheffer and Schachtschabel 2010), and only this P can be absorbed by plants. The soil solution contains predominantly inorganic P-compounds of $H_2PO_4^-$ and HPO_4^{2-} (Scheffer and Schachtschabel 2010). This small amount of plant available P is caused by a low content in the parent material, and the high reactivity of inorganic P and its strong retention by the soil´s mineral matrix (Jones and Oburger 2011), as well as by immediate uptake by plants and microbes.

Major processes in the P cycle are shown in Figure 1.1, and include:

- dissolution and precipitation processes which determine the mineral equilibria between primary P minerals and sorbed P.
- sorption and desorption processes with interaction between P in solution and P on solid surfaces (secondary P minerals).
- mineralization and immobilization processes that are biologically mediated conversions between organic and inorganic P forms (Sims and Pierzynski 2005).

According to the significant proportion of organically bound P, the role of microorganisms in P turnover is quite important (Jones and Oburger 2011). Microbes (like plants) have strategies to enhance P availability: they release protons, CO_2, and secondary organic metabolites and enzymes. By solubilizing insoluble organic- and mineral-bound P they have the potential to enhance the rate of P cycling in their closer environment (Jones and Oburger 2011).

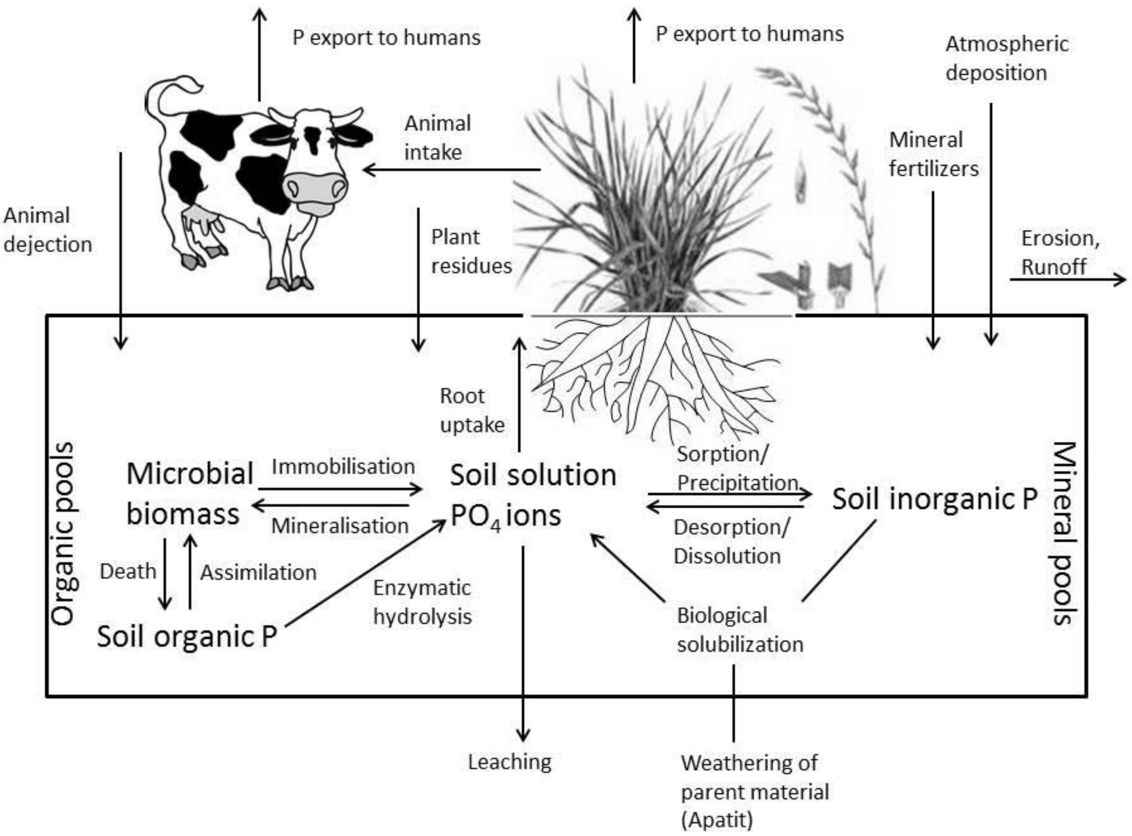

Figure 1.1 Soil P dynamics of cropped soils and grassland ecosystems (modified and combined from Oberson et al. 2011 and Jouany et al. 2011).

Countries like Germany with intensive agriculture and decades of large fertilizer inputs show a high P accumulation in the topsoil (Stutter et al. 2012, Tóth et al. 2014). To describe the extent of P accumulation: in the old federal states of Germany, the P input into agriculture by fertilization and feedstuff imports exceeded the outputs by 1,150 kg P ha^{-1} in the time period between 1959-2000 (Köster and Nieder 2007). Therefore in Germany 94 % of arable land currently has a sufficient supply of P (Römer 2014). With the intensification of conventional agriculture since the 1950s, the trend has been to specialize into cash crop farms or farms with intensive livestock production. This has led to unbalanced, regional distribution of plant-available P in soil. Regions with high animal density (e.g., Westfälische Bucht and Niederrheinisches Tiefland) show a high nutrient supply in soil (Figure 1.2, LANUV 2009). This is mainly caused by high nutrient imports with feedstuffs from other regions or global markets. Due to their P enrichment in soils, these areas should be used as nutrient sources a) by exporting excess P with manure and b) exporting P from soils by crops. In contrast, cash crop producing areas (e.g., Ostwestfalen, Bergisches Land and Sauerland) often have deficits (LANUV 2009) and depend on fertilizer imports.

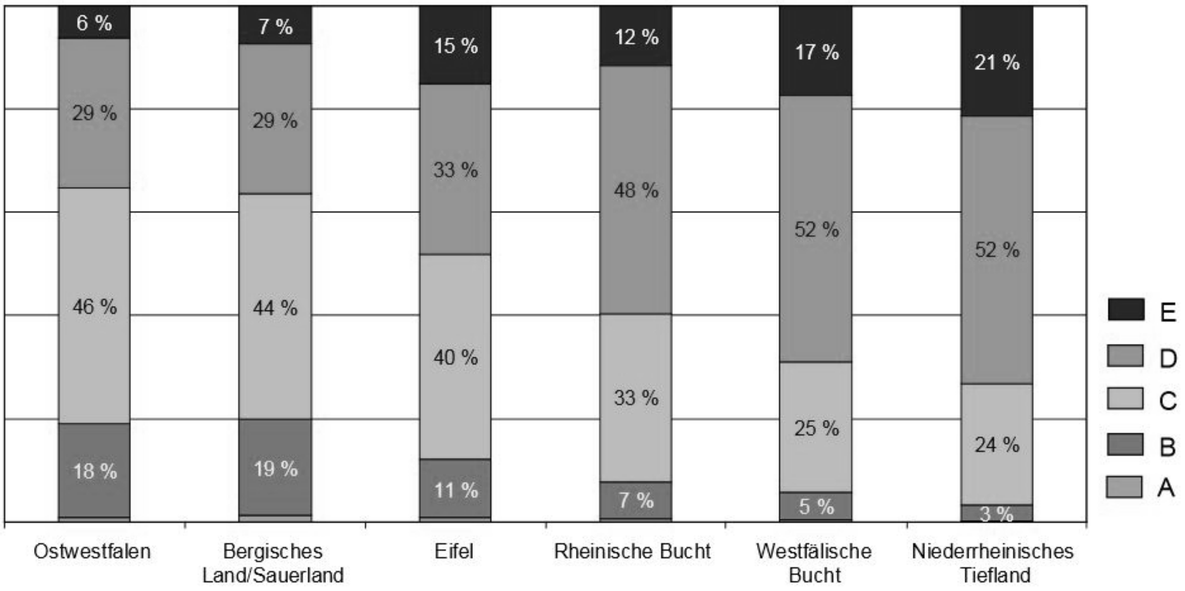

Figure 1.2 Phosphorus investigation of LUFA in 2007 in the federal state of North Rhine-Westphalia, Germany. Categories of Phosphorus supply in soil: A=very low, B=low, C=sufficient, D=high, E=very high (LANUV 2009).

In sum, P is an essential element for plant growth but only a small part of the P resource in soils is plant available. The availability depends on different processes, influencing the relation between the P forms and is also determined by environmental factors like vegetation cover, parent material, soil type, pH and cultivation (Bergmann 1988, Sims and Pierzynski 2005). Regions of intensive agriculture have been over-fertilized for decades and exhibit P-enriched soils which may act as nutrient sources for regions with nutrient demand, e.g, via nutrient transfer with feedstuff or resulting manures. For these reasons, recommendations based on the current understanding of P cycling and transport can improve P management (Sims and Pierzynski 2005). Due to high soil reserves and restrictions in fertilizer use on the one hand, and due to lower stocking densities and smaller yields on the other hand, the dynamics in the development of P supply in soils of organic farming should differ from those of intensive systems.

In organically managed soils, high percentages of areas with insufficient contents of available P in soils (7-30% of arable fields studied) are summarized in non-representative surveys in several federal states in Germany by Kolbe (2015). In Mecklenburg-Vorpommern stable P reserves were found over ten years under long term organic management with sufficient backflow of P with manure (Gruber und Thamm 2004). For organic farms in various districts in Austria, (Lindenthal 2000) reported high soil reserves of P and insignificant changes in available soil P at average farm balances of –1.5 kg a^{-1} P and +15.6 kg a^{-1} P. Also, when omitting P fertilization over a period of more than 40 years in a long term trial, only insignificant changes in soil available P were found (Lindenthal 2000). This excerpt of results shows that farm internal P flows, P imported with fertilizers, a history of P fertilization and the mobilization of P reserves from soils to large extent determine P supply in soils. Detailed studies on P considering all inputs, farm internal P flows and P mobilization processes on the farm level have, up to now, not been available for organic farming. Therefore the situation and development in a typical North German organic dairy farm serves as example for an analysis of P flows and aspects of P mobilization from soils in the current thesis.

1.2 Phosphorus as a limited resource in a broken cycle

Phosphate rock remains a non-renewable and finite resource (Van Kauwenbergh 2010). Since the 1950s, society has become dependent on the processing of phosphate rock to produce fertilizers, feed supplements, food additives, and detergents (Withers et al. 2015). Nearly all P fertilizer is produced from phosphate rock (Fixen and Johnston 2012). If soils are deficient in P, food production is restricted until this nutrient is added in the form of fertilizer (Syers et al. 2011). Contrary to former authors who estimated a fast decline of P reserves in the next 50-100 years (Cordell et al. 2009), a re-evalution of the worldwide resources by the US Geological Survey quadrupled the estimations in 2011 (US Geological Survey 2015). Therefore the expected life span of mineral reserves increased immediately, but nonetheless varies between the authors (Bundestag 2012, Fixen and Johnston 2012, Kratz et al. 2014, Rosemarin et al. 2011, Van Kauwenbergh et al. 2013). According to calculations by Van Kauwenbergh at al. (2013), the world reserves of phosphate rock that can currently be economically exploited using existing technology will be depleted in more than 300 years, whereas resources in any grade of availability and quality that may be produced at some time in the future will last more than 1,400 years. In comparison, Rosemarin et al. (2011) estimated the life span for P reserves for different scenarios (e.g., population growth rate, development of African agriculture, and expansion of bio-energy crops) at between 48 to 172 years. These authors also criticized the fact that information about the amount and the commercial viability of the exploitation of the possible reserves is not clear enough. It is stressed that data about rock phosphate reserves is only collected and published by the US Geological Survey, without any monitoring by a UN body.

Regardless of the exact life span of reserves, P is a non-renewable natural resource and there are many reasons for an efficent utilization of produced fertilizer and for the recycling of P from the food chain and other processes. First, northern European countries do not hold P reserves of their own, whereas Morocco and the Western Sahara hold three-quarters of the global P supplies (Van Kauwenbergh et al. 2013). Consequently food producers are, in the near future, in danger of becoming completely dependent on trade with Morocco (Elser and Bennett 2011, Kratz et al. 2014, Rosemarin et al. 2011). Second, the extraction and beneficiation of phosphate rock has potential negative environmental impacts, including damaging the landscape at mining sites, excessive water consumption, water contamination and air pollution (Syers et al. 2011). For example, in the production process of practically all conventionally used fertilizer, rock phosphate is treated with acid (e.g., sulfuric, nitric or phosphoric) to produce phosphoric acids or triple superphosphate (Van Kauwenbergh et al. 2013). Beside the impacts at the production site, problems can arise on the arable land due to an accumulation of fertilizer with heavy metals and radioactive elements like Uranium and Cadmium. In Germany up to 42 t Cadmium and 228 t of Uranium per year is added with P fertilizer (Smidt et al. 2012). The authors indicate a significant contamination risk of the agroecosystems with these toxic heavy metals. Right now, there is no efficient threshold value for Cadmium and Uranium contents in P fertilizer (Blazer et al. 2015). Third, the reduction of non-renewable recources decreases the potential for future generations to fullfill their nutrient needs and to freely choose their lifestyle (Ekardt et al. 2010). Moreover, the pressure on P increases related to rising population and food demand, increasing urbanization, and changes in diet (Schoumans et al. 2015).

Above all, a broken P cycle leads to severe environmental problems when P enters surface water (Figure 1.3). Accordingly, this can happen when excess fertilizer is applied to the soil, when soil is eroded, or when sewage effluents and its nutrients are discharged to water bodys in mining and processing regions (Syers et al. 2011). Currently, P losses by leaching and runoff in EU15 agriculture add up to 0.1 Tg P a^{-1} (Withers et al. 2015). As a consequence of disturbances of nutrient relations (C:N:P) in aquatic systems, a shift in biological communites and eutrophication can follow. Excessive algal and aquatic plant growth with oxygen depleted “dead zones” occurs in aquatic systems (Elser and Bennett 2011). In summary, the one way-flow of P into sweet water and coastal marine ecosystems leads to undesirable impacts on biodiversity, water quality, fish stocks and reduces the recreational value of water bodies (Syers et al. 2011). To exemplify the extent of the problem: In Schleswig-Holstein 75 % of the bodys of streaming water feature critical loads of total P, and consequently 80 % of the lakes and 100 % of ocean measurement points exceed threshold values of total P (LLUR 2014).

Subsequently, Schleswig-Holstein is not able to reach the targets of the EU Water Framework Directive (2000/60/EC) and Marine Strategie Framework (2008/56/EG) to achieve a good qualitative and quantitative status of existent water bodies.

In conclusion, essential mineral P fertilizer for agricultural production is derived from phosphate rock, for which reserves are located at few places on Earth (without significant mines in Europe) and are finite (Schoumans et al. 2015). Phosphorus fertilizer manufacture, distribution and application, and P losses in waterbodies lead to severe environmental impacts. Therefore it is necessary to implement coherent nutrient management strategies to close the P cyle, to redistribute P on the landscape level, and to avoid overflows on the field and farm levels to solve several of the major problems.

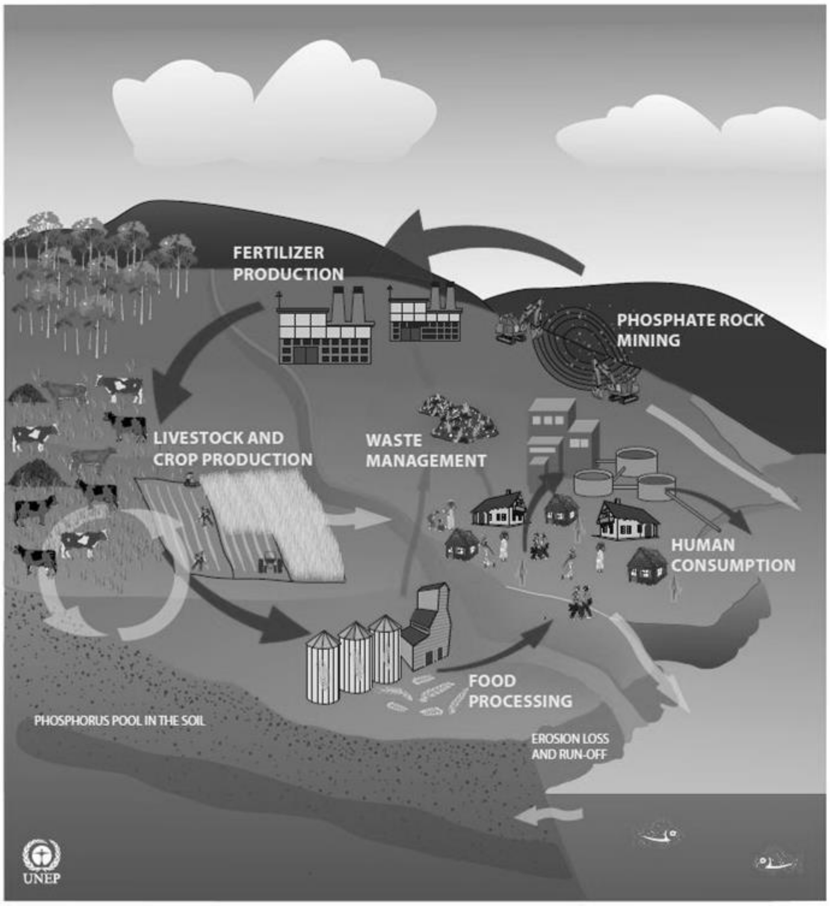

Figure 1.3 Phosphorus flows in the environment (Syers et al. 2011).

1.3 Organic farming and P management

Organic farming systems are linked by common objectives of economic, environmental and social sustainability (Stockdale et al. 2001). The IFOAM defines organic agriculture as follows: “Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved." The IFOAM established four principles of organic agriculture: health, ecology, fairness and care. In particular the principle of ecology says that in terms of nutrient cycling, inputs should be reduced by reuse, recycling and effective management to maintain and improve environmental quality and conserve resources (IFOAM 2015). Therefore organic agriculture calls for sustainable and balanced P management with a regional cycling of nutrients (Alföldi et al. 2014). Even early theories of organic farming included nutrient P flows from human food consumption waste streams back into agriculture (Rusch 1968, Howard and Wad 1931). Also, today, recycling P from excreta or other organic wastes seems to be an important opportunity to recover this nutrient (Syers et al. 2011).

But today's fertilisation practice in organic farming is problematic due to different limitations. The use of recycling products is restricted. Due to toxic components, the application of sewage sludge is not permitted. Otherwise there are various technologies to recover P from waste water and sewage sludge, whereas concentrations of nutrients and contaminants vary widely (Wollmann and Möller 2015). Therefore, currently suitable recycling products are discussed for use as fertilizers in organic farming (Hoffmann 2014, Wollmann and Möller 2015). Some P-containing organic materials like livestock manure and certified household compost are permitted (Commission Regulation (EC) No 889/2008). In addition to these recycling products, mineral fertilizers from non-renewable resources are restricted mainly to the use of rock-phosphates (EC No 889/2008), which have very limited plant availability in soils with pH ($CaCl_2$) > 5.5 (Scheffer and Schachtschabel 2010) – Noteworthy: The pH value of arable soils at the research farm serving as example in the current work is higher than 5.5, but grassland soil matches this value (Table 1.1, Figure 1.1). Anyway, for P with low solubility, a full utilisation can only be intrinsically expected over long periods (Schnug et al. 2003).

Due to accumulated soil reserves in agricultural soils in Europe (Barberis et al. 1996, Köster and Nieder 2007, Schröder et al. 2011, Withers et al. 2001, Schoumans et al. 2015) and relatively low yield levels, organic farmers often neglect P additions and rely on the biological mobilisation mechanisms of plants, microbes and mycorrhiza from soil reserves (Paulsen et al. 2016). However, the potential and suitability of this strategy is often unclear. In effect, organic farming may drift into nutrient mining, thus diminishing soil fertility and the sustainability of production (Schnug et al. 2003).

In brief, organic agriculture today can still cover the P demand of plants in significant parts of agricultural land in Western Europe in accordance with the current yield goal. The use of nutrient reserves in soils gives a time frame to develop closed systems – e.g., by recycling nutrients from the human food chain – but the duration until soil reserves are ultimately depleted is unclear.

1.4 Farm balances of P

In general, whole farm nutrient balances are used as nutrient management tools and for regulatory assessment on dairy farms (Gourley et al. 2012). An increasing nutrient surplus is especially associated with regions with high animal production (Schoumans et al. 2015). Surpluses imply the potential for negative environmental impacts (Gourley et al. 2012, Haas et al. 2005). In contrast to intensive conventional farming practice, organic farming primarily faces the problem of too few rather than too many nutrients, and therefore yield is often nutrient limited. There are several studies about P farm budgets in organic farming (e.g., Haas et al. 2007, Lindenthal 2000, Modin-Edman et al. 2007, Steinshamn et al. 2004). They found positive and negative farm P balances. The Austrian study mentioned above focused on farm gate P-balances of different organic farm types. Farm gate balances had a range of -1.9 to 7.8 kg P ha^{-1} a^{-1} and, when only mixed farms were considered, slightly positive P balances were observed (Lindenthal 2000). For 26 German organic farms, Haas et al. (2007) calculated mean farm gate deficits of -3 kg P ha^{-1} a^{-1} (range -14 to 4 kg P ha^{-1} a^{-1}). For federal states in Germany Kolbe (2015) calculated from seven studies about P-budgets of organic arable land a mean deficit of -5 kg P ha^{-1} a^{-1} (range -16 to 26 kg P ha^{-1} a^{-1}). In contrast to farmgate balances, inner farm nutrient cycles provide information about nutrient distribution and redistribution within the farm. For example, nutrient transfer between arable land and grassland can be estimated (Möller 2009). The internal nutrient flow is a useful tool to improve the nutrient utilization on organic dairy farms (Steinshamn 2004). Quantification of a detailed inner farm P flow of an organic dairy farm with a special focus on the P mobilization performance of grassland has not yet been done.

1.5 Grassland

In grassland ecosystems, grasses are, beside legumes and herbs in different proportions, the dominating species in the majority of cases. Correspondingly, grassland agriculture is a farming system that emphasises the importance of grasses and legumes, whereas pastures are maintained through grazing (Barnes and Taylor 1985). Grassland is defined as “permanent” if the land has not been ploughed for several years. Simultaneously, there are some areas where the grassland is called “absolute” (Klapp 1971) or “natural” (Whitehead 2000) in reference to its environmental condition. Likewise high water tables, high precipitation rates with short growing season or steep slopes make arable farming impossible (Klapp 1971) and therefore grassland agriculture is unrivalled. In Germany, areas with a high percentage of permanent grassland are located in mountain regions in the central and southern parts, as well as in coastal areas (Figure 1.4). In total, the area of German grassland comprised 4,772,000 ha in 2012, corresponding to 28.3 % of the total area of agricultural land (Statistisches Bundesamt 2014). Of this land, 209,600 ha of permanent grassland are unprofitable or abandoned (Statistisches Bundesamt 2014), but have potential to substitute other fodder sources for ruminants (Ohm et al. 2014). Overall, grassland-based food plays a more important role in organic farming (56 % of the organic farmed area are grassland) than in conventional farming (26 % of the area) (Statistisches Bundesamt 2014). These data are supported by an analysis of farm network data which showed that in organic farming, the ratio of feed of dairy cows from pasture is significantly higher than in conventional farming (Warnecke et al. 2014). In addition, grazing has consequences for animal welfare: Pasture access allows cattle to carry out their natural social behavior as well as their natural locomotion behavior including lying down and moving around (Bartussek 1999, Schrader and Mayer 2004), and pasture access can result in lower lameness rates in relation to zero-grazing systems (Haskell et al. 2006, Hernandez-Mendo et al. 2007, Olmos et al. 2009). Beside the impact on animal welfare, grassland fulfils different functions like obtaining biodiversity (Isselstein et al. 2005), flood protection (Wagner et al. 2009) or as a carbon sink (Scurlock and Hall 1998, Soussana et al. 2004). Biodiverse grassland makes the landscape more attractive and has an aesthetic value with a positive impact on tourism (Lindemann-Matthies et al. 2010, Parente et al. 2012).

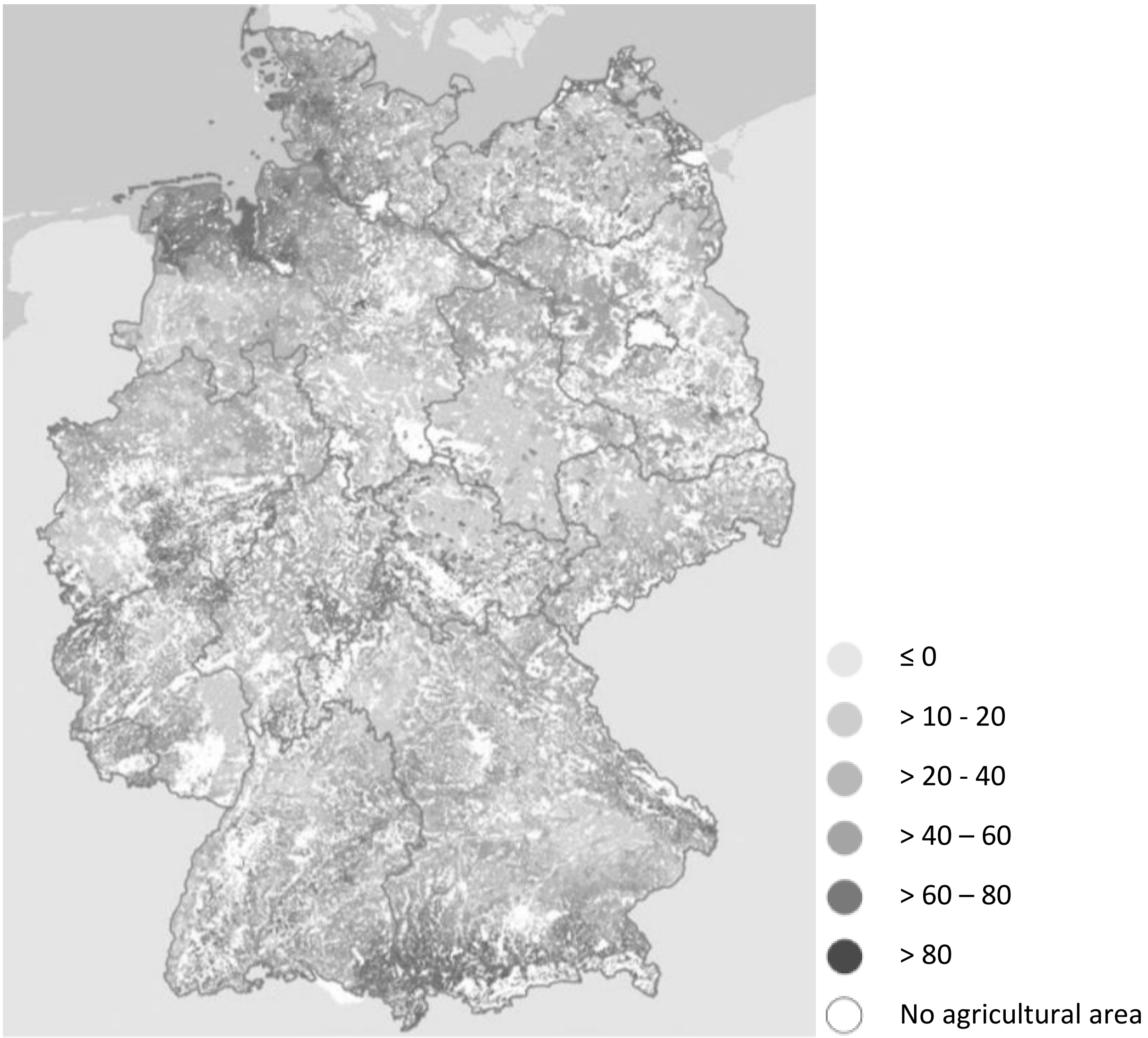

Figure 1.4 Proportion of permanent grassland of the agricultural land in Germany, 2010 (modified according to Röder et al. 2015).

Grassland ecosystems can exploit several pathways in the P cycle because biological and geochemical processes occur on different scales in the soil-plant system (cf. Chapter 1.1, Jouany et al. 2011). Particularly in grassland, the nutrient cycling is affected by ruminant animals, for example, by return of nutrients in excreta, repeated defoliation of plants, and compaction of the soil (Whitehead 2000). Root parameters (like root architecture, specific root length, and long root hairs) are positively affected due to the permanent ground cover. Furthermore, significant correlations were observed between root parameters and P uptake for rye grass and red clover (Steffens 1984). Also the biological activity is promoted by permanent vegetation cover. Thus, soil microorganisms are involved in many transformations like the release of nutrients in soluble and plant available forms (cf. Chapter 1.1, Whitehead 2000). Grassland soils (with low humus contents) have a lower pH optimum than soils of arable land. For example, sandy loam with a humus content between 0-4 % should have a pH-value between 5.6-6.5 on grassland and

6.3-7.0 on arable soils (Landwirtschaftskammer Niedersachsen 2011). If rock phosphate is applied as a fertilizer to acid soil it becomes slowly available (Whitehead 2000) and therefore might be better placed in grassland than arable land.

To sum up, grassland has a high relevance for agriculture, especially for organic farming. Within multifunctional services, grassland has high performance in the P cycle. It might act as a P resource due to the transfer of nutrients from grassland to arable land via food conserves and stable manure.

1.6 General goals of the thesis

Phosphorus is a finite resource but an essential element for plant nutrition in agriculture (Chapter 1.1 and 1.2). Organic agriculture is restricted in P fertilisation (Chapter 1.3), and therefore P supply is problematic until a closed nutrient cycle can be developed in the future. The optimization of inner farm nutrient flows is a useful tool to improve nutrient utilization (Chapter 1.4). Grassland might play a special role in inner farm nutrient transfer due to its performance in P cycling (Chapter 1.5). Therefore the overall goal of this case study is to develop knowledge about the mobilisation of P from organic grassland sites with fitting methods and to estimate its importance for farm P balances. The role of grassland is analysed in the context of development of P supply in soils and of enzymatic parameters at arable land and grassland sites after converting to organic farming over several years. In accordance to the overall aim of the thesis, different aspects and assumptions were investigated in the three scientific studies in Chapters 2, 3 and 4.

The first study (Chapter 2) focuses on grazing management and presents a suitable method for estimation of grazing intake of cattle on pasture plots. The data were used to calculate the global warming potential of milk due to effects of substituting grass silage by improved grazing management. This data also provide the basis for calculations of P cycling in dairy farming with livestock grazing in the second study (Chapter 3).

The second study (Chapter 3) calculates the inner farm P flow in an organic dairy farm for the years 2010 to 2012. The objective is to quantify P mobilization and the inner farm P under detailed inclusion of grassland, grazing animals and arable feedstock. Also the study discusses the inner farm P transfer between permanent grassland and arable land via the dairy stables to emphasise the contribution of grassland as a component of sufficiency P management.

In the third study (Chapter 4) initial soil parameters of the P supply are compared between two arable farming systems and permanent grassland on the same site under comparable soil and climate conditions. Soil samples taken directly after conversion to organic farming and after twelve years without additional P import are used for analysis. Soils of arable land of a stockless crop rotation (without P fertilizer or manure) and a dairy crop rotation (fertilized with manure) and its related grassland are analyzed. Different P fractions (primarly focusing on plant available P), enzyme activites in topsoils and P concentrations in plants are assessed. This study analyses the effects of the recent farming practice and indicates P mobilisation potential from soil reserves.

To sum up, the current work undertakes the following tasks:

1) Evaluate measurement methods to quantify grazing intakes of livestock and grassland yields on the research farm for use in farm nutrient balances.
2) Quantify the P flow on the organic dairy farm with a focus on the importance of grassland.
3) Analyze the effects of twelve years organic farming without external P fertilizer on parameters of P supply.

1.7 Study site

The experimental station of the Thünen-Institute of Organic Farming, Trenthorst, is located in northern Germany (53°46’ N, 10°30’ E; 10-43 m asl), approximately 20 km to the south of Lübeck (Figure 1.5). This area is typical for the landscape “Östliches Hügelland” (eastern hill country) in Schleswig-Holstein. Mean annual precipitation is 706 mm and mean annual temperature is 8.8°C (1978-2007). Prior to 2001, the farm was conventionally managed with dairy cows. In these former times, an over-fertilization with P was typical for European soils (cf. Chapter 1.1, Barberis et al. 1995, Schoumans et al. 2015). Also soils on the investigated farm showed sufficient available P contents in soils. The farm converted to organic farming in 2001 and is a representative example of an organic farm with a high nutrient supply when converting.

Figure 1.5 Location of the research farm Trenthorst (Map source: openstreetmap, photo: Thünen-Institute).

The soils of the grassland and arable land are characterized as Cambisols and Luvisols with soil type sandy loam (46 % sand, 34 % silt and 18 % clay in the topsoil). On average, the permanent grassland has 38 % sand, 41 % silt and 16 % clay. Soil properties of pH, C_{tot} and N_{tot} are listed in Table 1. The farm under study is geographically divided into different farm businesses, from which the dairy system and the stockless system are in focus (Figure 1.6). The stockless rotation is not fertilized at all and the dairy rotation is fertilized with organic dung. The ‘stockless’ crop rotation (36 ha) is cultivated by the following crop rotation: red clover – wheat – spring barley + pea – rape – triticale + red clover. The other system (‘dairy’) consists of 62 ha arable land and 54 ha grassland to provide food for the around 80 dairy cows and their offspring. The ‘dairy’ crop rotation consists of grass + clover – grass + clover – maize – wheat – faba bean – triticale.

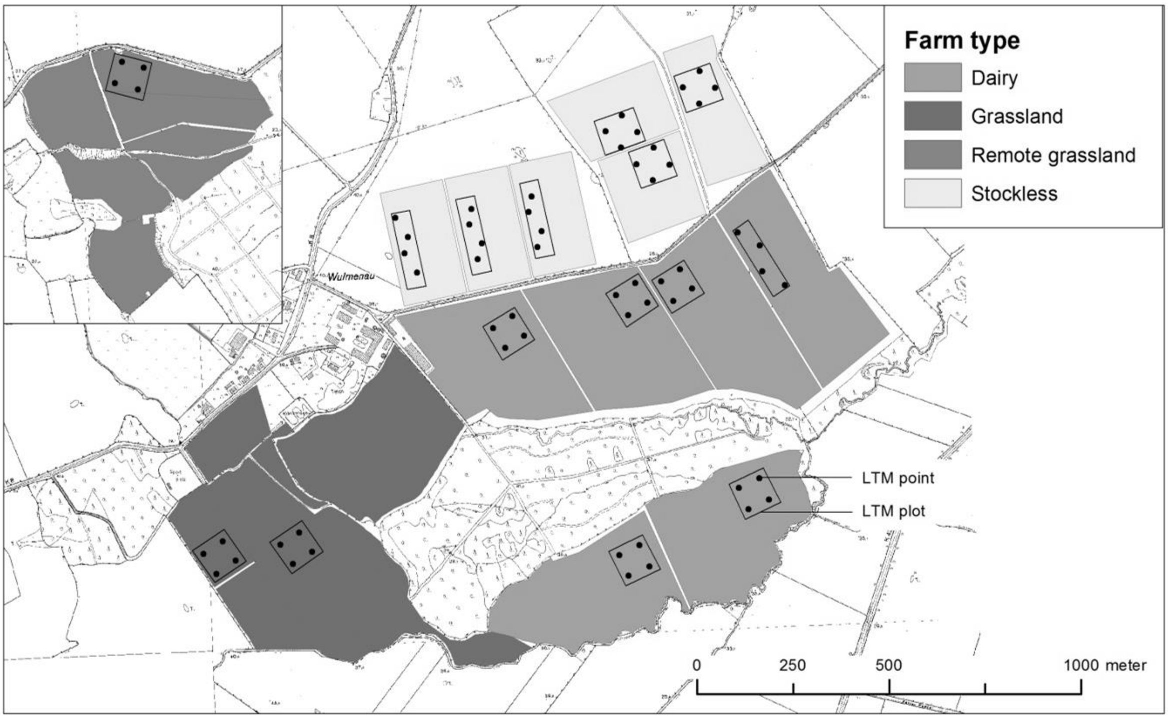

Figure 1.6 Different crop rotations at the research farm Trenthorst.

The grassland belongs to the dairy system and has mostly been intact for the last decades. Only two plots were subjected to sward cultivating and were ploughed, but more than five years before soil sampling. Therefore all plots can be defined as 'permanent grassland'. Only a few areas would be called "absolute" according to their high water tables (c.f. Chapter 1.5). Typically, farm grassland shows lower pH-values than arable land (Figure 1.7, Table 1.1, Chapter 1.5). Feed analysis of 17 samples from different grassland plots and different cuts on the site under study in one year showed the quality variation between the samples. The mean energy content was 6.4 (±0.85) MJ kg^{-1} NEL with a minimum of 4.8, and maximum of 7.5 MJ kg^{-1} NEL (Table 1.2).

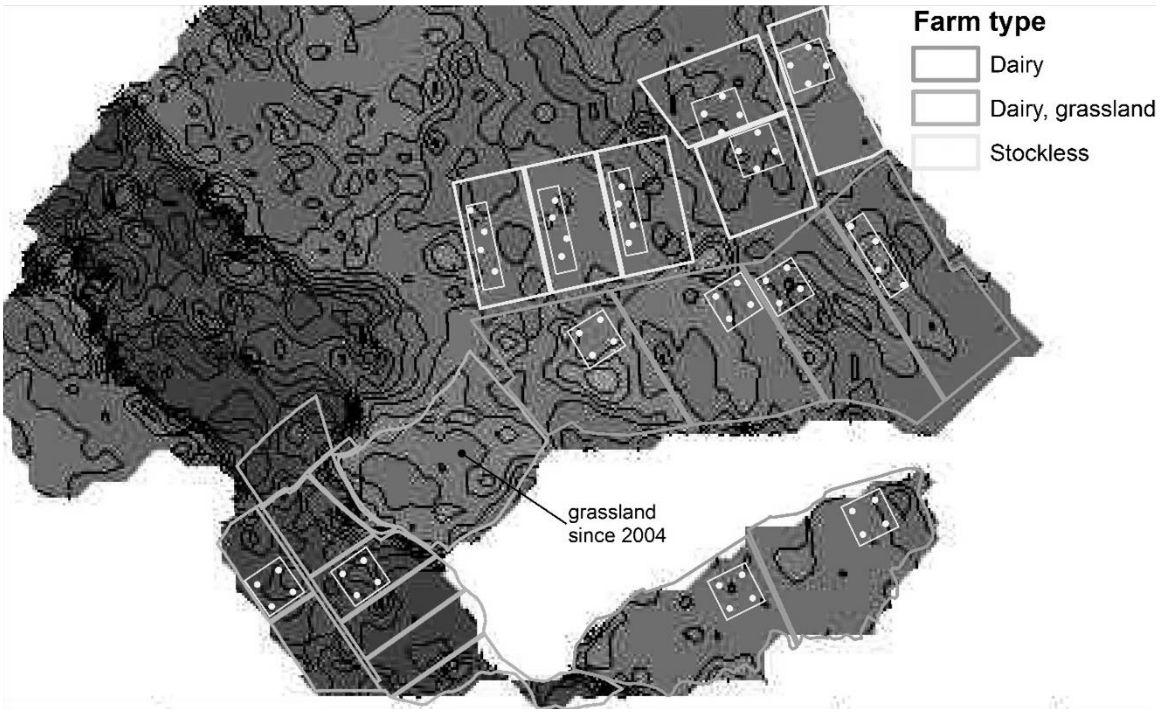

Figure 1.7 The pH-values in topsoils at the research farm Trenthorst (2002) show an obvious boundary between arable land and grassland (dark colored) (Min. 4.4– Max. 7.4) (Results from raster sampling: Paulsen, Thünen-Institute, personal communication).

The plant-available P fraction was determined as P (CAL) (Schüller 1969) and was twice as high in grassland as in arable land (Table 1.1). According to official fertilizing recommendations, the P (CAL) content of the arable land was categorized as sufficient (class C) and for permanent grassland as high (class D) (Landwirtschaftskammer Niedersachsen 2011). For organic farming, lower values (class B) are seen as sufficient (Kolbe 2001). So also K and Mg contents in topsoils (Table 1.1) were still in adequate ranges.

In relation to “Geest” (pleistocene sand) areas, the biological parameters of arable soils in “Östliches Hügelland” (boulder marl) in a landscape study in northern Germany were higher in microbial biomass and dehydrogenase and alkaline phosphatase activities (Beyer et al. 1992). In the current study alkaline phosphatase activities found in the loamy soils (boulder marl) in Trenthorst were found to be much higher and dehydrogenase activities in the same range (c.f. study 3).

In conclusion, the research farm represents an organic farm with nutrient (P, K, and Mg) contents in the topsoil ranging from sufficient to high, according to the recommendations for organic farms by Kolbe (2001). The farm faces continuous depletion of nutrient soil reserves due to continuous net nutrient exports, since the conversion occurred with a sufficient-to-high P level in top soil supply at the outset due to its conventional farming fertilization history.

Table 1.1 Soil properties of arable land and grassland calculated from long term monitoring data in 2003 and 2013 (per year n=24 for arable crop rotation and n=8 for grassland).

System	**Year**	**pH**	**C_{tot} g kg^{-1}**	**N_{tot} g kg^{-1}**	**Mg ($CaCl_2$) mg kg^{-1}**	**K (CAL) mg kg^{-1}**	**P (CAL) mg kg^{-1}**
Stockless	2003	6.9 ±0.22	14.1 ±2.1	1.4 ±0.2	195 ±51	149 ±31	92.5 ±21
	2013	6.6 ±0.25	12.6 ±2.1	1.2 ±0.2	110 ±21	101 ±20	66.6 ±13
Dairy	2003	6.7 ±0.19	14.0 ±5.6	1.4 ±0.5	181 ±67	136 ±29	90.3 ±28
	2013	6.5 ±0.26	12.7 ±1.6	1.2 ±0.2	105 ±18	112 ±18	66.1 ±14
Grassland	2003	5.5 ±0.16	35.3 ±5.5	3.6 ±0.5	339 ±68	228 ±13	160.8 ±25
	2013	5.5 ±0.13	26.2 ±2.6	2.5 ±0.2	199 ±20	194 ±7.8	132.8 ±9.7

Threshold value for sufficient soil supply from Landwirtschaftskammer Niedersachsen (2011) according to farm specific characteristics: for arable land pH > 6.3; Mg > 0.6 mg kg^{-1}; K > 1.1 mg kg^{-1}; P > 0.5 mg $kg^{-1}$and for grassland pH > 5.6; Mg > 1.4 mg kg^{-1}; K > 1.1 mg kg^{-1} soil; P > 0.5 mg kg^{-1}

Table 1.2 Results of feed quality analysis of grassland at different plots and cuts in Trenthorst 2012.

plot	cut	Height[1] [cm]	Grass [%]	Clover [%]	Herbs [%]	crude protein [%]	crude fibre [%]	sugar [%]	crude lipid [%]	NEL [MJ kg^{-1}]
1106	2	20.2	70	30	0	9.9	26.2	9.9	1.2	4.8
1107	2	9.3	95	0	5	9.1	24.8	18.4	1.2	5.1
1106	3	26.1	90	10	0	13.7	25.8	8.6	2.1	5.3
1102	5	11.2	75	5	20	12.8	23.5	12.1	2.2	5.7
1105	2	15.0	90	8	2	12.0	25.0	15.2	2.1	5.8
1109	3	18.4	70	20	10	11.5	24.3	13.3	2.1	5.8
1101	3	10.3	75	5	20	9.8	21.8	21.9	2.1	6.3
1101	1	32.0	60	10	30	13.6	22.4	11.8	2.9	6.4
1210	2	25.9	75	20	5	9.3	24.4	22.7	2.1	6.5
1109	4	17.9	70	5	25	14.8	20.3	15.0	3.2	6.6
1103	4	14.3	65	15	20	15.1	20.2	15.7	3.4	6.9
1101	1	25.4	60	20	20	13.3	18.8	19.0	3.1	7.0
1109	5	13.8	70	25	5	22.0	18.4	11.7	4.3	7.1
1109	1	28.1	80	10	10	14.0	19.9	19.0	3.1	7.2
1200	5	8.7	75	15	10	16.7	17.0	15.9	3.8	7.3
1102	4	15.9	65	10	25	19.4	17.1	6.9	4.3	7.4
1200	1	25.0	85	10	5	14.4	17.3	26.1	3.1	7.5

[1] Height is measured by rising plate meter (c.f. Study 1), NEL = Net energy lactation

1.8 References

Alföldi T, Nowack K, Bickel R, Rebholz T (2014) Biowissen-Fakten und Hintergründe zur biologischen Landwirtschaft und Verarbeitung. BIOWISSSEN Forschungsinstitut für biologischen Landbau (FiBL) und Bio Suisse, CH-Frick und CH-Basel

Barberis E, Marsan FA, Scalenghe R, Lammers A, Schwertmann U, Edwards A, Maguire R, Wilson M, Delgado A, Torrent J (1995) European soils overfertilized with phosphorus: Part 1. Basic properties. Fert Res 45(3):199-207

Barnes R, Taylor T (1985) Grassland agriculture and ecosystem concepts. In: Heath ME, Barnes RF, Metcalfe CD (eds) Forages: The science of grassland agriculture. Iowa, USA

Bartussek H (1999) Die Weidehaltung von Milchkühen aus der Sicht des Tierschutzes. Bericht über das 5. Alpenländische Expertenforum zum Thema "Zeitgemäße Weidewirtschaft" vom 18.-19.03.1999, BAL Gumpenstein, Irdning 5:1-14

Bergmann W (1993) Ernährungsstörungen bei Kulturpflanzen 3. Auflage, Gustav-Fischer-Verlag Jena Stuttgart, pp. 37-52, 111

Beyer L, Wachendorf C, Balzer FM, Balzer-Graf UR (1992) The use of biological methods to determine the microbials activity of soils under cultivation. Biol Fertil Soils 13:242-247

Bundestag (2012) Antwort der Bundesregierung auf die Kleine Anfrage der Abgeordneten Cornelia Behm, Friedrich Ostendorff, Dorothea Steiner, weiterer Abgeordneter und der Fraktion BÜNDNIS 90/ DIE GRÜNEN "Phosphatversorgung der Landwirtschaft sowie Strategien und Maßnahmen zur Förderung des Phosphatrecyclings". Drucksache 17/11264

Bünemann EK, Oberson A, Frossard E (2011) Phosphorus in action: Biological processes in soil phosphorus cycling. Heidelberg, Germany: Springer

Cordell D, Drangert JO, White S (2009) The story of phosphorus: Global food security and food for thought. Global Environ Chang 19(2):292-305

Ekardt F, Holzapfel N, Ulrich AE (2010) Phosphorus, Land Use and Absolute Quantity Reductions as a Legal Problem. Journal for European Environmental & Planning Law 7(3):267-286

Elser J, Bennett E (2011) Phosphorus cycle: a broken biogeochemical cycle. Nature 478(7367):29-31

Fixen PE, Johnston AM (2012) World fertilizer nutrient reserves: a view to the future. J Sci Food Agr 92(5):1001-1005

Gourley CJP, Dougherty WJ, Weaver DM, Aarons SR, Awty IM, Gibson DM, Hannah MC, Smith AP, Peverill KI (2012) Farm-scale nitrogen, phosphorus, potassium and sulfur balances and use efficiencies on Australian dairy farms. Anim Prod Sci 52(10):929-944

Gruber H, Thamm U (2004) Entwicklung der Grundnährstoffgehalte und des pH-Wertes im Boden nach 10-jähriger Bewirtschaftung nach den Richtlinien des ökologischen Landbaus. Mitteilungen der Landesforschungsanstalt für Landwirtschaft und Fischerei Mecklenburg-Vorpommern, 33.

Grundon NJ, Robson AD, Lambert MJ, Snowball K (1997) Nutrient Deficiency and toxicity symptoms. In: Reuter DJ, Robinson JB, Dutkiewicz C (ed.) Plant analysis: an interpretation manual. 2nd Edition. Collingwood, Australia: CSIRO publishing, pp.35-47

Haas G, Bach M, C. Z (2005) Landwirtschaftsbürtige Stickstoff- und Phosphor-Bilanzsalden. LÖBF-Mitteilungen (2/05):45-49

Haas G, Deittert C, Kopke U (2007) Farm-gate nutrient balance assessment of organic dairy farms at different intensity levels in Germany. Renew Agr Food Syst 22(3):223-232

Haskell M, Rennie L, Bowell V, Bell M, Lawrence A (2006) Housing system, milk production, and zero-grazing effects on lameness and leg injury in dairy cows. J Dairy Sci 89(11):4259-4266

Hernandez-Mendo O, von Keyserlingk MAG, Veira DM, Weary DM (2007) Effects of Pasture on Lameness in Dairy Cows. J Dairy Sci 90(3):1209-1214

Hoffmann C (2014) Untersuchung ausgewählter Phosphorrückgewinnungsverfahren – Wo liegt das Potenzial für den ökologischen Landbau? Bachelorarbeit, Fachbereich Ökologischer Land- und Pflanzenbau. Universität Kassel

Howard A, Wad YD (1931) The waste products of agriculture. Their Utilization as Humus. Oxford University Press

IFOAM (2015) Principles of Organic Agriculture. http://www.ifoam.bio/sites/default/files/poa_english_web.pdf (accessed 29.12.15)

Isselstein J, Jeangros B, Pavlu V (2005) Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe–a review. Agron Res 3(2):139-151

Jones DL, Oburger E (2011) Solubilization of Phosphorus by Soil Microorganisms In: Bünemann EK, Oberson A, Frossard E (eds.) Phosphorus in Action. Springer Berlin Heidelberg, pp. 169-198

Jouany C, Cruz P, Daufresne T, Duru M (2011) Biological Phosphorus Cycling in Grasslands: Interactions with Nitrogen. In: Bünemann EK, Oberson A, Frossard E (eds.) Phosphorus in Action. Springer, Berlin Heidelberg pp. 275-294

Klapp EL (1971) Wiesen und Weiden. Parey Berlin

Kolbe H (2001) Anleitung zur P-, K-, Mg-und Kalk-Düngung im ökologischen Landbau [Instructions for phophorous, potassium, magnesium and lime fertilisation in organic agriculture.]. SÖL-Berater-Rundbrief (3):3-9

Kolbe H (2015) Wie ist es um die Bodenfruchtbarkeit im Ökolandbau bestellt: Nährstoffversorgung und Humusstatus? Tagung des Verbandes der Landwirtschafts-kammern e. V. (VLK) und des Bundesarbeitskreises Düngung (BAD): Bodenfrucht-barkeit - Grundlage erfolgreicher Landwirtschaft, BAD Tagungsband 2015:89-123

Köster W, Nieder R (2007) Wann ist eine Grunddüngung mit Phosphor, Kalium und Magnesium wirtschaftlich vertretbar? Bodenfruchtbarkeit und Pflanzenernährung, Heft 1, 2. Auflage http://www.beratung-mal-anders.de/pdf/Wann_ist_eine_Grundduengung_wirtschaftlich_DIN_A_4.pdf (accessed 14.4.2015)

Kratz S, Schick J, Shwiekh R, Schnug E (2014) Abschätzung des Potentials erneuerbarer P-haltiger Rohstoffe in Deutschland zur Substitution rohphosphathaltiger Düngemittel. Journal für Kulturpflanzen, Verlag Eugen Ulmer KG, Stuttgart 66(8):261-275

LLUR Landesamt für Landwirtschaft und ländliche Räume S-H (2014) Nährstoffe in Gewässern Schleswig-Holsteins Entwicklung und Bewirtschaftungsziele. Schriftreihe LLUR SH- Gewässer, D 24

Landwirtschaftskammer Niedersachsen (2011) Richtwerte für die Düngung in Niedersachsen. http://www.lwk-niedersachsen.de/index.cfm/portal/pflanze/nav/341/article/11622.html

LANUV Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westphalen (2009) Biomasse aus Abfällen. Gibt es ein optimales Stoffstrommanagement? Tagungsband. LANUV-Fachbericht 18 https://www.lanuv.nrw.de/uploads/tx_commercedownloads/30018.pdf (accessed at 1.8.2016)

Lindemann-Matthies P, Junge X, Matthies D (2010) The influence of plant diversity on people’s perception and aesthetic appreciation of grassland vegetation. Biol Conserv 143(1):195-202

Lindenthal T (2000) Phosphorvorräte im Boden, betriebliche Phosphorbilanzen und Phosphorversorgung im Biologischen Landbau - Ausgangspunkte für die Bewertung einer großflächigen Umstellung ausgewählter Bundesländer Österreichs auf Biologischen Landbau hinsichtlich des P-Haushalts. Dissertation. Universität für Bodenkunde, Wien.

Marschner H, Marschner P (2012) Marschner's mineral nutrition of higher plants. Academic press.

Modin-Edman A-K, Öborn I, Sverdrup H (2007) FARMFLOW—A dynamic model for phosphorus mass flow, simulating conventional and organic management of a Swedish dairy farm. Agr Syst 94(2):431-444

Möller K (2009) Inner farm nutrient flows between arable land and permanent grassland via the stable in organic cropping systems. Eur J Agron 31(4):204-212

Oberson A, Pypers P, Bünemann EK, Frossard E (2011) Management Impacts on Biological Phosphorus Cycling in Cropped Soils In: Bünemann EK, Oberson A, Frossard E (eds.) Phosphorus in Action. Springer Berlin Heidelberg, pp. 431-458

Ohm M, Brinkmann J, March S, Warnecke S, Koopmann R, Paulsen HM (2014) Das Grünland und der Wiederkäuer - Futteransprüche und Tierwohl als Potentiale für die Biodiversitätserhaltung. Agrobiodiversität 34:178-202

Olmos G, Boyle L, Hanlon A, Patton J, Murphy JJ, Mee JF (2009) Hoof disorders, locomotion ability and lying times of cubicle-housed compared to pasture-based dairy cows. Livest Sci 125(2):199-207

Parente G, Bovolenta S, Warda M (2012) Grassland-a European resource? Proceedings of the 24th General Meeting of the European Grassland Federation, Lublin, Poland, 3-7 June 2012, pp. 733-743

Paulsen HM, Köpke U, Oberson A, Rahmann G (2016) Phosphorus - The predicament of organic farming. In Schnug E, De Kok LJ (eds.) Phosphorus-100% Zero, Springer Ntherlands, pp. 195-213

Römer W, Gerke J, Lehne P (2004) Phosphatdüngung erhöht Stickstofffixierung bei Leguminosen. Ökologie und Landbau 4(132):37-39

Römer W (2014) Die Versorgung der deutschen Ackerböden mit Phosphat und die Herausforderungen der Zukunft. Bodenschutz 4:125-130

Rosemarin A, Schroder JJ, Dagerskog L, Cordell D, Smit AL (2011) Future supply of phosphorus in agriculture and the need to maximise efficiency of use and reuse. Proceedings of the International Fertiliser Society - Proceedings 685 685:1-28

Rusch HP (1968) Bodenfruchtbarkeit: Eine Studie biologischen Denkens. Heidelberg: Haug

Scheffer F, Schachtschabel P (2010) Lehrbuch der Bodenkunde. Spektrum Akademischer Verlag, Berlin, pp. 412-420

Schnug E, Rogasik J, Haneklaus S (2003) The utilisation of fertiliser P with special view to organic farming. Landbauforsch Volk 53(1):1-11

Schoumans O, Bouraoui F, Kabbe C, Oenema O, van Dijk K (2015) Phosphorus management in Europe in a changing world. Ambio 44(2):180-192

Schrader L, Mayer C (2004) Aspekte der Tiergerechtheit bei der Weidehaltung von Rindern. Ressourcenschonende Grünlandnutzung–Erfolge, Probleme, Perspektiven– 32

Schröder J, Smit AL, Cordell D, Rosemarin A (2011) Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use. Chemosphere 84(6): 822-831

Schüller H (1969) Die CAL-Methode, eine neue Methode zur Bestimmung des pflanzenverfügbaren Phosphates in Böden. Z Pflanz Bodenkunde 123(1):48-63

Scurlock J, Hall D (1998) The global carbon sink: a grassland perspective. Global Change Biol 4(2):229-233

Sims JT, Pierzynski GM (2005) Chemistry of Phosphorus in Soils. Soil Sci Soc Am Bk (8):151-192

Smidt GA, Landes FC, Machado de Carvalho L, Koschinsky A, Schnug E (2012) Cadmium and Uranium in German and Brazilian Phosphorous Fertilizers. In: Merkel B, Schipek M (eds) The New Uranium Mining Boom. Springer Geology, Springer Berlin Heidelberg, pp. 167-175

Soussana JF, Loiseau P, Vuichard N, Ceschia E, Balesdent J, Chevallier T, Arrouays D (2004) Carbon cycling and sequestration opportunities in temperate grasslands. Soil Use Manage 20(2):219-230

Statistisches Bundesamt (2014) Federal Statistical Office https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/LandForstwirtschaftFischerei/FeldfruechteGruenland/AktuellGruenland2.html;jsessionid=D65B94E75E9AAD6F8DB8190653CFB9DC.cae2 (accessed 14.4.2014)

Steffens D (1984) Wurzelstudien und Phosphat-Aufnahme von Weidegras und Rotklee unter Feldbedingungen. Zeitschrift für Pflanzenernährung und Bodenkunde 147(1):85-97

Steinshamn H, Thuen E, Bleken MA, Brenøe UT, Ekerholt G, Yri C (2004) Utilization of nitrogen (N) and phosphorus (P) in an organic dairy farming system in Norway. Agr Ecosyst Environ 104(3):509-522

Stutter MI, Shand CA, George TS, Blackwell MS, Bol R, MacKay RL, Richardson AE, Condron LM, Turner BL, Haygarth PM (2012) Recovering phosphorus from soil: a root solution? Environ Sci Technol 46(4):1977-1978

Stockdale EA, Lampkin NH, Hovi M, Keatinge R, Lennartsson EKM, Macdonald DW, Padel S, Tattersall FH, Wolfe MS, Watson CA (2001) Agronomic and environmental implications of organic farming systems. In: Sparks DL (ed) Advances in Agronomy, Vol 70. San Diego: Elsevier Academic Press Inc, pp. 261-327

Syers K, Bekunda M, Cordell D, Corman J, Johnston J, Rosemarin A, Salcedo I, Lougheed T (2011) Phosphorus and food production. UNEP Year Book pp. 34-45 http://new.unep.org/yearbook/2011/pdfs/phosphorus_and_food_productioin.pdf (accessed at 1.8.2016)

Tóth G, Guicharnaud R-A, Tóth B, Hermann T (2014) Phosphorus levels in croplands of the European Union with implications for P fertilizer use. Eur J Agron 55(0):42-52

US Geological Survey (2015) Phosphate Rock Statistics and Information http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/ (accessed 11.4.2015).

Van Kauwenbergh SJ (2010) World phosphate rock reserves and resources. IFDC Muscle Shoals

Van Kauwenbergh SJ, Stewart M, Mikkelsen R (2013) World reserves of phosphate rock… a dynamic and unfolding story. Better Crops 97(3):18-20. http://www.ipni.net/publication/bettercrops.nsf/0/C3AB0523A890EBC685257BD50055E09A/$FILE/BC3%202013%20-%20p18.pdf (accessed at 1.8.2016)

Wagner K, Janetschek H, Neuwirth J (2009) Landwirtschaft und Hochwasser–Wechselwirkungen zwischen Landnutzung und Wasserrückhalt. Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie 18(3):137-146

Warnecke S, Paulsen HM, Schulz F, Rahmann G (2014) Greenhouse gas emissions from enteric fermentation and manure on organic and conventional dairy farms—an analysis based on farm network data. Org. Agr. 4(4):285-293

White RE (2006) Principles and practice of soil science: the soil as a natural resource. Blackwell Publishing, Fourth Edition

Whitehead DC (2000) Nutrient elements in grassland: soil-plant-animal relationships. Wallingford, UK. Cabi Publishing

Withers PA, van Dijk K, Neset T-S, Nesme T, Oenema O, Rubæk G, Schoumans O, Smit B, Pellerin S (2015) Stewardship to tackle global phosphorus inefficiency: The case of Europe. Ambio 44(2):193-206

Wollmann I, Möller K (2015) Assessment of Alternative Phosphorus Fertilizers for Organic Farming: Sewage Precipitation Products. Fact sheet Improve P, First edition. Universität Hohenheim http://orgprints.org/28142/ (accessed 1.8.2016)

2 Measurement methods on pastures and their use in environmental life-cycle assessment

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2.1 Abstract

Grassland agriculture plays an important role for livestock production and land management throughout the world. It is challenging to estimate the available feed on pasture plots. For this study, a rising plate meter was calibrated in swards of the organic experimental station of Trenthorst in Northern Germany to calculate grazing intake of cattle and to determine biomass regrowth. A LCA-model (FARM) that was used to calculate the global warming potential (GWP) of milk of the station showed that substituting grass silage by grazing reduces the GWP per kg energy-corrected milk by 1.5 %. High differences of dry matter intake that were found between the plots indicate a potential for improving the grazing management and hence for further reducing the GWP of milk production.

Key words: grazing intake, dairy, global warming potential, LCA

2.2 Introduction

A total of 70 % of the world's agricultural area is covered by grassland (FAO 2008). It is an important and energy extensive feed source for livestock. Good pasture management is required to maintain its productivity. Due to the selective grazing behaviour of dairy cows (Vallentine 2001), site and management related sward variability (Correl et al. 2003) and herbage regrowth during grazing bouts it is difficult to estimate pasture yield or pasture intake (McNaughton et al. 1996, Walker et al. 1979, Macoon et al. 2003, Smit et al. 2005). A proper estimation of feed intake of animals on grassland enables the farmer to appropriately manage his pastures. This paper presents a fast and easy-to-use method to estimate herbage intake without exclosure cages. The collected data are used to describe material flows from grassland. Subsequently environmental impacts of an improved grazing management based on the whole farm process are calculated with a flow model FARM (Flow Analysis and Resource Management) that is designed to conduct life-cycle assessments (LCA) of farm products.

2.3 Material and methods

Data were collected on the experimental station of the Thünen Institute of Organic Farming, Trenthorst in Northern Germany (53°46’ N, 10°30’ E; 10-43 m asl). For the dairy branch of the station an area of 37 hectares are used as permanent grassland for grazing and for producing silage and hay. The farm converted from conventional to organic farming in 2001. Mean annual precipitation is 706 mm and mean annual temperature is 8.8°C (1978-2007). In 2012 precipitation was as low as 534 mm, which is 34% lower than average. The soils of the permanent grassland are characterized as Cambisols and Luvisols. On the grassland, a mixture of grass, legumes (mostly Trifolium repens) and herbaceous plants is growing in different proportions. In 2012 the dairy cows (Black Holstein and Red Holstein dual purpose breed) grazed approximately 7 hours a day from 24th of April until 7th of October. The permanent grassland is divided into 13 plots (mean size 2.66 ha) and managed by rotational grazing with a duration of 2-10 days per plot. To estimate the pasture intake on a dry matter basis the following formula (1) was used: (biomass before grazing – biomass after grazing) + (daily growth rate x days of grazing). The biomass before and after grazing was measured at four representative GPS-located points per pasture plot (Fig. 2.1, left). The biomass was determined directly by cutting 0.5 m x 1 m to 1 cm above ground level. The dry matter (DM) yield was determined by drying the biomass (24 h, 60°C).

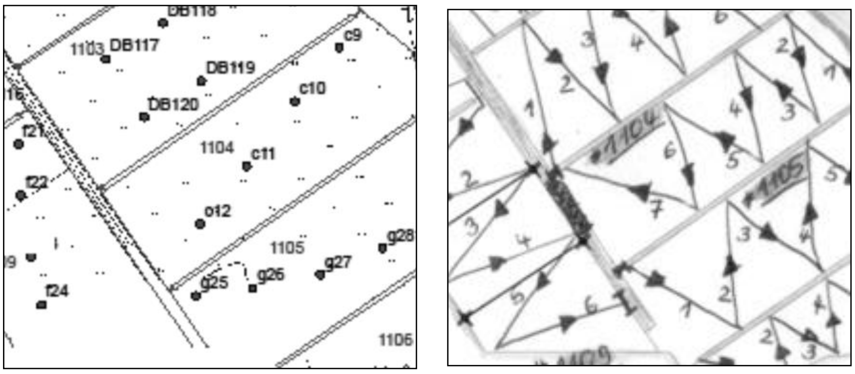

Figure 2.1 GPS-located sample points (left) were used to measure the difference before and after grazing and weekly zigzag plate meter measurements (right) were used to estimate the daily growth rates.

The average daily growth rate was calculated on the basis of weekly measurements at all ungrazed plots with a rising plate meter (FARMWORKS). It measures the compressed height of the pasture: the plate of the meter lowers from top to bottom until enough plant material carries the plate's weight. The instrument was calibrated to the farm conditions of the permanent grassland in Trenthorst. There was a linear relationship between DM [kg ha^{-1}] yield and compressed sward height (H in cm) with the function: $DM = 100.41 \times H + 1$ ($r^2 = 0.75$, $n = 396$). This function was used to calculate the dry matter yield by the sward height measurements. The sward height was measured every 10 steps while the plots were crossed in zigzag (Fig. 2.1, right). For every crossing line the mean height was recorded. Both methods (four points cutting and zigzag measurement with rising plate meter) showed similar results when yield estimation per plot was compared (Ohm et al. 2013). The LCA-FARM-Model was developed to calculate the environmental performance of milk production (Schüler and Paulsen 2012). The input data were obtained from the actual farming conditions on the experimental station. The parameters used were field work, crop yields, amount of manure, herd size, milk yields, feed intake and feeding regime, which includes the grazing management. Greenhouse gas emissions were calculated according to the emission factors specified in IPPC (2006) and Rösemann et al. (2011). The global warming potential (GWP) connected with grass silage production at Trenthorst depends on the total yield (Table 2.1). In 2011 grass silage yield was very low (17.5 t ha^{-1} DM) and the GWP (100 a) was 327.6 g CO_2 eq. kg^{-1} DM. Yields around 26.5 t ha^{-1} DM (mean of the years 2005, 2008, 2009) are more representative for the location and had a GWP of 293.9 g CO_2 eq. kg^{-1} DM. For the following calculations a value of 300 g CO_2 eq. kg^{-1} DM grass silage is assumed.

Table 2.1 Global warming potential (100 a) of grass silage for yields of 17.5 t ha^{-1} and 26.5 t ha^{-1} in g CO_2 eq. kg^{-1} DM (experimental farm Trenthorst, 2011 and mean of the years 2005, 2008 and 2009).

Emission source	**Grass silage 17.5 t ha^{-1} [g CO_2 eq. kg^{-1} DM]**	**Grass silage 26.5 t ha^{-1} [g CO_2 eq. kg^{-1} DM]**
Supply-chain1	11.8	8.8
Transports of silage film, lime and fuel to farm	0.3	0.2
Fuel combustion from fieldwork	89.4	66.4
Direct emissions from soil	226	218.5
Combustion of silage film	$5.96*10^{-6}$	$5.9*10^{-6}$
Sum	**327.6**	**293.9**

[1] The environmental burdens of all upstream products have been calculated with datasets from the ecoinvent v2.2 database.

2.4 Results

For calculating grazing intake, the biomass difference before and after grazing was added to the biomass gain calculated by daily growth rates. The daily growth varied widely during the grazing season. The maximum was in spring with more than 70 kg DM ha^{-1} (Fig. 2.2). The mean daily growth rate was around 25 kg DM ha^{-1}. It also shows some negative values which can be attributed to dry periods when the grass went limp.

Both the dry matter yields from direct cuttings and the estimated yield from growth rates (Formula 1) show variations between the plots (Fig. 2.3). The sum of both values is the basis to calculate the DM intake per cow and plot. This is the parameter for the LCA.

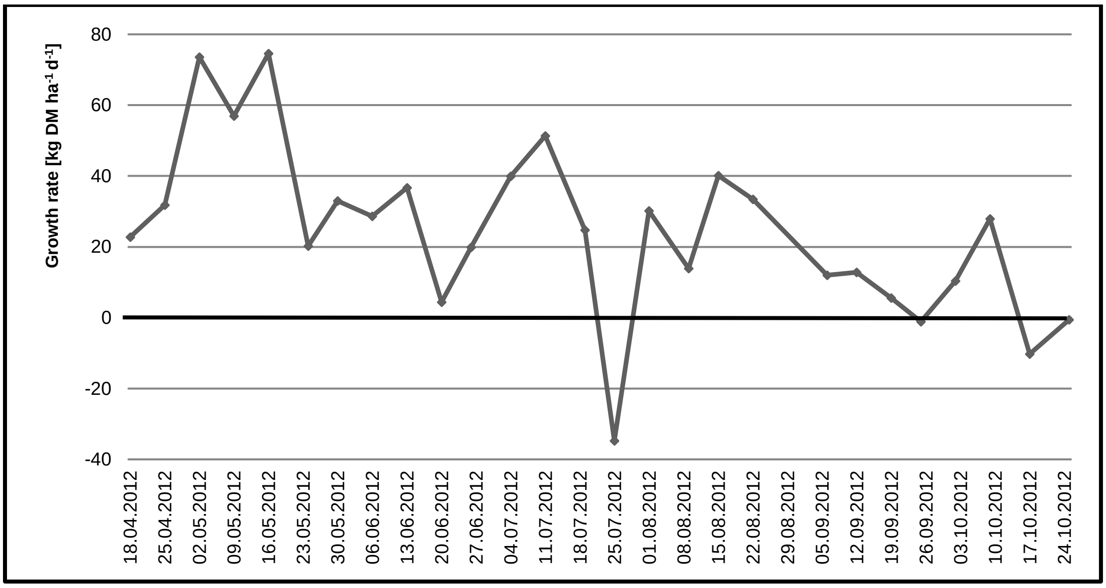

Figure 2.2 Daily growth rate of dry matter on ungrazed plots in 2012.

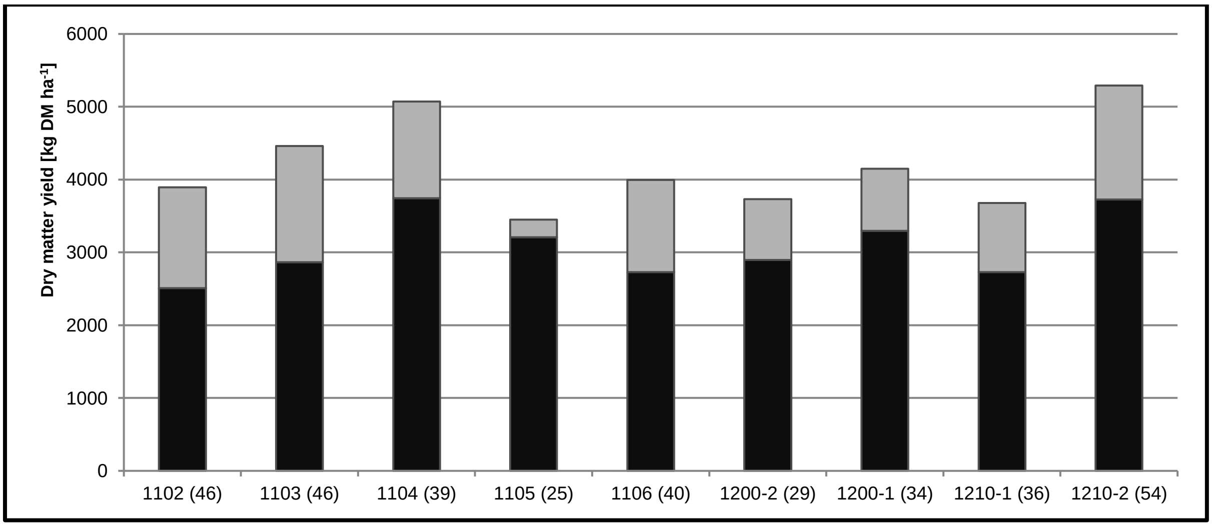

Figure 2.3 Dry matter yields of the grazed pasture plots calculated by the difference before and after grazing (black) and daily growth rate (grey) in 2012. In brackets: Number of grazing days.

In detail the dry matter intake per cow and day was calculated by the dry matter yield per plot, number of animals and days of grazing (Fig. 2.4). High differences occurred between the plots. If improved management decisions could increase the dry matter intake of the dairy cows during grazing by 1 kg dry matter per day, equivalently less grass silage would have to be fed for the same milk yield. Substituting grass silage by improving grazing management reduces GWP per kg energy-corrected milk (ECM). This is the potential of an improved grazing management to reduce the GWP of milk. Calculating the LCA for the experimental station results in (a) GWP of 300 g CO_2 eq. per kg grass silage DM (Tab.1) and (b) 1 kg CO_2 eq. per kg ECM. At daily milk yields of 20 kg ECM per cow and day, the GWP can be reduced by 15 g CO_2 eq. per kg ECM (= 1.5 %) by substituting 1 kg DM grass silage by 1 kg DM intake from pasture. At the pasture plot with the lowest DM intake (plot 1102, Fig. 2.4) the GWP of milk production could even be reduced by 8.2 % if daily DM intake during the grazing period could be more than doubled from 4.6 to 10 kg.

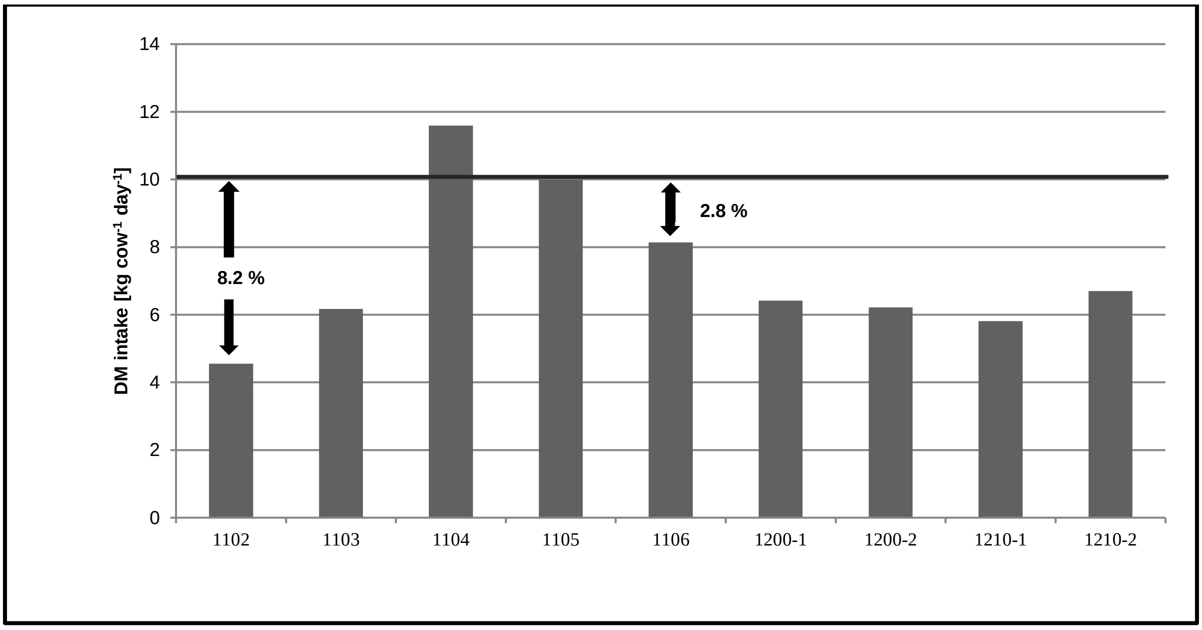

Figure 2.4 Daily dry matter (DM) intake per cow at the pasture plots in 2012. The % shows the reduction potential of global warming per kg ECM [%] by increasing the DM intake by grazing to 10 kg cow^{-1} d^{-1}.

2.5 Discussion

The considerable differences in DM intake that were found between the plots might on the one hand be caused by sward composition and soil site differences. On the other hand, they could be attributed to improper grazing management decisions because those can lead to a low DM intake per cow. The DM intake decreases if the biomass on the pasture becomes too short (because then the cows need more time to find enough feed) or if the biomass on the pasture becomes too old (a high fiber content results both in less palatability and in a long digestion time (Klapp 1971)). High differences in feed offer between plots might indicate a potential for improvement of pasture management. The fast and practical measurements with a rising plate meter allow estimating the variable feed offer at pasture plots. These data offer chances to improve grazing and pasture management (as they are commonly used for in New Zealand (Lile et al. 2001) and are also useful for calculations of DM intake per cow which can be used for LCA.

If pasture management is improved it is possible to substitute other roughage with grazing intake, hence improving the overall system efficiency and reducing environmental impacts such as global warming from milk production. The range of improvement depends on (a) the current farm and site specific performance, (b) the yield potential and food quality of the pasture site itself and (c) feeding management options within the farm. Further reductions can be achieved by improving feeding management and feed quality.

2.6 Conclusion

Measurements of the variable feed offer at pasture plots with a rising plate meter provide a data basis to improve grazing and pasture management. Calculating grazing intake by the use of regrowth values of biomass of temporarily ungrazed pastures might be a practical and fast alternative to measurements with exclosure cages. On the explored pasture plots, high differences in the dry matter intake of the cows between plots were found, and might indicate a potential for the improvement of pasture management. Optimizing pasture yields, e.g. by sward improvements and grazing management, offers chances to reduce environmental burdens. From the study it cannot be concluded that pasture based systems perform better than other systems, but that a well run pasture provides a great opportunity to avoid GHG emissions.

2.7 References

Correll O, Isselstein J, Pavlu V (2003) Studying spatial and temporal dynamics of sward structure at low stocking densities: the use of an extended rising-plate-meter method. Grass Forage Sci 58(4):450-454

FAO (2008) Are grasslands under threat? Brief analysis of FAO statistical data on pasture and fodder crops. http://www.fao.org/ag/agp/agpc/doc/grass_stats/grass-stats.htm. Accessed 7 May 2014

IPCC (2006) IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan

Klapp (1971) Wiesen und Weiden. 4. Edition, Parey-Verlag, Berlin/Hamburg, pp. 419-420

Lile J, Blackwell M, Thomson N, Penno J, Macdonald K, Nicholas P, Lancaster J, Coulter M (2001) Practical use of the rising plate meter (RPM) on New Zealand dairy farms. Proceedings of the Conference- New Zealand Grassland association, pp. 159-164

Macoon B, Sollenberger LE, Moore JE, Staples CR, Fike JH, Portier KM (2003) Comparison of three techniques for estimating the forage intake of lactating dairy cows on pasture. Journal of Animal Science 81(9):2357-2366

McNaughton SJ, Milchunas DG, Frank DA (1996) How can net Primary Productivity be Measured in Grazing Ecosystems? Ecology 77(3):974-977

Ohm M, Felix J, Schüler M, Paulsen HM (2013) Eignung von Methoden zur Ermittlung des Massenaufwuchses von Grünland am Beispiel eines ökologischen Milchviehbetriebes Kongressband VDLUFA 2013 Berlin pp. 342-349

Rösemann C, Haenel H-D, Poddey E, Dämmgen U, Döhler H, Eurich-Menden B, Laubach P, Dieterle M, Osterburg B (2011) Calculations of gaseous and particulate emissions from German agriculture 1990-2009. Landbauforsch vTI AG 342:402

Schüler M, Paulsen HM (2012) A LCA based comparison of two different dairy breeds in an organic farm. 2nd Organic Animal Husbandry Conference Hamburg, Trenthorst, 12-14 September, 2012, pp. 30-33

Smit HJ, Taweel HZ, Tas BM, Tamminga S, Elgersma A (2005) Comparison of techniques for estimating herbage intake of grazing dairy cows. J Dairy Sci 88(5):1827-1836

Vallentine JF (2003) Grazing Management. Second Edition, California, USA: Academic Press

Walters RJK, Evans EM (1979) Evaluation of a Sward Sampling Technique for Estimating Herbage Intake by Grazing Sheep. Grass Forage Sci 34(1):37-44

3 Redistribution of Soil Phosphorus from Grassland to Cropland in Organic Dairy Farming

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3.1 Abstract

Limited knowledge is available on inner farm nutrient transfer from organic grassland to arable land in organic farms. This study quantifies the phosphorus (P) mobilization of permanent grassland and different arable crops for inner farm P transfer and discusses in how far P reserves in grassland soils can be a component of sufficiency P management in organic farming. A North German organic dairy farm with sufficient soil P supply is analyzed. Over three years its P balance showed an average deficit of 7.9 kg ha^{-1} yr^{-1} in permanent grassland and 10.9 kg ha^{-1} yr^{-1} in arable land. Maize (30.5 kg P ha^{-1} yr^{-1}), grass-clover (23.9 kg P ha^{-1} yr^{-1}) and mixed faba bean and oats (19.8 kg P ha^{-1} yr^{-1}) had the highest P uptake in cropland. At grassland, grazing intake of P by livestock was 15.9 kg P ha^{-1} yr^{-1} and via storage feed and manure it directly fed arable land with 64 kg P (average 1 kg P ha^{-1} yr^{-1}). Especially on grassland, soil P mining does not endanger soil fertility yet, according to sufficient available P-contents in the soils (CAL-extract averages [mg 100 g^{-1} P]: grassland 14.7, arable land 6.7). Generally, the inclusion of unexploited grassland sites with high soil P contents in farm nutrient flows (via feed conserves for livestock or biogas) would address unused soil P reserves for redistribution.

Keywords: pasture, phosphorus-cycle, P-scarcity, P-balances, grazing, organic farming

Umverteilung von Bodenphosphor aus Dauergrünland zu Ackerland in einem ökologischen Milchviehbetrieb

3.2 Zusammenfassung

Zum Nährstofftransfer von Grünland zu Ackerland in ökologischen Betrieben gibt es nur wenige Untersuchungen. Diese Fallstudie eines norddeutschen ökologischen Milchviehbetriebs mit ausreichenden P-Reserven in Böden quantifiziert die Phosphor (P) Mobilisierung aus Böden von Dauergrünland und von Ackerland für die innerbetriebliche P-Umverteilung detailliert. Möglichkeiten der Steigerung der P-Umverteilung werden vor dem Hintergrund schwindender weltweiter P-Reserven diskutiert. Die P-Flüsse und P-Bilanzen werden über drei Jahre anhand der Ertragsdaten (Milch, Fleisch, Ernteerträge) und P-Konzentrationen gesamtbetrieblich, für die einzelnen Betriebsteile sowie kulturartspezifisch erfasst. Die mittleren P-Bilanzen in Dauergrünland und Ackerland im untersuchten Betrieb waren negativ (-7,9 bzw. -10,9 kg ha^{-1} Jahr^{-1}). Bei den Ackerkulturen hatten Mais (30,5 kg P ha^{-1} Jahr^{-1}), Rotkleegras (23,9 kg P ha^{-1} Jahr^{-1}) und Ackerbohnen/Hafer-Gemenge (19,8 kg P ha^{-1} Jahr^{-1}) die höchsten P-Entzüge. Auf Grünland wurden 15,9 kg P ha^{-1} Jahr^{-1} durch Beweidung aufgenommen und mit Milch und Fleisch zum Teil exportiert. 64 kg P Jahr^{-1} (ca. 1 kg P ha^{-1}) wurden durch Futterkonserven von Grünland über die Wirtschaftsdünger auf das Ackerland umverteilt. Vor allem in Grünland sind die negativen P-Bilanzen im untersuchten Betrieb derzeit noch unproblematisch für die Bodenfruchtbarkeit, da ausreichend pflanzenverfügbares P vorhanden ist (mittlere P Gehalte in CAL-Extrakt [mg 100 g^{-1} P]: Grünland 14,7, Ackerland 6,7). Generell könnten z.B. bisher ungenutzte und möglicherweise hohe P-Vorräte bisher wenig genutzter Grünlandflächen durch Intensivierung der Biomasseabfuhr für die Tierfütterung oder Biogasgewinnung adressiert und umverteilt werden.

Stichworte: Grünland, Phosphor-Kreislauf, P-Knappheit, P-Bilanz, Beweidung, Ökologischer Landbau

3.3 Introduction

Phosphorus (P) is a non-renewable resource and an essential plant nutrient. Accumulations of fertilizer P in soils have to be avoided to increase fertilizer efficiency and soil reserves should be addressed to save limited worldwide P resources (Cordell, 2009). In Western Europe, conventional crop production historically relied on high P fertilizer application rates and considerable soil reserves accumulated (Barberis et al., 1996; Schröder et al., 2011; Tóth et al., 2014). For this reason, organic farmers today often neglect the import of P fertilizers in arable crops and in grassland. Supported by the principles of organic production (Council Regulation (EC) 834/2007), they rely on the soil ecosystem to nourish their plants and also on the backflow of nutrients with wastes from animal or plant production mostly from their own farms. Without fertilizer imports soil reserves must cover balance deficits. In this situation biological processes are of high importance for a successful P acquisition (Richardson et al., 2009; Simpson et al., 2011).

As phosphate diffusion is limited in soils (Schachtman et al., 1998), root density and distribution are very important factors for physical access to the soil volume and for phosphate acquisition (Ho et al., 2005, Vance, 2001). Microbial activity in the root zone and mycorrhiza further enhance biological P turnover (Oberson and Joner, 2005; Whitehead, 2000; Smith and Read, 2010). In grassland, different plant species, high rooting density and the permanent vegetation cover, as well as droppings of grazing livestock, might favor a continuous P uptake from soil reserves. The importance of biological activation of P in grassland is described in various studies. For example, biological uptake and translocation of P to the soil surface with plant material from deeper soil layers is reported from an analysis of grassland soils along a precipitation gradient in the Great Plains (USA) (Ippolito et al., 2010). Also, sufficient P supply in the topsoil of extensive Australian grassland farms with limited available P reserves and without fertilizer input is explained by P cycling upwards from the subsoil by deep rooting perennial-grassland plants (Cornish, 2009).

Nutrient mining in grassland and the transfer of its nutrients to arable land made grassland historically the ‘mother of arable land’, but at the same time adequate fertilization measures are demanded to cover deficits (Klapp, 1971). Worldwide 40.5 % of the terrestrial areas are grassland (excluding Greenland and Antarctica, Suttie et al., 2005). In Germany grassland constitutes 28 % of agricultural land and represents 56 % of the organic farmland in Germany (Federal Statistical Office, 2014). As 67 % of German organic farms have both arable land and permanent grassland (Rahmann and Nieberg, 2005) plant nutrient redistribution from grassland to arable land is of special interest here.

The assessment of nutrient flows in farms is an important prerequisite for an improved nutrient management (Oenema et al., 2003). But there are only a small number of detailed studies available on P flows in organic farms under inclusion of grassland and with grazing animals. For instance, Steinshamn et al. (2004) calculated nitrogen (N) and P flows in a Norwegian mixed dairy farm. They found negative overall soil surface balances of 6.3 kg P ha^{-1} yr^{-1}. Fystro et al. (2014) analyzed N, P, potassium (K) and magnesium (Mg) cycling in Norwegian organic grassland dairy farms. Here additional P input to the intensively used inner farm area is generated from feed imports from remote grassland in the hills that was defined to be outside the system boundary. But most of the P is imported via concentrates and outweighs the exports via milk. Möller (2009) analyzed the P, N, K and Mg flows in an organic dairy system. Due to low N-efficiency when applying livestock manures in legume rich grassland, he suggests the redistribution of nutrients originating there via manures to N-demanding arable crops under consideration of adequate P and K loads. By inference P, K and Mg should be preferably applied in mineral form in grassland, which traditionally has high legume proportions and biological N fixation in organic farms. Due to higher K/P-relations in grassland based feedstocks compared to those from arable crops, on farm level this would indicate a relatively higher transfer of K when P is used as reference for the manure application in cropland. On 26 German organic farms, farm gate deficits of -3 kg P ha^{-1} yr^{-1} (range -14 to 4 kg P ha^{-1} yr^{-1}) including grassland were found (Haas et al., 2007). For Austria farm gate P-balances of from -1.9 to 7.8 kg P ha^{-1} yr^{-1} were observed (Lindenthal, 2001). In the Swedish research farm Öjebyn, barn balances of 0.5 kg P yr^{-1} cow^{-1} in organic as well as in conventional farming (Gustafson et al., 2003), and field balances of 1 and 5 kg P ha^{-1} yr^{-1} respectively, were found (Bengtsson et al., 2003). The farm includes a small amount of pasture, which is excluded from specific calculations. The two latter types of analysis do not offer possibilities to analyze and improve inner farm nutrient flows like nutrient transfer between arable land and grassland. Thus, limited knowledge is available on P flows in organic farms with inclusion of grassland and livestock. Therefore, the objective of the current study is (1) to quantify P mobilization and the inner farm P transfer at a mixed organic dairy farm in a case study under detailed inclusion of grassland, grazing animals and arable feedstock in North Germany and (2) to discuss whether grassland can be a component of sufficiency P management in organic farming in the short run.

3.4 Material and Methods

3.4.1 Experimental site/ System under study

The dairy farm of the experimental station of the Thünen Institute of Organic Farming, Trenthorst (116 ha), was used as geographical system boundary to determine P flows in the time period between 2010 and 2012. The farm is located in Northern Germany (53°46’ N, 10°30’ E; 10-43 m asl) and was converted from conventional to organic farming in 2001. Mean annual precipitation is 706 mm and mean annual temperature was 8.8°C (1978-2007). For the last decades the grassland can be seen as mostly intact. Solely two plots were subjected to sward cultivating but have not been ploughed during the last five years, meaning the grassland can be defined as ‘permanent grassland’. The soils of grassland and arable land are characterized as Cambisols and Luvisols with sandy loamy texture. The mean humus content in the topsoil was 2.2 % (n = 76) for arable land (0-30 cm) and 5.3 % in grassland (n = 24, 0-10 cm) between 2010 and 2012. Soil properties are listed in Table 3.1. The plant available P fraction was determined as P (CAL) (100 ml CAL solution (0.1 m Calcium acetate, 0.1 m Calcium lactate, and 0.3 m acetic acid; pH 4.1) and 5 g soil are shaking for 2 h, photometrical P determination) (Schüller, 1969). According to official fertilizing recommendations, the P content of the arable land was categorized as sufficient and of permanent grassland as high (Landwirtschaftskammer Niedersachsen, 2011). The farm did not import organic or mineral P fertilizer since 2001.

Table 3.1 Soil properties of arable land (0-30 cm) and permanent grassland (0-10 cm) (Trenthorst, 2010 – 2012).

utilization		pH			P_{CAL} [mg 100 g^{-1}]			K_{CAL} [mg 100 g^{-1}]			Mg ($CaCl_2$) [mg 100 g^{-1}]		
	n	mean	SD	TV	mean	SD	TV	mean	SD	TV	mean	SD	TV
arable	80	6.4	0.3	> 6.3	6.7	1.6	> 5	12.3	3.1	> 11	10.7	1.9	> 6
grassland	24	5.3	0.2	> 5.6	14.7	1.5	> 6	11.2	4.0	> 11	20.7	3.1	> 18

SD, Standard deviation; TV, threshold value for sufficient soil reserves (Landwirtschaftskammer Niedersachsen, 2011)

The livestock units (1 LU = 650 kg live weight) of the dairy cows and their followers changed during the first year, 2010, from 164.4 LU to 155.7 LU. The year 2011 ended with 136.5 LU and increased to 145.5 LU in 2012. To provide forage and concentrates for the cattle, 62 ha arable land were cultivated with a 6-year crop rotation which consisted of grass-clover (1) - grass-clover *(Lolium perenne, Phleum pratense, Trifolium pratense*) (2) - maize (*Zea mays)* (3) - wheat (*Triticum aestivum*) (4) - faba beans (*Vicia faba*) / oats (*Avena sativa*) (5) - triticale (*Triticosecale*) (6). The permanent grassland (54 ha) with a mixture of grasses, legumes (mostly *Trifolium repens*) and herbaceous plants was used for grazing and storage feed production (silage, hay). A total of 33 ha of grassland, located next to the stable, are divided into 13 plots. In the reference period 2012 they were managed by rotational grazing with duration of 2-10 days (7 hours a day from 24 Apr. to 7 Oct.). Three of these plots were also used for a first cut for silage production on May 13th. Another 21 ha remote grassland were used more extensively with full time grazing of young stock, heifers and dry cows (6.8 ha for 205 days) and for harvesting of storage feed (14.2 ha). Additional feed was imported from farm areas outside the dairy crop rotation. No changes in feed stock were assessed in the mass balances for the examined period. Cattle had free access to licking blocks and water. Straw was used as bedding material. Calves were fed with whole milk in the first thirteen weeks. Actual weight of feed supply for the cattle in the stables was used for the calculations.

Due to joint storage facilities and farm management decisions, livestock manure was partly exported from the dairy section to other farm parts.

3.4.2 Mass flow calculation

Equations to calculate mass flows for the P farm balance are shown in Table 3.2. Phosphorus contents of materials were based on site specific analyses or reference values (Table 3.3).

Table 3.2 Equations to calculate mass flows in the P farm balance.

P flow = mass flow * specific P content [1]

Pasture intake = $(\text{DM biomass}_{\text{before grazing}} - \text{DM bimass}_{\text{after grazin}})$ + daily growth rate * days of grazing [2]

Manure export = Total fodder + litter – milk – net production of live weight – manure output inside the boundaries [3]

Net production of live weight = weight of sold animals + change in herd size [4]

$\text{Soil P balance}_{\text{grassland}}$ = excretion on pasture + slurry + atmospheric deposition – grazing – storage food – losses [5]

$\text{Soil P balance}_{\text{arable land}}$ = stable manure + slurry + seeds + atmospheric deposition – crop yield – losses [6]

P Farm balance = Input – Output = mineral fodder + imported storage fodder + seeds + atmospheric deposition – milk – net production of live weight – manure export – losses [7]

Table 3.3 P content of different farm materials, atmospheric P deposition and soil losses.

Parameter	**Year**	**P content**	**comment**	**source**
Permanent grassland	2012	3.92 g kg^{-1} DM	± 0.6, n = 17	Farm specific, different cuts
Grass-clover	2010	3.10 g kg^{-1} DM	± 0.2, n = 2	Farm specific, different silos
	2011	3.20 g kg^{-1} DM	± 0.4, n = 3	
	2012	3.00 g kg^{-1} DM	± 0.3, n = 5	
Maize silage	2010	2.80 g kg^{-1} DM	± 0.4, n = 4: 2011 & 2012	Farm specific
	2011	3.10 g kg^{-1} DM	MV of 2.9 & 3.3	Farm specific
	2012	2.45 g kg^{-1} DM	MV of 2.4 & 2.5	Farm specific
Triticale	2010-2012	2.78 g kg^{-1} DM	± 0.096, n = 4, 2005	Resident experimental data[†] of rye
Spring wheat grain	2011	3.34 g kg^{-1} DM	± 0.17, n = 8: 2004 & 2005	Resident experiment[†]
Winter wheat grain	2010, 2011	3.31 g kg^{-1} DM	± 0.14, n = 8: 2004 & 2005	Resident experiment[†]
Faba bean grain	2010-2012	6.75 g kg^{-1} DM	2002-2005	Resident experiment[‡]
Oats grain	2010-2012	3.6 g kg^{-1} DM	2002-2005	Resident experiment[‡]
Triticale straw	2010-2012	0.9 g kg^{-1} DM	± 0.11, n = 4, 2005	Resident experimental data[†] of rye
Winter wheat straw	2010, 2011	0.65 g kg^{-1} DM	± 0.28, n = 4, 2005	Resident experiment[†]
Spring wheat straw	2011	0.5 g kg^{-1} DM	± 0.09, n=8: 2004 & 2005	Resident experiment[†]
Faba bean straw	2010-2012	1.3 g kg^{-1} DM		Characteristic values[§]
Oat straw	2010-2012	1.1 g kg^{-1} DM		Characteristic values[§]
Milk	2010-2012	0.97 g kg^{-1} FM	± 0.09, n = 24	Swedish study[¶]
Animal fresh mass	2010-2012	7.5 g kg^{-1} FM		France Study[#]
Solid manure	2010- 2011	1.01 g kg^{-1} OS	2009: 1.004 & 2010: 1.017	Farm specific
Slurry	2010	0.154 g kg^{-1} OS	± 0.02; n = 3	Farm specific
	2011	0.151 g kg^{-1} OS	± 0.03, n = 6: 2010 & 2012	Farm specific
	2012	0.148 g kg^{-1} OS	± 0.045, n = 3	Farm specific
Wheat, oat & triticale seeds	2010-2012	3.5 g kg^{-1} FM		Characteristic values used for imported seeds[§]
Faba bean seeds		4.7 g kg^{-1} FM		
Maize seeds		3.3 g kg^{-1} FM		
Grass seeds		3.0 g kg^{-1} FM		
Clover seeds		6.4 g kg^{-1} FM		
Atmospheric deposition	2010-2012	0.2 kg ha^{-1}		LLUR[††]
Soil losses	2010-2012	0.3 kg ha^{-1} a^{-1}		Swedish study[‡‡]
Mineral feed	2010-2012	20 g kg^{-1} OS	Mineral feed	Supplier specification
Lick minerals	2010-2012	40 g kg^{-1} OS	Rindereimer, eco certified	Supplier specification

[†] Paulsen and Schochow, 2006, [‡] Böhm, 2007, [§] Kape et al., 2008 (Organic characteristic values of Ministry of Agriculture in Mecklenburg-Vorpommern), [¶] Gustavson et al., 2007, [#] Nesme et al., 2012, [††] LLUR (Landesamt für Landwirtschaft, Umwelt und Ländliche Räume Schleswig Holstein), 2014, [‡‡] Modin-Edman et al., 2007

DM= Dry matter, FM= fresh matter, OS= Original substance, MV= mean value

Grazing intake and storage feed yields were analyzed in a detailed field study in 2012 (Ohm et al., 2014). Plot-specific pasture intake was quantified and results were also used as representative for 2010 and 2011. For the few full-time grazing cows in dry period (avg. 14 cows per year), at the remote plots dry matter (DM) intake was estimated at 10 kg d^{-1} cow^{-1} (Jeroch, 1999). According to Knowlton and Herbein (2002) livestock excretes 50 to 80 % of P intake. In a study with Holstein dairy cows, a low P diet with 0.31 % P was tested, leading to 45 % P digestibility (Wu et al., 2001). Due to comparable feedstuff concentrations in Trenthorst (mean of 0.33 % P in the ration) this value was used for calculating the net P export from the grazed plots. Total sold animals, sold farming products, actual forage, grain and straw harvests and manure application were taken from the farm database. Harvest yields were measured with a drive-on scale and corrected to the actual dry matter contents in storage (grains 85 – 88 %, straw 84 – 85 %, grass-clover silage 35 %, haylage 70 %, hay 86 %, maize 28.5 – 32.1 % DM each). Phosphorus input from seeds was calculated according to the concentrations in Table 3.3 and the following seed densities (fresh matter = FM, 86 % DM): 220 kg wheat, 180 kg triticale, faba bean 70 kg in combination with 170-180 kg of oats, 20 kg maize and for the grass-clover plots 15 kg in proportion of 70 % grass seeds and 30 % clover seeds per ha.

The feed flow into the stable, also for mineral feed and lick mineral, was taken from the actual feeding lists. Manure, litter, feeding rests and storage residues was transferred to the manure storage. No P losses were assumed between stable and manure storage.

Herd management data of the farm based on regularly scheduled weighing of each animal, as well as departure dates and weights, provided data of net live weight production. Milk exports were taken from yearly delivery accounts. Also milk supply to the calves was specified by the actual feeding lists for inclusion in the internal farm circle of P. Phosphorus flows entering the manure cycle were determined based on P input in the stable and P output in animal products (milk, weight gains).

The atmospheric deposition of P given by official values for the farm region is 0.2 kg ha^{-1} yr^{-1} (LLUR, 2014). Only minor losses of P from the soil by leaching had to be considered for farm land (Cooke and Williams, 1973, White, 2006) and low P losses through surface run-off and erosion were anticipated on the site under study due to the plain nature of the area. Therefore P losses from the soil by leaching and run-off were estimated to be 0.3 kg P ha^{-1} yr^{-1}. This is in line with a Swedish study (Modin-Edman et al., 2007) and with mean estimated losses from German soils (Scheffer and Schachtschabel, 2010).

Soil P balances of grassland and arable land (Table 3.2, Eq. [5, 6]) indicated the net change of P soil reserves. The farm balance is calculated by inputs minus outputs (Table 3.2, Eq. [7]). Drinking water for the cows was not considered because P contents were below the detection limit. If concentrations had been set to a threshold of 1 mg L^{-1}, 3,000 m^3 drinking water per year for the cows would have accounted for only for 3 kg P yr^{-1}. In the farm balance outputs crossing the system boundary were: sold milk, net production of live weight, manure export and run off. The software e!sankey 3.2 (IFU Hamburg, Germany) was used to visualize results.

3.5 Results

In grassland, grazing management regimes on the plots differed in intensity and frequency, resulting in high ranges in dry matter (DM) yields (Fig. 3.1) and in high differences in P in plant material that is harvested or grazed between the plots (mean intake by grazing 15.9 kg ha^{-1} yr^{-1} P ± 2.7; range 9.5 - 20.7 kg ha^{-1} yr^{-1} P; mean export per cut by harvesting 6.9 kg ha^{-1} yr^{-1} P ± 2.9, range 3.5 – 12.5 kg yr^{-1} P; ± values are characterizing the standard deviations). Phosphorus mobilization potential from the grassland soils (including applied P from organic fertilizers and animal droppings) is characterized by plant uptake of up to 23.4 kg P ha^{-1} yr^{-1}. In the study this maximum value was reached on plot 1105 with herbage taken up by grazing livestock and exported by additional harvests (Fig. 3.1). The total estimated grazing intake of cows and young stock on the farm was 160,062 kg DM yr^{-1} (Table 3.4). From the total amount of grazed P (627 kg yr^{-1}), 282 kg P yr^{-1} (8.62 kg P ha^{-1} yr^{-1}) were removed from the fields with milk and meat, and 345 kg were excreted at pasture. Considering also manure imports and harvest exports the mean soil P balance for grassland was -429 kg yr^{-1} or -7.9 kg ha^{-1} yr^{-1} (Table 3.4) which means a P stock reduction in soil.

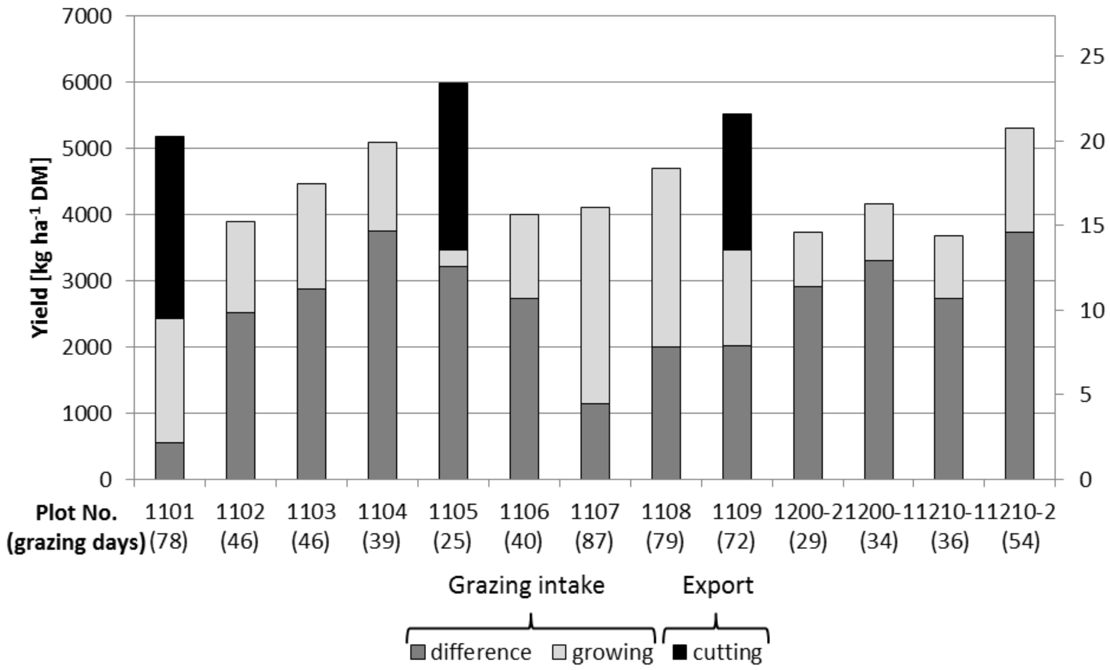

Fig. 3.1 Herbage yields by grazing (Eq. [2]) and cutting in pasture plots neighbouring the stable, Trenthorst 2012. Plot No. are indicating separate grassland units, grazing days are the sum of days animals were present on each plot.

The soil P balance of arable land resulted in -676 kg P yr^{-1} or -10.9 kg ha^{-1} yr^{-1} (Table 3.5). Slurry was brought out every year (mean 2,667,768 kg FM), solid manure was applied at some of the plots only in 2010 (281,798 kg FM) and 2011 (254,936 kg FM). P exports varied between crops and years. The mean P export of the different crops was in descending order [kg P ha^{-1} yr^{-1}]: Maize (silage) 30.4 ±11.1, range 17.7 – 38.2, grass-clover 23.7 ±6.3, range 17.3 – 32.4, faba bean and oats in mixed cropping (grains) 19.4 ±8.5, range 10.3 – 27.1, wheat and triticale (grains) 9.1 ±3, range 5.5 – 14.3, and cereal straw 1.25 ±0.6, range 0.8 – 2.4. Straw of oats and faba beans as well as cereal straw in the headlands remained on the plots. For calculation of the P redistribution from soil-to-plant-back-to-soil with mulched clover grass no yields were determined. They were estimated to 4 kg ha^{-1} P according to the three lowest grass clover yields per cut found in the study. Due to their uncertainty the values of on-site recycling of P via mulching were not visualized. In total grassland and arable land had a mean P balance of -1,105 kg yr^{-1}.

The farm P flow is visualized in Figure 3.2 according to the values from Table 3.3 to 3.6 and gives an impression of the demand and transfer of P in and between the different farm segments. The boundary around the cycle indicates the farm gate for bought inputs (imported fodder, seeds) and outputs (milk, net production of live weight, exported manure). Fodder (imported and from farm own origin, from arable land and grassland), grazed grass and milk for calves were the sources for P input into the stable. In the stable the fodder was transferred into animal products and manure. One part of the manure was redistributed to the arable land and grassland another part was exported to farmland outside the dairy system. Biomass products from arable land and grassland were fodder for cows. P flows via the soil are shown in the middle of Figure 3.2: P from the soil buffered the gap between P in biomass export and natural losses and P in manure and atmospheric input at arable land and grassland. The quantities of P flowing in the different farm parts are described in the following.

Table 3.4: Data basis and calculation of the average soil P balance of grassland (Trenthorst, 54 ha, 2010-2012).

	Soil P balance grassland	**Mass flow**				**P flow**	
		Total [kg yr^{-1}]	**SD [kg yr^{-1}]**	**[kg ha^{-1} yr^{-1}]**	**SD [kg ha^{-1}]**	**Total [kg yr^{-1}]**	**[kg ha^{-1} yr^{-1}]**
=	Excretion	-		-	-	345	6.4
+	manure application	501,427 FM	±597,123	9,286 FM		75	1.4
+	Atmospheric deposition	-		-	-	11	0.2
	Grazing intake neighbouring plots (33ha)	*131,362 DM*		*3,980 FM*	*±751*	*514.9*	[†]*15.6*
	Grazing intake remote plots (6.8 ha)	*28,700 DM*		*4,221 FM*	-	*112.5*	*16.5*
-	Grazing[‡] (total) (39.8 ha)	160,062 DM		4,046 DM	±724	627	11.6
-	Storage food (23.3 ha)	55,408 DM		2,422 DM	±577	217	4
-	Losses (run of, leaching)	-		-	-	16	0.3
Balance (Eq. [5])						**-429**	**-7.9**

[†]Italic numbers: based on actual grazed area [‡]grazing data: year 2012 as representative

Table 3.5: Data basis and calculation of the average soil P balance of arable land (Trenthorst, 62 ha, 2010-2012).

	Soil P balance arable land	**Mass flow**			**P flow**	
		Total [kg yr^{-1}]	**SD [kg yr^{-1}]**	**[kg ha^{-1} yr^{-1}]**	**Total [kg yr^{-1}]**	**[kg ha^{-1} yr^{-1}]**
=	Stable manure	178,911 FM	±155,522	2,886 FM	181	2.9
+	Slurry	2,166,341 FM	±1,092,222	34,941 FM	329	5.3
+	Seeds	710 FM	±30	11.4 FM	28	0.45
+	Atmospheric deposition	-		-	12	0.2
	Grass-clover silage (21 ha)	*163,639 DM*	*±46,852*	*7,705 DM*	*504.2*	*23.7*
	Maize silage (10 ha)	*113,324 DM*	*±54,550*	*10,998 DM*	*313.2*	*30.4*
	Grain (total, seeds) (30.5 ha):	*96,423 DM*	*±27,955*	*3,279 DM*	*365.7*	*12.5*
	Oats and beans (9.9 ha)	*34,859 DM*	*±15,779*	*3,798 DM*	*173.1 (193.4)*[†]	*19.4*
	Triticale (10.4 ha)	*28,392 DM*	*±8,170*	*2,731 DM*	*80.5 (78.8)*[†]	*7.6*
	Wheat (10.2 ha)	*33,172 DM*	*±6,047*	*3,309 DM*	*112.1 (106.8)*[†]	*10.7*
	Straw (triticale, wheat) (19 ha)[‡]	*28,413 DM*	*±570*	*1,505 DM*	*24*	*1.25*
-	Crop yield (total)	401,800 DM		-	1,207	19.5
-	Losses (run of, leaching)	-		-	19	0.3
Balance (Eq.[6])					**-676**	**-10.9**

[†]Based on total DM yields (based on avg DM yields), [‡]without headlands, FM, DM: Fresh matter, dry matter, SD: Standard deviation.

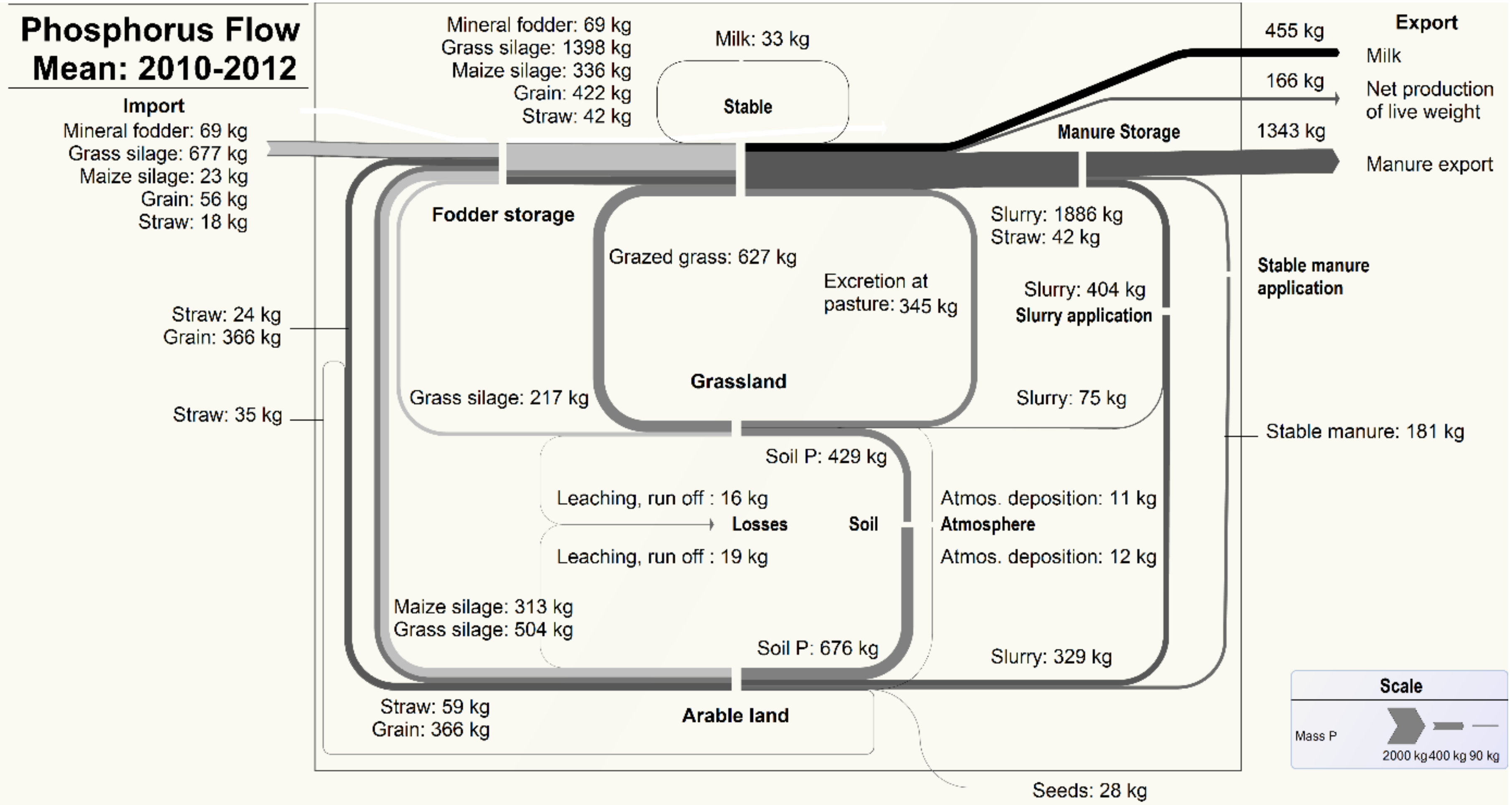

Fig. 3.2 Mean yearly phosphorus imports and exports at the farm gate and internal flows between and within different farm parts of the dairy farm Trenthorst between 2010 and 2012 based on practice data.

Altogether, the farm balance (Table 3.6, Fig. 3.2) showed total P outputs of 1,965 kg yr^{-1}. The sum of total inputs from imports and depletion of P soil reserves was 1,975 kg P yr^{-1}. Net losses from atmospheric deposition and leaching were 12 kg P yr^{-1}. Thus these values did not exactly match the input side due to roundings and settings.

Table 3.6 Data basis and calculation of the P farm balance (Trenthorst, 2010-2012).

P balance $_{\text{farm}}$		**Mass flow**		**P flow**
		Mean [kg yr^{-1}]	**SD [kg yr^{-1}]**	**kg yr^{-1}**
=	Mineral fodder	2,617 FM	±233	69
+	Imported storage fodder and straw	265,868 DM	±76,224	774
+	Seeds (62 ha)	710 FM	±30	28
+	Atmospheric deposition (116 ha)	-	-	23
-	Milk	469,086 FM	±19,655	455
-	Net production of live weight	22,091 FM	±1,015	166
-	Manure export	-	-	1,343
-	Losses (run of, leaching) (116 ha)	-	-	35
Balance (Eq. [7])				**-1,105**

FM, fresh matter; DM, dry matter; SD, standard deviation.

The export of meat was 75,722 kg live weight during the three-year period. The change in herd size from 164.4 LU to 145.5 LU accounted for 9,450 kg. Therefore, the net production of live weight was 66,272 kg in three years, which corresponds to 1 kg P yr^{-1}. Another 455 kg P a^{-1} were exported in form of sold milk (Table 3.6). The P flows from the fed biomass to manure in storage accumulated to 1,887 kg P yr^{-1}. Another 42 kg P yr^{-1} in the manure originated from straw that was used as bedding material. Only 585 kg P (30.3 %, Fig. 3.2) from this amount were recycled within the dairy crop rotation under the management regime of the farm under study (87.2 % at arable land, 12.8 % at grassland). Assuming no unaccounted losses the mean P output at the stable gate was in sum 2,895 kg P per year with milk, meat and manure for storage and excretion at pasture (Fig. 3.2). This P originated from stable inputs of 41.7 % with forage and concentrates from farm own production in the arable crop rotation (Table 3.5), of 21.7 % from grazing intake and bound in animal products, of 7.5 % with roughage conserves from permanent grassland (Table 3.4), and of 2.4 % with purchased mineral feed additions. Another 26.7 % of the P was imported with feedstuff and litter (Table 3.6) from plots outside of the defined system boundary. These were mainly clover-grass silage and small amounts of maize silage, grains and straw (Fig. 3.2). In the years 2010, 2011, and 2012 an internal flow of 32.9 kg, 21.4 kg and 43.8 kg P with whole milk was calculated to fed the calves, respectively. Imported seeds, mineral feed additions and imported feed and litter totaled 871 kg P yr^{-1} as inputs at the system boundary. Focused only on feedstuff (without calves' milk), grassland directly accounted for 29.2 % of the P supplied to the cattle, on average (Fig. 3.2). In quantifying the redistribution of P from grassland to arable land by the material flows 217 kg P yr^{-1} were transferred from grassland to the stable as conserved feed. From this amount, 78 kg yr^{-1} P were converted into animal products. A total of 139 kg P yr^{-1} ended up in manure, from which 75 kg P yr^{-1} were reapplied on grassland. The difference of 64 kg P yr^{-1} (which is 29.4 % of the P from storage fodder from grassland) must have been covered by soil reserves of grassland. It is transferred to arable land via feed conserves and manure. On average this means that on the farm under study grassland (54 ha) serves arable land (62 ha) with ~1 kg P ha^{-1} yr^{-1}.

3.6 Discussion

Uncertainties in balance calculation

Any material balance of farm flows under practical conditions must deal with uncertainties and assumptions. For this study all sub-processes have a consistent P-balance leading to a reliable balance on farm level. The P concentrations in plant materials highly influence the calculated P flows, especially in high yielding crops. Uncertainties might be caused by the settings for P concentrations, digestibly of feed, mass determinations and temporal system boundaries for storage of feed or manure. Due to the important effects of sampling and nutrient concentration in plants and manure, P flows should preferably be based on farm specific results. Also the three years studied showed high variability in P flows along with varying annual yields and differences in manure management and exports (Table 3.5). Representative periods should be used for calculations of long term trends in inner farm P transfer. Even with uncertainties and variability, e.g., in P contents of materials, the analysis of nutrient farm flows is an important step in order to address and balance out spatial differences in P soil reserves on farms by cropping management and manure redistribution.

Grassland in farm P cycle

Grazing animals indirectly reduced the pressure of the forage production on arable land by 627 kg P yr^{-1} (10.1 kg P ha yr^{-1}) due to feed stuff from grassland compared to hypothetic scenarios solely producing forage crops in arable rotations. Compared to Swedish organic dairy farms (Gustafson et al., 2007) P concentration in grassland plants in this study is high, likely caused by high P level in the soil. A depletion of P in soil through continuous mining would probably lead to lower P concentrations in plants in the near future. How long grassland yields will be unaffected is completely unclear due to missing knowledge on biochemical and activation forces that might improve P availability with declining P reserves (Antunes et al., 2012; Schick et al., 2013). Regular soil analyses and/or plant tissue analyses on available P contents and also yield checks, should be used as a practical measure to avoid critical situations and to track the dynamics.

To follow the idea of grassland providing nutrients to arable land, nutrient transfer from areas with high soil P reserves and high activation potential to areas with lower soil P reserves should be improved. In the current study, high differences in the DM intake of grazing cows were obvious (Fig. 3.1). This indicates a potential for a future improvement of swards, grazing management and storage feed yields on grassland in targeting enhanced P flows and transfers. A forced and controlled mining of soil P in grassland of the examined site, seems to be acceptable at the current soil P levels. In experimental loamy soils with P contents well over the agricultural optimum, phytomining over 7-16 yr only decreased the P content between 11 and 37 %, showing additional buffer capacities of soils for longer time periods (Svanback et al., 2015).

Arable land in P farm cycle

According to the methodology used in this study, variations in P mobilization for different crops were generally related to biomass DM yields (Table 3.5) and its P content. Different P acquisition strategies of plants were not considered in detail to explain differences in uptake. Generally, high P uptake of crops serves the biological P cycle on the farm. It can be expected that long-term immobilization of P in soil can be partly prevented by P remaining in biomass and thus be made available more rapidly after decomposition for plant and microbial uptake in general (Richardson et al., 2009, Schnug et al. 2003). Therefore, mulching of clover grass and even the direct backflow of straw after harvest and root biomass might support the rapid P cycling in soils on the farm. Inclusion of the high P yielding faba beans (in mixed cropping) improved P uptake compared to the lower P yielding cereals in monocultures (Simpson et al., 2011). Generally, the varying P uptake of species can be caused by,e.g., root growth patterns, root hairs, proton and organic acid release of roots, acid and alkaline phosphatases excreted by roots and microorganisms as well as mycorrhiza (Eichler-Löbermann et al., 2008; Jungk and Claassen, 1986; Scheffer and Schachtschabel, 2010; White, 2006). Yet, the high P levels found in the analyzed soils will interfere with mycorrhization (Gosling et al., 2006). Any factors that alter the level of primary production and inputs, as well as the transformation of organic carbon, will additionally affect the dynamics of organic P in soil (Condron and Tiessen, 2005).

While P concentrations in plant tissue in arable crops and soils on the site under study are still sufficient (Table 3.1, Kuchenbuch and Buczko, 2011) P exports were found to be higher than from grassland. As with grassland, it is not predictable how long soil reserves will be sufficient, especially under low yield conditions of organic farming and crop rotations with high biological P transfer by feed crops. Further analyses of buffering effects of soil P reserves for P supply to plants in systems with restricted P input are of high interest for an efficient use of P soil reserves in organic farming and should be further addressed in research.

Entire P farm cycle

In the study, P exports of livestock products and manure were not balanced referred to the farming system. The farm gate deficit of 1,105 kg P yr^{-1} needed to be mobilized from soil under actual farm conditions (Fig. 3.2). The manure P export was 473 kg higher than P import with feed and seeds. If this amount were to be spread within the system, exported products and losses would be reduced to 632 kg P yr^{-1}. This deficit would be innate to the system. Kuchenbuch and Busczko (2011) recommend external P fertilizers when P (CAL) is lower than 4.4 mg 100 g^{-1} P in the topsoil. Therefore the level of P concentrations in soils under study can still be decreased without endangering soil fertility. Stutter et al. (2012) evaluated the soil P reserves for Germany and estimated more than 3,000 kg P per ha^{-1} in the upper 15 cm layer for agricultural land irrespective of its plant accessibility. However, the plot-specific P mining potential that can be tolerated without endangering soil fertility is unknown. Finding a system specific optimal P level for the yield levels and crop rotations of organic farming and defining suitable fertilization strategies needs further scientific work. Especially biological mechanisms should be addressed as they have an important role for P cycling and activation (Dotaniya and Meena, 2015; Talge et al., 2014; Péret et al., 2014; Gerke and Meyer, 1995). On the actual farm reducing the P export through manure would prolong the period of acceptable soil P mining.

Potential role of grassland for an improved P supply

Beside the mentioned possibility to intensify the grassland use on farm, grassland can act as transformer for sparingly soluble phosphate rock to plant available forms. Due to the higher intensity of biological processes and lower pH values of grassland soils than arable soils, mineral P fertilizers might be correctly placed here and their P might be transferred from here in the arable farm cycle via feeding and resulting manures (Mengel et al., 2001; Möller, 2009). As the import of mineral fertilizers in organic farming according to European standards is restricted to low solubility products mainly sparingly soluble rock phosphates are available for mineral P supply (Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91), this aspect could be of special importance for this farming system (MacNaeidhe and O'Sullivan, 1999; Sinclair et al., 1990).

Meanwhile, the nutrient supply of 34 % of the German grassland is categorized as high or very high (Scheffer and Schachtschabel, 2010) caused by former P balance surpluses. Nowadays in Germany, 209,600 ha of permanent grassland is unprofitable or abandoned (Federal Statistical Office, 2014). Also biomass from nature conservation areas, e.g., from neglected grassland where biomass needs to be removed to achieve nature protection targets, could be valuable (Diacon-Bolli et al., 2012; Isselstein et al., 2005; Sutherland 2002). Its potential to substitute other fodder sources for ruminants could be exploited and thus it could act as a new P source for P redistribution. Due to the fact that the feed and energy demand of dairy cows changes throughout lactation, grassland of very different quality could be integrated more actively in farm nutrient and P flows. For example, extensively managed grassland can be a fitting fodder source in the first phase of the dry period (Brinkmann et al., 2012), thus avoiding malnutrition-caused diseases. Its use relieves the pressure for forage production on arable land or on high quality pastures. This biomass is also discussed as substrate for bio-energy generation in biogas plants (Ebeling, 2013; McKenzie, 2013) but the potential for nutrient transfer is not yet in focus. With 56 % of grassland in German organic farms, these aspects are worth looking into to address and use P accumulations in soils by vegetative mining and redistribution as part of a sustainable use of worldwide P resources.

3.7 Conclusions

The P balance of the 116 ha North German organic dairy farm Trenthorst showed a net P export of 1,105 kg P yr^{-1} over three reference years. The deficit is supplied from soil P reserves. Visualizing farm specific P flows is helpful to develop P management on farm. Due to high variations in yields and P contents of the different materials, the use of farm specific values and representative farm periods are suggested. In the presented situation, grassland directly fed arable land with 64 kg P yr^{-1} (this was ca. 1 kg P ha^{-1} yr^{-1}) from soil reserves of grassland via manure. Yield increase by sward improvement and optimizing grazing and cutting management might improve this positive loop. Despite several years without external P supply the mining of soil P on grassland does not yet endanger soil fertility on the site under study, since available P (CAL) contents in the soil are still sufficient. But especially for the extensive conditions and for the wide range of crops used in organic farming it is unclear how long soil P reserves can be addressed. If critical situations are avoided based on evaluation of soil and plant analyses, forced and controlled P mining on grassland sites with P contents over the agricultural optimum and redistribution to arable land could be a component of sufficiency P management to safe worldwide mineral P resources. The inclusion and use of remote or marginal grassland sites with sufficient soil P supply in nutrient cycling by ruminant and biogas systems should be evaluated as source for redistribution of nutrients in landscapes and farms.

3.8 Acknowledgement

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3.9 References

Antunes PM, Lehmann A, Hart MM, Baumecker M, Rillig M (2012) Long-term effects of soil nutrient deficiency on arbuscular mycorrhizal communities. Funct Ecol 26(2):532-540

Barberis E, Marsan FA, Scalenghe R, Lammers A, Schwertmann U, Edwards AC, Maguire R, Wilson MJ, Delgado A, Torrent J (1996) European soils overfertilized with phosphorus 1. Basic properties. Fert Res 45(3):199-207

Bengtsson H, Öborn I, Jonsson S, Nilsson I, Andersson A (2003) Field balances of some mineral nutrients and trace elements in organic and conventional dairy farming—a case study at Öjebyn, Sweden. Eur J Agron 20(1–2):101-116

Böhm H (2007) Mineralstoffgehalte in Körnerleguminosen und Sommergetreide. 9. Wissenschaftstagung Ökologischer Landbau; March 2007; Universität Hohenheim, Tagungsband, pp 20-23

Brinkmann J, Schumacher U, Weidmann G (2012) Euter- und Stoffwechselgesundheit bei Biomilchkühen. First ed. FiBL-Merkblatt 1580 [online]. To be found at <http://literatur. ti.bund.de/digbib_extern/dn050112.pdf> [quoted 30.7.2015]

Condron LM, Tiessen H (2005) Interactions of Organic Phosphorus in Terrestrial Ecosystems, In: Turner BL, Frossard E, Baldwin DS, editors, Organic phosphorus in the environment. CABI, UK, pp 295-307

Cooke GW, Williams RJB (1973)3 Significance of man-made sources of phosphorus: Fertilizers and farming. Water Res 7(1–2):19-33

Cordell D, Drangert JO, White S (2009) The story of phosphorus: Global food security and food for thought. Global Environ Chang 19(2):292-305

Cornish P (2009) Phosphorus management on extensive organic and low-input farms. Crop Pasture Sci 60(2):105-115

Diacon-Bolli J, Dalang T, Holderegger R, Bürgi M (2012) Heterogeneity fosters biodiversity: Linking history and ecology of dry calcareous grasslands. Basic Appl Ecol 13(8):641-653

Dotaniya ML, Meena VD (2015) Rhizosphere Effect on Nutrient Availability in Soil and Its Uptake by Plants: A Review. Proc. Natl. Acad. Sci., India, Sect. B Biol Sci 85(1):1-12

Ebeling D, Breitsameter L, Bugdahl B, Janssen E, Isselstein J (2013) Herbage from extensively managed grasslands for biogas production: methane yield of stands and individual species. Grassland Science in Europe 18:560-562.

Eichler-Löbermann B, Köhne S, Kowalski B, Schnug E (2008) Effect of Catch Cropping on Phosphorus Bioavailability in Comparison to Organic and Inorganic Fertilization. J Plant Nutr 31(4):659-676

Federal Statistical Office (Statistisches Bundesamt) (2014) Ackerland und Dauergrünland des ökologischen Landbaus in Deutschland und Dauergrünland nach Art der Nutzung im Zeitvergleich [online]. To be found at <https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/LandForstwirtschaftFischerei/FeldfruechteGruenland/FeldfruechteGruenland.html> [quoted at 30.7.2015]

Fystro G (2014) Nitrogen, Phosphorous and Potassium – balances and efficiency. Slide presentation of original data; Miljømelkseminar; Bioforsk Norway; 31 Oct. 2014; Mold, Norway

Gerke J, Meyer U (1995) Phosphate acquisition by red clover and black mustard on a humic podzol. J Plant Nutr 18(11):2409-2429

Gosling P, Hodge A, Goodlass G, Bending GD (2006) Arbuscular mycorrhizal fungi and organic farming. Agric Ecosyst Environ 113(1–4):17-35

Gustafson GM, Salomon E, Jonsson S (2007) Barn balance calculations of Ca, Cu, K, Mg, Mn, N, P, S and Zn in a conventional and organic dairy farm in Sweden. Agric Ecosyst Environ 119(1–2):160-170

Haas G, Deittert C, Köpke U (2007) Farm-gate nutrient balance assessment of organic dairy farms at different intensity levels in Germany. Renew Agr Food Syst 22(3):223-232

Ho MD, Rosas JC, Brown KM, Lynch JP (2005) Root architectural tradeoffs for water and phosphorus acquisition. Funct Plant Biol 32(8):737-748

Ippolito J, Blecker S, Freeman C, McCulley R, Blair J, Kelly E (2010) Phosphorus biogeochemistry across a precipitation gradient in grasslands of central North America. J Arid Environ 74(8):954-961

Isselstein J, Jeangros B, Pavlu V (2005) Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe – a review. Agronomy Res 3(2):139-151

Jeroch H, Drochner W, Simon O (1999) Ernährung landwirtschaftlicher Nutztiere. Ulmer, Stuttgart

Jungk A, Claassen N (1986) Availability of phosphate and potassium as the result of interactions between root and soil in the rhizosphere. Z Pflanz Bodenkunde 149(4):411-427

Kape H-E, Wulffen von U, Roschke M (2008) Richtwerte für die Untersuchung und Beratung zur Umsetzung der Düngeverordnung in Mecklenburg-Vorpommern. Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern [online]. To be found at <http://www.lms-beratung.de/upload/59/1294212632_30690_19228.pdf> [quoted 10.8.2015]

Klapp EL (1971) Wiesen und Weiden. 4th ed. Parey, Berlin

Knowlton KF, Herbein JH (2002) Phosphorus Partitioning During Early Lactation in Dairy Cows Fed Diets Varying in Phosphorus Content. J Dairy Sci 85(5):1227-1236

Kuchenbuch RO, Buczko U (2011) Re-visiting potassium- and phosphate-fertilizer responses in field experiments and soil-test interpretations by means of data mining. J Plant Nutr Soil Sc 174:171-185

LLUR Landesamt für Landwirtschaft Umwelt und ländliche Räume Schleswig Holstein (2014) Nährstoffe in Gewässern Schleswig-Holsteins Entwicklung und Bewirtschaftungsziele. Schriftreihe LLUR SH- Gewässer, D 24

Landwirtschaftskammer Niedersachsen (2011) Richtwerte für die Düngung in Niedersachsen [online]. To be found at <http://www.lwk-niedersachsen.de/index.cfm/portal/pflanze/nav/341/article/11622.html> [quoted 10.1.2015]

Lindenthal T (2000) Phosphorvorräte im Boden, betriebliche Phosphorbilanzen und Phosphorversorgung im Biologischen Landbau - Ausgangspunkte für die Bewertung einer großflächigen Umstellung ausgewählter Bundesländer Österreichs auf Biologischen Landbau hinsichtlich des P-Haushalts. Ph.D. diss. Universität für Bodenkunde, Wien

MacNaeidhe FS, O'Sullivan AN (1999) The evaluation of phosphorus sources for nutrient budgeting on organic farms. End of project report ARMIS 4510, Rural Environmental Series No.16, Johnstown Castle Research Centre, Wexford, Dublin, Ireland

MacKenzie E (2013) Marginal grassland has potential for anaerobic digestion. Farmers Weekly, 14 January 2013 [online]. To be found at <http://www.fwi.co.uk/business/marginal-grassland-has-potential-for-ad.htm> [quoted 10.7.2015]

Mengel K, Kosegarten H, Kirkby EA, Appel T (2001) Principles of plant nutrition. 5th ed. Springer, Netherlands

Modin-Edman A-K, Öborn I, Sverdrup H (2007) FARMFLOW — A dynamic model for phosphorus mass flow, simulating conventional and organic management of a Swedish dairy farm. Agr Syst 94(2):431-444

Möller K (2009) Inner farm nutrient flows between arable land and permanent grassland via the stable in organic cropping systems. Eur J Agron 31(4):204-212

Nesme T, Toublant M, Mollier A, Morel C, Pellerin S (2012) Assessing phosphorus management among organic farming systems: a farm input, output and budget analysis in southwestern France. Nutr Cycl Agroecosys 92(2):225-236

Oberson A, Joner EJ (2005) Microbial turnover of phosphorus in soil. In: Turner, B.L., Frossard, E., and D.S. Baldwin, editors, Organic phosphorus in the environment. CABI, Wallingford, pp 133-164

Oenema O, Kros H, de Vries W (2003) Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. Eur J Agronomy 20(1-2):3-16

Ohm M, Schüler M, Warnecke S, Paulsen HM, Rahmann G (2014) Measurement methods on pastures and their use in environmental life-cycle assessment. Org Agr 4:325-329

Paulsen, HM, Schochow M (2006) Anbau von Mischkulturen mit Ölpflanzen zur Verbesserung der Flächenproduktivität im ökologischen Landbau: Nährstoffaufnahme, Unkrautunterdrückung, Schaderregerbefall und Produktqualitäten. Final report of project nr. 03OE113. Braunschweig: FAL. Landbauforsch Völkenrode SH 309:142

Péret B, Desnos T, Jost R, Kanno S, Berkowitz O, Nussaume L (2014) Root Architecture Responses: In Search of Phosphate. Plant Physiol 166(4):1713-1723

Rahmann, G, Nieberg H (2005) New insights into organic farming in Germany – empirical results of a survey in 218 farms. Landbauforsch 3(55):93-202

Richardson AE, Barea JM, McNeill AM, Prigent-Combaret C (2009) Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms. Plant and Soil 321(1-2):305-339

Schachtman, DP, Reid, RJ, Ayling S.M. (1998) Phosphorus uptake by plants: from soil to cell. Plant Physiol 116(2):447-453

Scheffer F, Schachtschabel P (2010) Lehrbuch der Bodenkunde. Spektrum Akademischer Verlag, Berlin, pp. 412-420

Schick J, Hanelklaus S, Schnug E (2012) Baltic Manure WP 4 Standardisation of manure types with focus on Phosphorus Prototype model for the phosphorus turnover in soils (P-Engine) in relation to varying environmental conditions in the Baltic Sea Region. Knowledge report. Baltic Forum for Innovative Technologies for Sustainable Manure Management [online]. To be found at <http://balticmanure.eu/download/Reports/pengine_report_final.pdf> [quoted 10.7.2015]

Schnug E, Rogasik J, Haneklaus S (2003) The utilisation of fertiliser P with special view to organic farming. Landbauforsch Volkenrode 53(1):1-11

Schüller H (1969) Die CAL-Methode, eine neue Methode zur Bestimmung des pflanzenverfügbaren Phosphates in Böden. Z Pflanz Bodenkunde 123 (1):48-63

Schröder JJ, Smit AL, Cordell D, Rosemarin A (2011) Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use. Chemosphere 84(6):822-831

Simpson RJ, Oberson A, Culvenor RA, Ryan MH, Veneklaas EJ, Lambers H, Lynch JP, Ryan PR, Delhaize E, Smith FA, Smith SE, Harvey PR, Richardson AE (2011) Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems. Plant Soil 349(1-2):89-120

Sinclair AG, Dyson CB, Shannon PW (1990) The long-term effectiveness of reactive phosphate rock as a phosphate fertilizer for New Zealand pastures. Proceedings of the New Zealand Grassland Association 51 [online]. To be found at <http://www.grassland.org.nz/publications/nzgrassland_publication_977.pdf> [quoted 1.7.2015]

Smith SE, Read DJ (2010) Mycorrhizal Symbiosis. 3rd ed. Burlington Elsevier Science, New York.

Steinshamn, H., Thuen, E., Bleken, M.A., Brenøe U.T., Ekerholt, G., and C. Yri. 2004. Utilization of nitrogen (N) and phosphorus (P) in an organic dairy farming system in Norway. Agric Ecosyst Environ 104(3):509-522

Stutter MI, Shand CA, George TS, Blackwell MS, Bol R, MacKay RL, Richardson AE, Condron LM, Turner BL, Haygarth PM (2012) Recovering phosphorus from soil: a root solution? Environ Sci Technol 46(4)1977-1978

Sutherland WJ (2002) Conservation biology: Openness in management. Nature 418(6900):834-835

Suttie JM, Reynolds SG, Batello C (2005) Grasslands of the world. Rome: Food and Agriculture Organization of the United Nation [online]. To be found at <http://www.fao.org/docrep/008/y8344e/y8344e00.htm> [quoted 15.7.2015]

Svanback A, Ulen B, Bergstrom L, Kleinman PJA (2015) Long-term trends in phosphorus leaching and changes in soil phosphorus with phytomining. J Soil Water Conserv 70(2):121-132

Talgre L, Lauringson E, Roostalu H, Makke A (2014) Phosphorus and potassium release during decomposition of roots and shoots of green manure crops. Biol Agric Hortic 30(4):264-271

Tóth G, Guicharnaud R-A, Tóth B, Hermann T (2014) Phosphorus levels in croplands of the European Union with implications for P fertilizer use. Eur J Agron 55:42-52

Vance CP (2001) Symbiotic nitrogen fixation and phosphorus acquisition. Plant nutrition in a world of declining renewable resources. Plant Physiol 127(2):390-397

White RE (2006) Principles and practice of soil science: the soil as a natural resource, 4th ed. Blackwell Publishing, Malden, USA, pp 201-228

Whitehead DC (2000) Nutrient elements in grassland: soil-plant-animal relationships. Cabi, UK, Cambridge

Wu Z, Satter LD, Blohowiak, AJ, Stauffacher RH, Wilson JH (2001) Milk Production, Estimated Phosphorus Excretion, and Bone Characteristics of Dairy Cows Fed Different Amounts of Phosphorus for Two or Three Years. J Dairy Sci 84(7):1738-1748

4 Continuous decrease of soil P pools in soil after changing from conventional to organic farming

The main results of this manuscript are published 2017 in Agronomy for Sustainable Development 37(3):17, doi: 10.1007/s13593-017-0425-y Long-term negative phosphorus budgets in organic crop rotations deplete plant available phosphorus from soil.

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4.1 Abstract

In organic farming phosphorus (P) can be imported in mineral form with rock phosphate, or in organic form by feedstuff for livestock or suitable organic fertilizers. However, many organic farmers rely mainly on soil P reserves and tolerate negative P balances, not knowing when soil reserves will be depleted. In this study two organic systems with (dairy system) and without (stockless system) recirculation of P with livestock manure were analyzed for arable land and permanent grassland on a loamy site in North Germany. The development of plant available P (CAL) in top-soils was monitored over twelve experimental years, and the mineral soil P fractions (Hedley) and the total P content were assessed in 2001, 2009 and 2013. Enzymatic parameters (phosphatase and dehydrogenase activities) were analyzed in 2001 and 2013. The P balances were negative for all tested systems which resulted in a decrease of the P (CAL) and of the labile mineral P fractions (H_2O P and Resin P). However, the recommended thresholds for sufficient P supply in soil (P CAL) and in plant tissue were still reached on all sites at the end of the study. The grassland soil showed higher enzymatic activities than arable land. Phosphatase activities did not change during the study, while in both arable systems the activities of acid and alkaline phosphatase in the topsoil increased. In grassland dehydrogenase activity was found to be lower in 2013 than in 2001, whereas in arable land activity remained constant. Higher activities of phosphatases hint at the potential of plants and microbes to mobilize P from less available soil reserves. Site specific management options to improve biological P-mobilization from soils should be focused in more detail on extensive systems in the future.

Keywords: nutrient management; organic farming; organic fertilization; cropping system, crop rotation and management; P-balances

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4.2 Introduction

Phosphorus (P) is an essential element for plant growth, e.g., as a structural element of genetic information or by its role in energy transfer (Bergmann 1988, Marschner and Marschner 2012). Soil persists as a temporal reservoir for P, but only a relatively small fraction of total soil P is provided for direct plant or microbial uptake (Mengel et al. 2001). Inorganic and organic P forms in soils are a result of the multifaceted P turnover processes which are affected by plants, microorganisms and abiotic factors (Requejo et al. 2014, Annaheim et al. 2013). As in organic farming plants are to be nourished primarily through the soil ecosystem (Council Regulation (EC) No 834/2007, §5), this reservoir must be especially addressed for plant nutrition. In European agricultural soils P is often enriched due to former application of inorganic and organic fertilizers (Tóth et al. 2014). This offers reserves for organic farms with low external feed and fertilizer imports which often have negative average P balances (Haas et al. 2007, Steinshamn et al. 2004) and lead to low plant available P contents in soil (Keller et al. 2012). Approved organic fertilizers for P import are organic materials (e.g., livestock manures, compost) and chemically untreated mineral materials (e.g., rock-phosphates) which has low solubility in soils. As yield levels are restricted in organic farming – and consequently also the P-uptake of organic crops – suitable lower thresholds for sufficient P contents in soils under organic management are still under discussion (Paulsen et al. 2016, Kolbe 2001).

The mineralization of organic P in soil is mediated largely by microbial activity and by phosphatases of either plant or microbial origin (Oberson and Joner 2005). Microbial activity can by estimated by that of intracellular enzymes, e.g., dehydrogenases (Nain et al. 2010). The mobilization of less available inorganic P sources is steered, e.g., by excretion of protons and organic acids (Hinsinger 2001, Richardson and Simpson 2011, Simpson et al. 2014). On the other hand, the access to inorganic P can also have an effect on soil microbial P turnover, as it reduces the excretion of phosphatases and therefore the hydrolyzation of organic P compounds (Dick et al. 2011). Generally, soil microbial activity is strongly linked to the organic matter management (Krey et al. 2013, Bachmann et al. 2014), crop rotation (Hassan et al. 2012a, Simpson et al. 2011), tillage (Redel, 2007) and is highly influenced by environmental conditions (Oberson et al. 2011).

The P release from organic material is also influenced by its C:N:P ratio (Güsewell and Gessner 2009) and is a result of immobilization and mineralization processes (Bünemann et al. 2012). E.g., the relatively narrow C:P ratio of legume crops results in more or less balanced P mobilization/immobilization processes after their incorporation into the soil, whereas the decomposition of grass species can temporarily immobilize P (Withehead 1970). However, differences may also occur between different legume crops (Hassan et al. 2012b). E.g., after incorporation of red cover plants into the soil, a delayed P release was observed in comparison to other forage legumes by Talgre et al. (2014).

Although biological P mobilization processes are important for P supply for organic farming, there are only few long-term studies regarding their indicators and the subsequent effects on soil P availability: e.g., Keller et al. (2012) found no hints of an increased access of microorganisms and plants to recalcitrant soil P sources under continuous negative P field balances in the Swiss DOK trial. They point to the inclusion of arable crops with higher P mobilizing capacities to address soil reserves. In grassland, organic P is seen as an important source to sustain the P nutrition of plants. Management strategies effectively addressing organic P are needed (Nash et al. 2014, Chen et al. 2004). As a fostering biological P mobilization processes by agricultural measures which diminish soil reserves have not been developed for practical use in agriculture, many organic farmers tolerate negative P-balances not knowing when soil reserves will be depleted.

Within this thematic framework, the development of different P forms and biochemical indicators for P-mobilization in soil is assessed over long periods in the current study. Different organic farming systems with negative P-balances are analyzed. Mineral P fractions and phosphatase and dehydrogenase activities in topsoils of a livestock holding system (dairy system) and a stockless system as well as under grassland were investigated on one site under comparable soil conditions. Practical implications for the resilience of organic farming against balance deficits in P are derived.

4.3 Material and methods

Arable soils of a stockless system without livestock manure backflow, arable soils from a mixed dairy system and soils from permanent grassland were analyzed. The developments of biochemical indicators for P mobilization (acid and alkaline phosphatases), of the microbial activity (dehydrogenases) and of P supply (P (CAL), mineral P-fractions and of total P) were evaluated. This was done on the basis of soil samples from long-term monitoring (LTM) plots from the different arable and grassland systems on one site until twelve years after the conversion to organic farming. The farming systems had continuous negative P balances and no external fertilizer inputs.

4.3.1 Location and soil properties

The farming systems were located at the organic experimental station Trenthorst in Northern Germany (53°46’ N, 10°31’ E). Mean annual precipitation was 706 mm and mean annual temperature was 8.8°C (1978-2007). No mineral or imported organic P fertilizers were applied on this site since conversion to organic farming in 2001. The soils were characterized as Cambisols and Luvisols from boulder clay with sandy loamy texture (averages, 0-30 cm depth: arable land 46 % sand, 34 % silt 18 % clay, grassland 38 % sand, 41 % silt, 16 % clay). Soil properties of the different crop rotations under research are given in Table 4.1.

Table 4.1 Average soil properties of arable land and grassland calculated from long term monitoring data in 2003 and 2013 (per year n=24 for arable crop rotations, 0-30 cm sampling depth, and n=8 for grassland, 0-10 cm sampling depth, ± values indicate standard deviations).

System	Year	pH	C_{tot} g kg^{-1}	N_{tot} g kg^{-1}	Mg ($CaCl_2$) mg kg^{-1}	K (CAL) mg kg^{-1}	P (CAL) mg kg^{-1}	C:N Ratio
Stockless	2003	6.9 ±0.22	14.1 ±2.1	1.4 ±0.2	195 ±51	149 ±31	92.5 ±21	10:1
	2013	6.6 ±0.25	12.6 ±2.1	1.2 ±0.2	110 ±21	101 ±20	66.6 ±13	10:1
Dairy	2003	6.7 ±0.19	14.0 ±5.6	1.4 ±0.5	181 ±67	136 ±29	90.3 ±28	14:1
	2013	6.5 ±0.26	12.7 ±1.6	1.2 ±0.2	105 ±18	112 ±18	66.1 ±14	10:1
Grassland	2003	5.5 ±0.16	35.3 ±5.5	3.6 ±0.5	339 ±68	228 ±13	160.8 ±25	9.8:1
	2013	5.5 ±0.13	26.2 ±2.6	2.5 ±0.2	199 ±20	194 ±7.8	132.8 ±9.7	10.5:1

Threshold values for sufficient soil supply from Landwirtschaftskammer Niedersachsen (2011) and according farm specific characteristics: for arable land pH > 6.3; Mg > 60 mg kg^{-1}; K > 110 mg kg^{-1}; P > 50 mg kg^{-1}and for grassland pH > 5.6; Mg > 140 mg kg^{-1}; K > 110 mg kg^{-1} soil; P > 50 mg kg^{-1}

4.3.2 Experimental design

After the conversion to organic farming from 2001, the experimental farm was divided in two adjacent farm types (stockless and dairy) on six fields each in 2003 (Figure 4.1). Each field had a monitoring plot for continuous soil and plant sampling in 2001 and from 2003 over the years. For the special analyses of this study focus areas were chosen from these plots. Both systems had six-field crop rotations but differed in input of livestock manure, crops and percentage of forage legumes and grain legumes. The crop rotation in the stockless system consisted of pure legume fields (1/6 red clover and 1/6 grain legumes). In the dairy system grain-legumes were mainly grown in mixtures with grasses or cereals (1/3 red clover grass, 1/3 to 2/3 grain legume-cereal mixtures) (Table 4.2).

Table 4.2 Crops grown in the focus areas within the crop rotations of the farming system comparison in Trenthorst (harvest years 2001-2014).

	Stockless (36 ha)	**Dairy (62 ha)**	
2001[a]	winter oilseed rape (*Brassica napus*)	winter oilseed rape (*Brassica napus*)	Conversion phase
2002[a]	white clover (*Trifolium pratense*)	red clover grass *(Lolium perenne, Phleum pratense, Trifolium pratense*)	
2003	winter wheat (*Triticum aestivum*)	red clover grass	First rotation
2004	oats (*Avena sativa*)	winter wheat	
2005	field pea (*Pisum sativum*)	faba bean (*Vicia faba*) +oats	
2006	winter oilseed rape	field pea+spring barley	
2007	triticale (*Triticosecale*)+red clover	triticale+red clover grass	
2008	red clover	red clover grass	Second rotation
2009	winter wheat	red clover grass	
2010	spring barley (*Hordeum vulgare*)	maize (*Zea mays*)	
2011	field pea	winter wheat	
2012	winter oilseed rape	faba bean	
2013	triticale+red clover	triticale+red clover grass	

[a] grown on the focus areas (Figure 1) in 2001 and 2002.

In the permanent grassland under study the sward was intact for decades. It contained a mixture of grasses (e.g., *Lolium perenne, Festuca pratensis, Dactylis glomerata*) legumes (mostly *Trifolium repens*) and herbaceous plants (e.g., *Taraxacum officinale, Ranuculus, Carduus, Stellaria media, Rumex*).

The grains from the stockless system were exported from the farm. The fields didn’t receive external plant nutrients except by biological N fixation. Clover grass mulch remained completely on the fields.

Manure was applied according to the management scheme of the farm in 2004, 2005, 2007 and 2010 in the focus area of the dairy rotation that was chosen for detailed analyses of P fractions and enzymatic activity in this study (Figure 4.1). The grassland sites received slurry in 2005, 2007, 2009 and 2012 and were grazed by dairy cattle from 2003. Additionally they were harvested for the preparation of feed conserves. manure quality was not consistently documented for the different years due to practise conditions. Therefore nutrient and C input couldn’t be exactly quantified and were not used to underpin soil analysis data. Manure input must be seen as an unquantified system effect. Altogether the dairy crop rotation (62 ha) and the grassland (54 ha) covered most of the feed requirements (silage, grazing, concentrates) of up to 100 dairy cows. Extra feedstuff imports didn’t balance out the field and farm P-balances of the dairy farm. For the representative years 2010 - 2012, analyzed in an earlier study, an average mining of soil P reserves of -7.9 and -10.9 kg P ha^{-1} a^{-1} occurred on grassland and arable land, respectively (Ohm et al. 2015).

4.3.3 Sample procedure

According to the long term monitoring (LTM) approach to evaluate changes of soil parameters on the research station, four GPS-located points with a distance of 60 m were located in square in a 1 ha monitoring plot on each arable field and on two plots of the permanent grassland (Figure 4.1) (Schaub et al. 2007). At each of the four sample points topsoil material from three drillings of 4 cm diameter with a depth of 30 cm was collected and stored deep-frozen for conservation in May 2001 and May 2013. Enzyme activities, P (CAL), mineral P fractions and total P in these soil samples were analyzed for the years 2001 and 2013. Additionally P (CAL), mineral P fractions and total P according to Hedley et al. (1982) were analyzed in deep frozen samples taken at the end of winter 2009. Enzymatic parameters were not analyzed as the sampling time differed in 2001 and 2013. Development of plant available P (CAL) was described by continuous once-a-year samples taken between 2003 and 2013. The samples for this analysis were taken at the end of winter each year on all 14 fields of the LTM (sampling depth 0–30 cm in arable land and 0–10 cm in grassland) and stored in dry form prior to analysis. To evaluate the nutritional status of plants with P, aboveground plant biomass samples of cereals and grassland were taken by cutting plants at the LTM points (cereals 2 m^2; permanent grassland 0.5 m^2 – 1 m^2) directly before harvest or grazing. Cereals were threshed. Additionally the cereals were sampled at the beginning of stem elongation (BBCH 30/31, Meier 1997) for determination of nutrient concentration (no biomass yield determination). Plant material for analysis was available from 2004 on. All wheat, triticale and grassland samples available from the different crop rotations and focus areas were assessed in this study.

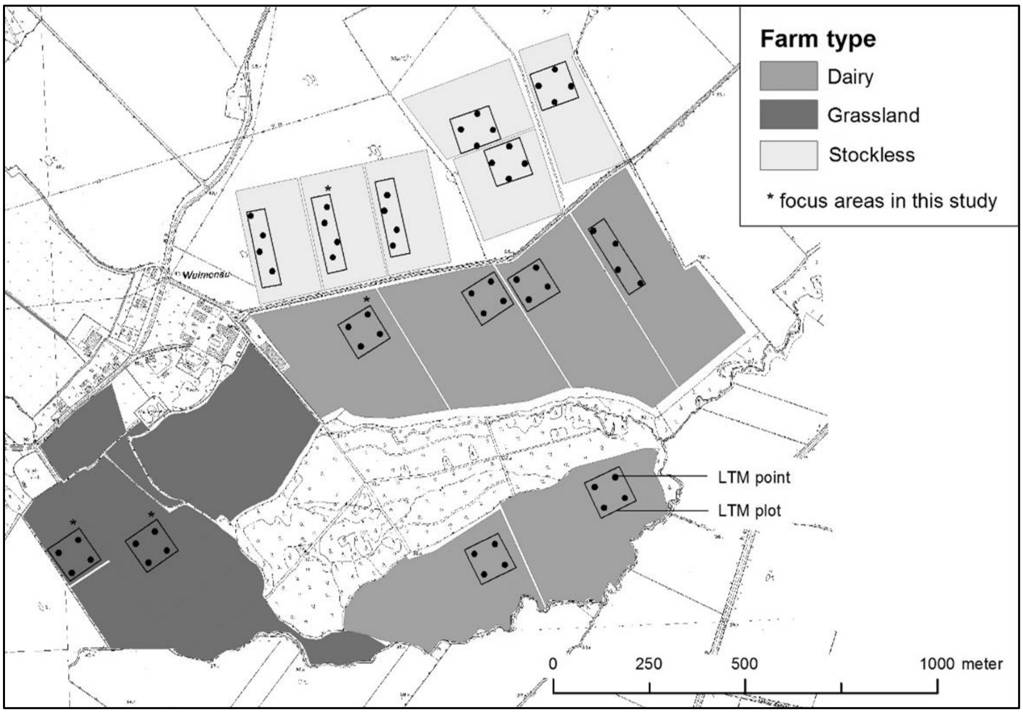

Figure 4.1 Sampling scheme in the long-term monitoring (LTM) at arable systems and grassland at the organic experimental station Trenthorst and focus areas for initial comparisons of bio-chemical parameters of soil P.

4.3.4 Plant and soil analysis

The soil was air-dried and sieved to 2 mm for the analysis of the chemical soil parameters. Deep-frozen (-20°C) samples were thawed and kept at room temperature for 24 h to determine the effects on the activity of soil microorganisms. Roots were rejected using tweezers before analyses started. Acid and alkaline phosphatase activities were measured according to Tabatabai and Bremner (1969) as p-nitrophenol released from p-nitrophenylphosphate solution of 1 g soil after incubation at 37°C for 1 h. Thereafter the samples were measured photometrically at 400 nm.

The dehydrogenase activity was analyzed according to Thalmann (1968) by suspending 1 g soil in 0.8 % triphenyltetrazoliumchloride (TTC) solution followed by incubation at 37°C for 24 h. TTC will be reduced to triphenylformazan (TPF) by most microorganisms. The released TPF was extracted with acetone before its concentration was photometrically measured at 546 nm.

In Germany, the plant available P fraction is standardly described as P (CAL) (Schüller 1969). A total of 5 g air-dry soil and 100 ml CAL solution (0.1 m Calcium acetate, 0.1 m Calacium lactate, and 0.3 m acetic acid; pH 4.1) were shaken for 2 h. The P concentration was determined photometrically with the molybdenum blue method (Murphy and Riley 1962).

To characterize the inorganic soil P forms in more detail, a modified P fractionation method has been applied after Hedley et al. (1982). In theory, the most labile P fractions are removed first with mild extractants, and then less biologically available fractions are subsequently removed with stronger solvents (Crews and Brookes 2014, Table 4.3). Our analysis took the following steps: Resin stripes (Art. 551642S), previously stored at 4 °C, were twice soaked in 0.5 mol l^{-1} $NaHCO_3$ for one hour and afterwards washed three times with distilled H_2O. Subsequently 0.5 g pestled soil, 30 ml distilled H_2O and a previously-prepared resin stripe were poured into 50 ml centrifuge tubes. Then the samples were shaken for 18 h in a horizontal position. Afterwards the resin stripe was washed with distilled H_2O and put into a new tube with 20 ml 1 mol l^{-1} hydrochloric acid for 2h. After this the resin stripe was removed and the tube filled to 50 ml with hydrochloric acid. Next, the tubes containing 0.5 g soil and distilled H_2O were centrifuged at 4°C at 3500 rpm for 20 minutes. The clear supernatant was poured off leaving the soil pellet. The residuum was then centrifuged a second time with 20 ml distilled H_2O, and together with this supernatant, the new tube was filled to 50 ml with distilled H_2O. Thereafter 30 ml 0.5 mol l^{-1} $NaHCO_3$ were added to the tubes containing the soil residuum and shaken for 18 h. Then the solution was treated exactly in the same way as before but with $NaHCO_3$ instead of distilled H_2O. Thereafter the residuum was treated with the same procedure with 0.1 mol l^{-1} NaOH followed by 1 mol l^{-1} HCl. The residual P was extracted from the residuum of the HCl fractionation. For this the residuum was transferred to Kjeldahl tubes together with 10 ml distilled H_2O. Boiling stones and 5 ml H_2SO_4 were added and heated to 360°C. After cooling, 0.5 ml H_2O_2 were added and the solution was heated for 30 minutes. This procedure was repeated until the solution was colorless. Then the tubes were filled to 50 ml with distilled H_2O. The total P was extracted by the same procedure as residual P, but with untreated soil.

To determine the amount of total P in plant material 0.5 g dry biomass was treated by 8 ml 65 %-solution of nitric acid (HNO_3) and 2 ml 35 %-solution of hydrogen peroxide (H_2O_2). Samples were heated for one hour at 200° C in a microwave oven (Mars Xpress Vessels). After filling the solution with distillated water to 50 ml, the P-concentration was analyzed by a photometer according to the molybdenum blue method (Murphy and Riley 1962).

Table 4.3 Sequential-fractionation scheme

Pools	**Extraction Procedure**	**Properties of P Fraction**
Resin P	Anion exchange resin	Most plant available P form (mostly P_i)
Water soluble P	distilled H_2O	H_2O dissolved or soluble forms
$NaHCO_3$-P	0.5 M $NaHCO_3$	Highly labile P fraction
NaOH-P	0.1 M NaOH	Moderately labile P fraction
HCl-P	1 M HCl	Stable P_i fraction
Residual P	Aqua regia digestion	Very stable P_i fraction
Total P	Addition of all P fractions or aqua regia digestion with untreated soil	

4.3.5. Statistical analysis

Statistical analyses were conducted using R 3.2.2 (R Development Core Team 2015). Results on P-fractions, P (CAL), P-total and activity of phosphatases and dehydrogenases from the focus areas of 2001, (2009) and 2013 were compared by pairwise t-test or, if data were not normally distributed, by Wilcoxon signed ranks test. The development of soil P (CAL) concentrations between 2001 and 2013 was analyzed using linear mixed effects models (LMM). As the data were not normally distributed they were log-transformed. For the data from arable land (dairy, stockless) the LMM was set up with year, farming system and the interaction of these two as fixed effects and LTM-point nested within LTM-plot and crop as random intercept effects. The model for the grassland data used year as fixed effect and LTM-point nested within LTM-plot as random intercept effect. For mixed effects modelling the R package lme4 (Bates et al. 2014) was used. Marginal and conditional R2 were calculated for the mixed models according to Johnson 2014 and Nakagawa and Schielzeth 2013 by using the function r.squaredGLMM from the R-package MuMIn (Barton 2015). While marginal R2 deals with the variance explained by the fixed factors, conditional R2 deals with the variance explained by the entire model (fixed + random factors). After modelling least-square means were extracted using R package lsmeans (Lenth 2016).

A correlation analysis between P (CAL) and plant P content of wheat in the development stage BBCH 30/31 was done by Spearman's rank correlation test, because of the nonparametric distribution of the P (CAL) values (Dormann 2013).

4.4 Results

Parameters of P supply in soil

As expected, total P, the activity of phosphatases and dehydrogenase, P fractions and available P (CAL) were found to be higher in grassland than in arable land.

In 2013, in the arable soils, the activity of alkaline phosphatase and acid phosphatase was significantly increased compared to 2001. Dehydrogenase activity did not show any significant differences (Table 4.4). In contrast to this, at grassland the activity of phosphatases was constant between 2001 and 2013. Whereas the activity of the dehydrogenase was significantly lower in 2013 compared to 2001 (Table 4.4).

In plant available P (CAL) concentrations in topsoils of arable land and grassland, a declining trend was found between 2001 and 2013 when analysing all fields over all years (Figures 4.2 and 4.3). The mixed model for arable land and grassland had a marginal R^2 of 0.21 and 0.52 and conditional R^2 of 0.69 and 0.60, respectively. There are relatively high explanation rates of the variance with the entire models for arable land and grassland. Whereas the different marginal R^2 indicate a higher explanation rate of the fixed effect (year) in grassland compared to the fixed effects (year, farming system) used in the model approach for arable land.

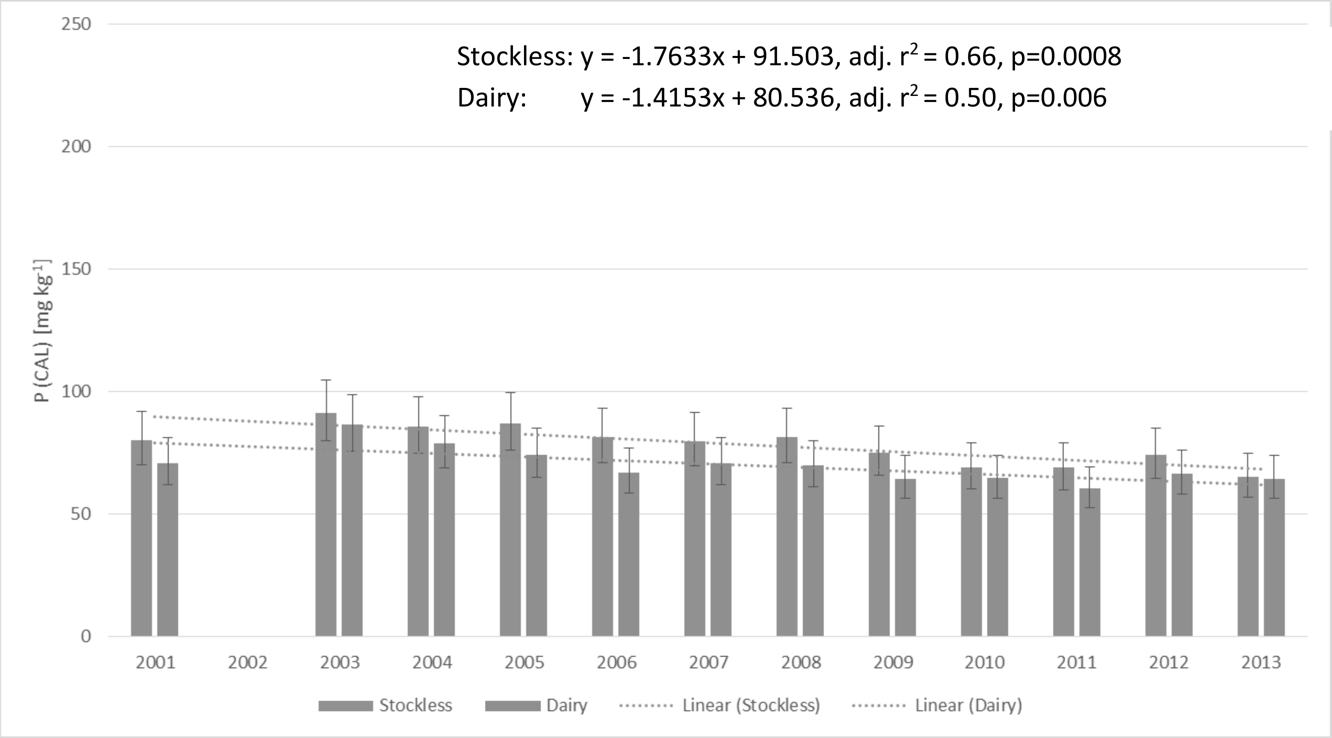

Figure 4.2 Development of P (CAL) values (LS-means) between 2001 and 2013 in Trenthorst per year and crop rotation (n=24 per year and crop rotation, sampling depth: 0-30 cm). Error bars indicate the 95%-confidence interval of the Least-Squares Means.

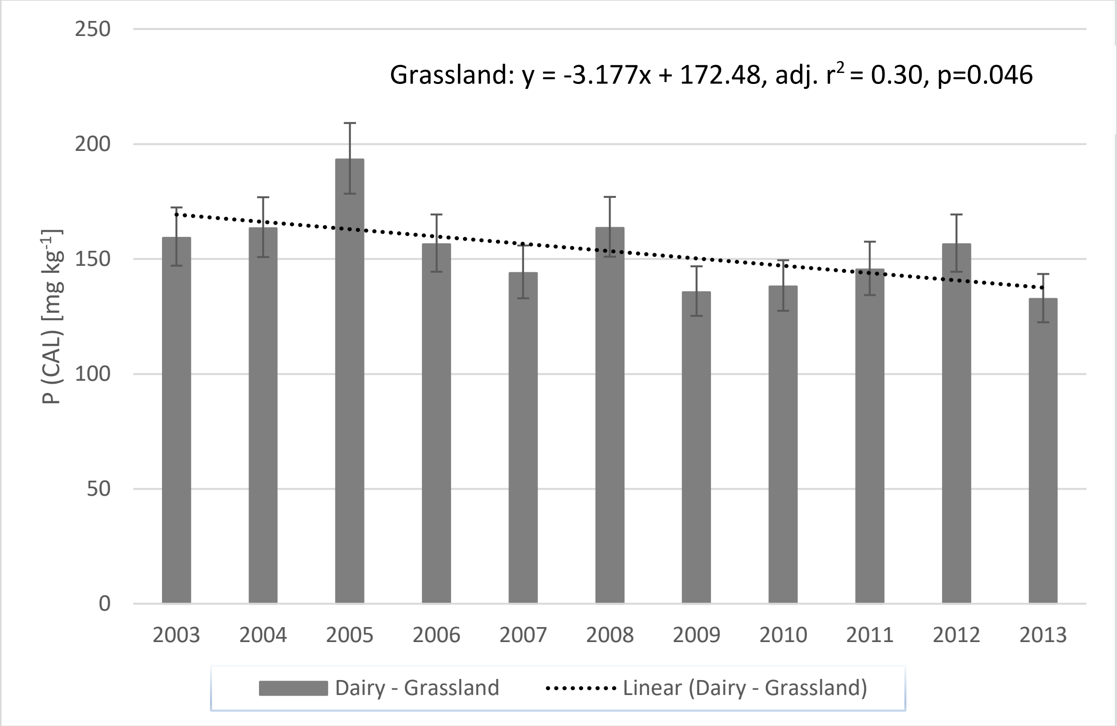

Figure 4.3 Development of P (CAL) values (LS means) between 2003 and 2013 in Trenthorst on grassland belonging to the dairy rotation (n=8 per year, sampling depth: 0-10 cm). Error bars indicate the 95%-confidence interval of the Least-Squares Means.

In the samples of the focus areas, the P (CAL) content of topsoils from the stockless crop rotation and for mean of the crop rotations was significantly reduced in 2013 compared to 2009. Also the concentration in grassland samples (0-30 cm sampling depth) was significantly lower in 2013 compared to 2001. This is in line with the development of labile mineral P-fractions according to Hedley et al. (1982) (all values in Table 4.4). Here, in the stockless crop rotation the labile P fractions extracted with H_2O and Resin were significantly lower in 2013. In the mean of the crop rotations, values in 2001 were significantly lower than in 2013. In the dairy crop rotation the H_2O fraction declined between 2001 and 2009. The $NaHCO_3$ fraction declined significantly between 2009 and 2013. In the mean of the arable crop rotations, the H_2O and Resin fraction declined over the whole research period, and the H_2O and $NaHCO_3$ fraction between 2009 and 2013. It should be emphasized that the labile P fractions as well as P (CAL) values in 2009, after growing grass clover (see Table 2), were quite high. The more stable P fractions NaOH, HCl, Residual and Total P did not change significantly. In samples of grassland the P fractions H_2O, Resin P, $NaHCO_3$, NaOH and total P were significantly lower in 2013 compared to 2001 (Table 4.4).

Table 4.4 Development of soil P characteristics (P fractions, and enzyme activity). Measurements are done at the same LTM-points in 2001, 2009, and 2013 at arable land and grassland in Trenthorst (arable land: n=4 in stockless and dairy rotation each; grassland: n=8, 0-30 cm). Stars indicate the significance of paired t-test with bonferoni p-adjustment, only in grassland P (CAL) wilcoxon signed ranks test is used.

					P fractions [mg kg^{-1}]				P (CAL) [mg kg^{-1}]	Phosphatase activity [µg p-Nitrophenol 1 g DM soil^{-1}]		Dehydrogenase [µg TPF 1g DM soil^{-1}]
Year	**System**	**H_2O**	**Resin**	**$NaHCO_3$**	**NaOH**	**HCl**	**Residual**	**Total**		**alkaline**	**acid**	
2001^1	Stockless	8.3	65.3	43.6	113.5	102.9	154.1	444.0	66.3	138.5	133.1	40.6
		±3	±15.6	±9.9	±20.7	±35.6	±21.4	±85.6	±20.8	±11.73	±8.95	±14.98
2009^2	Stockless	9.6	59.1	59.0	111.8	112.6	167.0	461.0	71.5			
		±0.9	±10.8	±9.9	±5.3	±24.6	±28.2	±76.2	±16			
2013^3	Stockless	5.1	54.3	37.9	95.0	114.8	145.5	532.0	65.8	142.3	160.2	33.0
		±2.1	±10.7	±5.5	±11.3	±27.4	±33.5	±66.9	±.15.2	±4.52	±6.89	±6.9
	2001-2009	1	0.384	0.2	1	0.57	0.13	1	0.581			
p	2001-2013	0.168	0.125	0.39	0.61	0.65	1	0.22	1	0.38	0.0002***	0.42
	2009-2013	0.038*	0.027*	0.1	0.28	1	0.28	0.07	0.027*			
2001^1	Dairy	7.3	55.3	41.0	103.5	97.6	149.6	479.0	63.8	151.3	148.7	18.4
		±1.2	±15.4	±8.8	±21.2	±41.7	±16.5	±136.6	±24.2	±1.37	±11.48	±4.95
2009^2	Dairy	9.4	65.5	39.1	87.0	133.4	148.8	544.0	62.8			
		±1.1	±44.4	±5.4	±12.9	±40.4	±23	±66.7	±18.2			
2013^3	Dairy	5.0	40.5	30.9	84.0	100.9	153	497.5	56.8	156.4	156.1	27.3
		±1.9	±5.2	±5.2	±9	±31.3	±13.3	±37.1	±11.3	±1.81	±7.49	±2.15
	2001-2009	0.02*	1	1	0.64	0.71	1	0.95	1			
p	2001-2013	0.279	0.28	0.333	0.62	1	1	1	1	0.026*	0.078	0.072
	2009-2013	0.098	0.92	0.021*	1	0.32	1	0.18	0.64			
2001^1	Arable land^	7.8	60.3	42.3	108.5	100.3	151.9	461.5	65.0	144.9	140.9	29.5
		±2.2	±15.3	±8.8	±20.1	±36.0	±17.9	±107.2	±20.9	±10.3	±12.7	±15.7
2009^2	Arable land^	9.5	62.3	49.1	99.4	123.0	157.9	502.5	67.1			
		±0.9	±30.1	±12.9	±16.1	±32.9	±25.7	±79.8	±16.5			
2013^3	Arable land^	5.1	47.4	34.4	89.5	107.8	149.3	514.8	61.3	149.4	158.2	30.6
		±1.9	±10.7	±6.2	±11.1	±28.2	±23.9	±53.4	±13.3	±8.2	±7.0	±5.9
	2001-2009	0.092	1	0.521	0.89	0.34	1	0.55	1			
p	2001-2013	0.014*	0.017*	0.055	0.13	0.91	1	0.49	1	0.043*	0.0035**	0.82
	2009-2013	0.001***	0.559	0.015*	0.18	0.49	1	1	0.043*			
2001	Grassland	14.1 ±3.8	141.2	169.8	431.3	194.9	130.1	1365.5	132.0	173.1	175.6	133.0
			±17.8	±26.3	±36.1	±65	±18.2	±115.5	±22.1	±5	±9.39	±25.5
2013	Grassland	9.6 ±3.6	90.6	104.3	279.3	164.3	127.1	951.0	107.1	174.3	183.7	81.4
			±29	±36.8	±105.9	±67.3	±17.2	±28.0	±9.4	± 9.74	±8.6	±27
p	2001-2013	0.0081**	0.007**	0.0018**	0.0053**	0.22	0.79	0.0061**	0.008**	0.66	0.18	0.0047**

p=<0.001***, 0.001<p>0.01**, 0.01<p>0.05*, p>0.05

^{1}rape was cropped ^{2}pre-crop clover-grass, ^{3}triticale, ^mean of stockless and dairy rotation, ± standard deviation

P concentrations in plant tissue

Table 4.5 shows the nutrient concentrations (Mg, K, P) in plant material of cereals and grassland in the focus areas in 2004 and 2013. Some of the values were below the threshold values for suitable supply for crops given by Bergmann (1988).

The mean P concentration of all biomass samples taken in grassland was 0.28 % P in DM (dry matter) with a high range between 0.13 and 0.45 % P in DM. The P content of the first cut was obviously lower in 2004 than in 2013 (Table 4.5). In a mean of all years, first (0.27 ±0.05) and second cut (0.27 ±0.05) showed lower mean P concentrations (%) than the third (0.32 ±0.05) and fourth one (0.32 ±0.04). In grassland was no correlation between P (CAL) and plant P.

Table 4.5 Nutrient concentration in cereals (n=4) and grassland (n=8) from the focus areas at BBCH 30/31 for 2004 and 2013.

			Mg	**K**	**P**
Utilization	**Species[1]**	**Year**		**[%] in dry matter**	
Stockless	Wheat	2004	0.10 ±0.005	3.28 ±0.15	0.23 ±0.02
	Triticale	2013	0.09 ±0.001	2.49 ±0.07	0.22 ±0.03
Dairy	Wheat	2004	0.11 ±0.015	4.08 ±0.39	0.25 ±0.03
	Triticale	2013	0.10 ±0.007	2.74 ±0.2	0.22 ±0.03
Grassland	Grassland, First cut	2004	0.23 ±0.029	3.66 ±0.89	0.24 ±0.02
		2013	0.19 ±0.03	3.09 ±0.04	0.33 ±0.04

DM= Dry matter [1]Threshold values according to Bergmann (1988) at the begin of stem elongation were 0.15 - 0.3 % Mg in DM, 3.5 - 5.5 % K in DM and 0.3 – 0.6 % P in DM for wheat *(Triticum aestivum)* and 0.15 - 0.3 % Mg in DM, 2.8 - 4.5 % K in DM, and 0.3 – 0.6 % P in DM for rye (*Secale cereale*) and for first cut of grassland was 0.2 - 0.6 % Mg in DM, 2 – 3 % K in DM, and 0.35 – 0.6 % P in DM.

The average P concentration of wheat and tricticale plants at beginning of stem elongation (BBCH 30/31) in all available samples from 2004 to 2010, and 2013 was 0.23 %. There was a positive correlation between the plant available P (CAL) in soil and plant P content (Spearman´s rank correlation, $\rho = 0.372$, $p = 0.003$**, Figure 4.4).

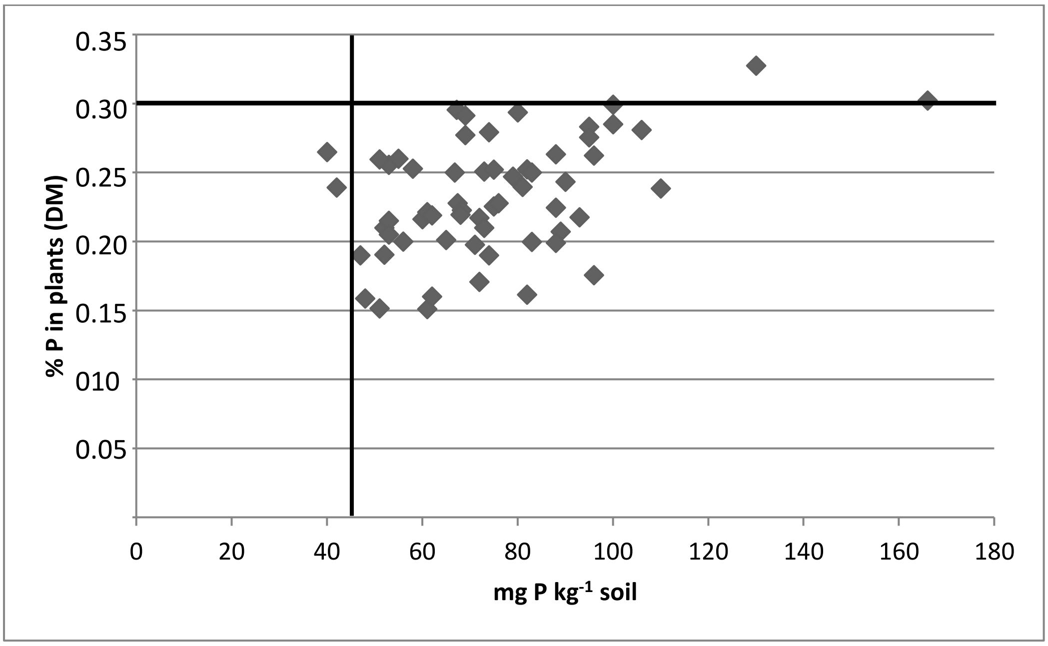

Figure 4.4 Relationship between P plant content (wheat and triticale BBCH 30/3, n=60) and plant available P in soil (2004-2010, 2013) and sufficiency threshold values. The vertical line shows the critical value (44 mg P kg^{-1} soil) according to Kuchenbuch and Buczko (2011). The horizontal line shows the critical value in plant dry matter (DM) according to Bergmann (1988) at the beginning of stem elongation with 0.3 – 0.6 % P in DM.

4.5 Discussion

4.5.1 Enzyme activity

Compared to topsoil samples of 2001, the activity of the acid and alkaline phosphatase was elevated on average in arable fields that have been managed according to organic farming standards for twelve years (Table 4.4). Generally this increases the potential to mineralize P from organic compounds (Bachmann et al. 2014). As in the current study elevated phosphatase activity coincided with diminishing labile P forms in soil higher microbial inorganic P demand might be assumed. Also the raised enzymatic activity could indicate that the role of organic P sources for crop production increased during the experimental time. The widened range of crop varieties with conversion to new crop rotations might have favored biological activity in soils.

In contrast to arable land, in grassland no difference was determined in phosphatase activities between 2001 and 2013. In grassland, a constant vegetation cover and high organic P soil reserves might have stabilized the values. As expected, the analyzed enzyme activities in soils were typically higher in grassland than in arable land (Oberson and Joner 2005).

Nonetheless, a correlation between P (CAL) and phosphatase activity could not be observed by the small data set generated for this initial study. But the finding is in line with the results of Bachmann et al. (2014) where no correlation of phosphatase activity to water- and double-lactate P in arable soils was found either.

The activity of dehydrogenase in arable land as indicator for general microbial activity needs further evaluation as the values were not statistically different in the analyzed fields between 2001 and 2013. But values in the dairy and stockless system seemed to develop in different directions (Table 4.4). The two focus areas started with differing values in activity of dehydrogenase (18.4 (dairy) vs. 40.6 (stockless) µg TPF 1g DM soil^{-1}) (Table 4.4) and a wider C:N relation in the dairy system (Table 4.1). This disparity is probably reasoned in different pre-treatment of the fields in former management. It might be explained further by high input of plant material (straw) and missing backflow of manure and lower N input due to lower percentage of forage legumes in the stockless system. This could have influenced the nutrient relations and organic carbon turn-over by soil biota (Hartman and Richardson 2013, Huang et al. 2005). An increase of dehydrogenase activity after twelfe years in the dairy system could be reasoned in the manure backflow and high share of clover-grass in the crop rotation which promote biological activity in soil due to input of organic matter (Krey 2013, Mascandiaro et al. 2004). Also the lowered C:N ratio in 2013 compared to the begin of the organic dairy crop rotation (Table 1) supports this interpretation.

The importance of nutrient supply for biological activity was underlined by the comparison with results of an LTM-plot in a conventional field in 2012. The field is located directly adjacent to the fields of the analyzed organic crop rotations. It had a long term cereal-cereal-rapeseed crop rotation and intensive mineral and organic fertilization. There, the activity of dehydrogenase showed significantly higher values (87.5 µg TPF 1g soil^{-1}) than the mean of organic arable plots (46.1 µg TPF 1g soil^{-1}) (Ohm et al. 2013). These differences hint at higher microbial activity in the conventionally managed soils and implies that C-turnover can happen more rapidly there, e.g., due to higher amounts of available N from mineral fertilizers is soils. Nitrogen promotes the number of microorganisms, as it is a component of their bodies. Additionally, the activity of soil microorganisms depends strongly on the presence of available organic C (Bachmann et al. 2014). The steady C-delivery in the short conventional cereal-cereal-oilseed crop rotation with yearly slurry application, compared to variable C-inputs in a six year organic crop rotation, might have offered steady state conditions for the development of a stable microbiota community in soils under conventional management leading to this consistent discrimination of the systems. Therefore, it seems that the microbial activity at the organic arable plots in Trenthorst is below its potential. In contrast to arable land, dehydrogenase activity was significantly decreased in grassland in 2013 compared to 2001. In parallel, all nutrient concentrations in soil (N, P, Mg, and K) were decreased from 2003 to 2013 and the C:N ratio increased in the same time (Table 4.1). This lower nutrient supply might have led to a lower overall microbial activity, resulting in reduced dehydrogenase activity. Also biological soil parameters react to changing environmental conditions. Chen et al. (2003) found microbial processes being influenced by seasonal changes in rainfall, soil moisture and temperature with an increasing microbial activity in spring and summer. Also Liu et al. (2009) highlight the temporal dynamics of parameters of biological activity in soils at different sampling times. So also the cutout of samples and results in this study might be influenced. But samples of our study were taken at similar vegetation times. Differences in soil moisture or temperature between 2001 and 2013 probably influenced the results, but due to the sampling depth of 0-30 cm, the effect of these parameters might be less pronounced (Bachmann et al. 2014).

4.5.2 Soil P fractions

Plant available P (CAL)

In arable land a decline of P (CAL) contents in soils occurred over time but minimum thresholds for sufficient plant growth have not yet been reached (Figure 4.4, Table 4.1). Nevertheless, a decline from high P levels in soil to still sufficient levels has positive effects, as for an efficient use of P-sources P-accumulations in soils should be avoided (Cordell et al. 2009), and managing soil fertility near the critical P level maximizes P-efficiency (Simpson et al. 2011). So emptying P soil reserves, as obvious in the decline of P (CAL) on arable land in the analyzed farm, seems a suitable prerequisite for efficiency gains in P use. According to official fertilizing recommendations for conventional farming in Germany (e.g., Landwirtschaftskammer Niedersachsen, 2015) on loamy soils more than 50 mg P kg^{-1} soils are sufficient for an adequate nutrient supply to plants (category C, 50-90 mg P kg^{-1} soil). Kuchenbuch and Buczko (2011) derived a critical value of 44 mg P kg^{-1} soil as sufficient with the results of thousands of P fertilization trials in Germany. Due to the lower yield expectations, in organic farming category B (30-40 mg P kg^{-1} soil) is seen as adequate (Kolbe 2001). Depending on the chosen reference, the focus area in the dairy crop rotation (56.8 mg P (CAL) kg^{-1}) as well as in the stockless crop rotation (65.8 mg P (CAL) kg^{-1}, Table 4) were situated in sufficient or high nutrient supply conditions. Therefore, P-imports corresponding to the P deficits to avoid plant growth deficits seem to be dispensable in the next years in both systems. For the future, an adequate management and fertilization regime must be developed for keeping the necessary P threshold in soils.

The P (CAL) content of grassland also declined (Figure 4.3, Table 4.4) but was still in the category D (100-150 mg P kg^{-1} soil), standing for high nutrient supply. The upper soil layer (0-10 cm), which is generally used for recommendation of nutrient supply shows even higher values (Table 1). Also the reduced amount of P (CAL) did not yet lead to a raised phosphatase activity in soil. That might underline the sufficient amount of available P for microorganisms and plants. Therefore, grassland does not need P fertilization so far. Even P reserves of grassland soils might be addressed and emptied more efficiently by management, e.g., by higher offtake with food conserves. Phytomining P from well-supplied grassland soils could be an acceptable option to save non-renewable resources. An improved P transfer via manures from grassland to arable land could stabilize the supply there for a limited period (Ohm et al. 2015).

Phosphorus fractions

The labile P fractions (H_2O, Resin P) decreased in arable soils between 2001 and 2013 (reduction of 35 % and 21 %) and grassland soils (reduction of 31 % and 36 %) (Table 4.4). This decline of plant available P in arable land under organic management is similar to findings of other authors (Løes und Øgaard 1997 and 2001, Ebbesvik and Løes 2013, Gosling and Shepherd 2005, Keller et al. 2012). In grassland NaOH, $NaHCO_3$ and total P had also declined already in the time span over twelve years. Also in a longer lasting German long term experiment in grassland (69 years), with two cuts per year, a depletion of all P fractions, except residual P, was shown (Pätzold et al. 2013).

The development of P supply in Trenthorst topsoils suggests that labile P fractions in soils will continuously exhaust over time with negative P-balances. Whereas stable inorganic P fractions (NaOH, Residual, HCl and also total P) remained unaffected in arable land over twelve years (Table 4.4). They might be seen as potential buffer for future P release when appropriately addressed. Generally, mechanisms addressing the utilization of this buffer by different plants and microorganisms and general options to enhance these processes with agricultural measures are known (Eichler-Lobermann 2008, Braum et al. 1995, Richardson and Simpson 2011, Maltais-Landry 2015). But the use of these mechanisms at the borderline of accepted minimal plant available P contents in soils has not been developed for practical agricultural management. An example for this can be found in a study of Fortune et al. (2005). Here even at low Olsen-P levels in soils, P fertilization with manure (or rock phosphates) neither influenced P contents nor P uptake of established clover grass swards. Furthermore reduction in available Olsen-P content in soils did not outweigh P removal of harvests. It must be assumed that short term mobilization and immobilization processes for P in soil (e.g., within one year) manifest in concentration changes of other binding forms of P in soils and in P bound in plant-residues and soil organisms.

Especially forage legumes like clover have high P requirements and uptake because of their higher demands for P associated with N_2 fixation (Oelmann et al. 2011), exuded carboxylates from roots (Gerke 1992, Gerke et al. 1994, Johnson et al. 1996) and their root architecture (López-Bucio et al. 2003, Johnson et al. 1996). Therefore, the high P amounts in this study in 2009 (Table 4.4), after growing grass and red clover, might be explained by P release of decomposing plant residues (Nuruzzaman et al. 2005, Talgre et al. 2014). This principle that P-mobilizing species in crop rotations enhance growth and P uptake in following crops is well described (Eichler-Löbermann 2008, Simpson et al. 2011, Nuruzzaman et al. 2005). But still, the findings on the site in Trenthorst clearly reveal the concentration loss of labile inorganic P fractions in soils of arable land over the years, although forage crops (red clover and red clover grass) were introduced in the crop rotations and a backflow of organic material (clover grass mulch, slurry and manure) exists.

In grassland, the negative P balances differed between the measured and the calculated reduction of the total P content in the topsoil. The measured value was -17.4 kg P ha^{-1} (calculated with bulk density of 1.4 g per cm^3, 0-30 cm) and the calculated value was -94.8 kg P ha^{-1} (calculated with the average deficit of -7.9 kg P ha^{-1} a^{-1} over 12 years) between 2001 and 2013. This difference might be caused by two things: On the one hand, the measured values do not include differences in deeper soil layers than 30 cm. On the other hand, vertical P transfer from the lower soil layers into the upper soil might have occurred. Oehl et al. (2002) found this P transfer in a long-term study on tested soils with negative P balances in organic treatments. In addition, Requejo and Eichler-Löbermann (2014) found more than 100 kg difference between the measured and calculated P contents in a non-fertilized plot with a calculated negative P balance of 264 kg P ha^{-1} after 10 years.

The higher contents of all soil P fractions in the analyzed grassland compared to arable land are to be explained by input of organic matter by excretion of grazing cows, slurry application, and high amounts of plant residuals. Also the P input due to manure in our study was higher at grassland (7.8 kg P ha^{-1} a^{-1}) than at arable land (5.3 kg P ha^{-1} a^{-1}) and the yearly P balance deficits in grassland were even lower (Ohm et al. 2015). In line with this Crews and Brooks (2014) found by Hedley P fractionations that herbaceous perennials maintain a greater proportion of native or fertilizer P in relatively available organic forms (0.5 M bicarbonate + 0.1 M NaOH fractions) compared to annual wheat. Also Krey et al. (2013) showed increased organic soil P pools due to the application of organic P fertilizer. Similarly, Stutter et al (2015) found decreasing values of total monoester P in the order of intensive grassland > extensive grassland > arable land.

4.5.3 Phosphorus supply of plants

The mean plant P concentration in the grassland sward of 0.28 % P in DM can be seen as sufficient for plant growth. According to the results from Liebisch et al. (2013) for mixed grassland with grasses, legumes and herbaceous plants, a range between 0.21 to 0.3 % P in DM is recommended for optimum yields. Despite this the recommended values for *Lolium spp.* from Bergmann (1988) are much higher 0.35-0.5 g P 100g^{-1} DM. This range seems not to be suitable for practical use within organic conditions because the actual P concentration is significantly lower even though grassland showed a high P (CAL) supply.

The lower P concentrations in the first two cuts in comparison to the third and fourth cut of grassland in the current study might be a dilution effect due to high biomass amounts. High variations within one cut might be caused by differences in the vegetation compositions of grass, legumes and herbs between the LTM sample points, and different development stages of plants caused by varying conditions between the years.

For the arable land the overall P content of wheat at the beginning of stem elongation (0.235 % P in DM, Table 4.5) was not in the range proposed by Bergmann (1988) for sufficient supply (0.3 to 0.6 % P in DM). Also on both LTM-points with soil P (CAL) below the lower threshold value of common fertilizer recommendation P concentrations in plant material were found that were comparable to plants on areas with a sufficient soil supply (Figure 4.4). So it must be expected that soil P did not limit the plant P supply on the analyzed site. Even so, Krey et al. (2013) found only a small impact of P supply on maize growth at suboptimal plant available P levels in soil after a ten-year period without fertilizing the crop rotation. This indicates the potential of crops to overcome possible P shortages (Krey et al. 2013), e.g., by increased rooting access. Also in grassland higher P content in plants was found in 2013 than in 2004 (Table 4. 3), whereas P (CAL) values in soil reduced in this timeline (Figure 4.3). Therefore, it can be concluded that soils in the analyzed systems could still satisfy the P-demand of plants even with declining content of labile, plant available P-forms in soils. Whether common plant threshold values for cereals, like the ones by Bergmann (1988), fit to yield levels and plant growth demands in organic farming systems remains an open question.

4.6 Conclusion

In organically managed arable land and grassland the twelve-year negative P balances reduced the levels of P (CAL) and labile inorganic P-forms (Hedley fractionation) in soil, while the P (CAL) contents are still above the minimum threshold that is considered to be sufficient for organic farming. On the other hand, the activity of phosphatases increased on arable land with the introduction of diversified organic crop rotations. This was independent from manure recycling. This hints at the potential of plants and microbes to mobilize P from less available soil reserves. Especially for crop rotations in organic farming with lower yield level and lower P uptake, undetected temporally mobilization and immobilization processes of labile P in soil could be of high importance for the P nutrition of plants. The common expectation of organic farming, that biological activation will enable the soil system in providing nutrients – here P – from soil reserves must be analyzed and quantified in more detail to derive practical recommendations. After twelve years of organic farming the system still profits from P soil reserves. However, it is necessary to find a site-specific optimal P level at which the amount of P removed by the crop harvest should be balanced by fertilizer application.

4.7 References

Annaheim KE, Rufener C, Frossard E, Bünemann E (2013) Hydrolysis of organic phosphorus in soil water suspensionsafter addition of phosphatase enzymes. Biol Fertil Soils 49:1203–1213

Bachmann S, Gropp M, Eichler-Löbermann B (2014) Phosphorus availability and soil microbial activity in a 3 year field experiment amended with digested dairy slurry. Biomass Bioenergy 70:429 – 439

Barton K (2015) MuMIn: Multi-Model Inference. R package version 1.15.1

Bates D, Maechler M, Bolker B, Walker S (2015) lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-8

Bergmann W (1988) Ernährungsstörungen bei Kulturpflanzen: Entstehung, visuelle und analytische Diagnose. Gustav Fischer Verlag, Jena

Braum SM, Helmke PA (1995) White lupin utilizes soil phosphorus that is unavailable to soybean. Plant Soil 176(1):95-100

Bünemann E, Oberson A, Liebisch F, Keller F, Annaheim K, Huguenin-Elie O, Frossard E (2012) Rapid microbial phosphorus immobilization dominates gross phosphorus fluxes in a grassland soil with low inorganic phosphorus availability. Soil Biol Biochem 51:84-95

Crews TE, Brookes PC (2014) Changes in soil phosphorus forms through time in perennial versus annual agroecosystems. Agr Ecosyst Environ 184:168-181

Chen CR, Condron LM, Davis MR, Sherlock RR (2003) Seasonal changes in soil phosphorus and associated microbial properties under adjacent grassland and forest in New Zealand. Forest Ecol Manag 177(1):539-557

Chen CR, Condron LM, Davis MR, Sherlock RR (2004) Effects of plant species on microbial biomass phosphorus and phosphatase activity in a range of grassland soils. Bio Fert Soils 40(5):313-322

Cordell D, Drangert JO, White S (2009) The story of phosphorus: Global food security and food for thought. Global Environ Chang 19(2):292-305

Dick CF, Dos-Santos ALA, Meyer-Fernandes JR (2011) Inorganic Phosphate as an Important Regulator of Phosphatases. Enzyme Res 2011, 7

Dormann CF (2013) Parametrische Statistik: Verteilungen, maximum likelihood und GLM in R. Springer-Verlag, Heidelberg

Ebbesvik M, Løes AK (2013) Long-term changes in soil nutrients and grass/clover yields on Tingvoll farm. In: Løes A-K, Askegaard M, Langer V, Partanen K, Pehme S, Rasmussen IA, Salomon E, Sørensen P, Ullvén K, Wivstad M (eds.) Organic farming systems as a driver for change, NJF Report Nr. 9(3):119-120

Eichler-Lobermann B, Kohne S, Kowalski B, Schnug E (2008) Effect of catch cropping on phosphorus bioavailability in comparison to organic and inorganic fertilization. J Plant Nutr 31(4):59-676

Fortune S, Robinson JS, Watson CA, Philipps L, Conway JS, Stockdale EA (2005) Response of organically managed grassland to available phosphorus and potassium in the soil and supplementary fertilization: field trials using grass-clover leys cut for silage 102. Soil Use Manage 21(4):370-376

Gerke J (1992) Phosphate, aluminium and iron in the soil solution of three different soils in relation to varying concentrations of citric acid. Z Pflanz Bodenkunde 155(4):339-343

Gerke J, Römer W, Jungk A (1994) The excretion of citric and malic acid by proteoid roots of Lupinus albus L.; effects on soil solution concentrations of phosphate, iron, and aluminum in the proteoid rhizosphere in samples of an oxisol and a luvisol. Z Pflanz Bodenkunde 157(4):289-294

Gosling P, Shepherd M (2005) Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. Agr Ecosyst Environ 105:425-432

Güsewell S, Gessner MO (2009) N : P ratios influence litter decomposition and colonization by fungi and bacteria in microcosms. Funct Ecol 23(1):211-219

Haas G, Deittert C, Köpke U (2007) Farm-gate nutrient balance assessment of organic dairy farms at different intensity levels in Germany. Renew Agr Food Syst 22(3):223-232

Hartman WH, Richardson CJ (2013) Differential Nutrient Limitation of Soil Microbial Biomass and Metabolic Quotients (qCO(2)): Is There a Biological Stoichiometry of Soil Microbes? PLoS ONE 8(3)

Hassan HM, Marschner P, McNeill A, Tang C (2012a). Grain legume pre-crops and their residues affect the growth, P uptake and size of P pools in the rhizosphere of the following wheat. Biol Fert Soils 48(7):775-785

Hassan HM, Marschner P, McNeill A, Tang C (2012b). Growth, P uptake in grain legumes and changes in rhizosphere soil P pools. Biol Fert Soils 48(2):151-159

Hedley MJ, Stewart JWB, Chauhan BS (1982) Changes In Inorganic And Organic Soil Phosphorus Fractions Induced By Cultivation Practices And By Laboratory Incubations. Soil Sci Soc Am J 46:970-976

Hinsinger P (2001) Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant Soil 237:173-195

Huang PM, Wang MK, Chiu CY (2005) Soil mineral-organic matter-microbe interactions: Impacts on biogeochemical processes and biodiversity in soils. Pedobiologia 49(6):609-635

Johnson JF, Vance CP, Allan DL (1996) Phosphorus deficiency in Lupinus albus (altered lateral root development and enhanced expression of phosphoenolpyruvate carboxylase). Plant Physiol 112(1):31-41

Keller M, Oberson A, Annaheim K E, Tamburini F, Mader P, Mayer J, Frossard E, Bunemann EK (2012) Phosphorus forms and enzymatic hydrolyzability of organic phosphorus in soils after 30 years of organic and conventional farming. J Plant Nutr Soil Sci 175:385-393

Kolbe H (2001) Instructions for phosphorous, potassium, magnesium and lime fertilisation in organic agriculture (in german). SÖL Beraterrundbrief 3:3-9

Kuchenbuch RO, Buczko U (2011) Re-visiting potassium-and phosphate-fertilizer responses in field experiments and soil-test interpretations by means of data mining. J Plant Nutr Soil Sci 174:171-185

Krey T, Vassilev N, Baum C, Eichler-Löbermann B (2013) Effects of long-term phosphorus application and plant-growth promoting rhizobacteria on maize phosphorus nutrition under field conditions. Eur J Soil Biol 55:124-130

Landwirtschaftskammer Niedersachsen (2015) Richtwerte für die Düngung in Niedersachsen http://www.lwk-niedersachsen.de/index.cfm/portal/pflanze/nav/341/article/11622.html (accessed at 26.6.2016)

Lenth RV (2016) Least-Squares Means: The R Package lsmeans. Journal of Statistical Software 69:1-33

Liebisch F, Bünemann EK, Huguenin-Elie O, Jeangros B, Frossard E, Oberson A (2013) Plant phosphorus nutrition indicators evaluated in agricultural grasslands managed at different intensities. Eur J Agron 44:67-77

Liu M, Hu F, Chen X, Huang Q, Jiao J, Zhang B, Li H (2009) Organic amendments with reduced chemical fertilizer promote soil microbial development and nutrient availability in a subtropical paddy field: the influence of quantity, type and application time of organic amendments. Appl Soil Ecol 42(2):166-175

Løes AK, Øgaard AF (1997) Changes in the nutrient content of agricultural soil on conversion to organic farming in relation to farm-level nutrient balances and soil contents of clay and organic matter. Acta Agriculturae Scandinavica, Section B — Soil Plant Sci 47:201-214

Løes AK, Øgaard A (2001) Long-term changes in extractable soil phosphorus (P) in organic dairy farming systems. Plant Soil 237:321-332

López-Bucio J, Cruz-Ramírez A, Herrera-Estrella L (2003) The role of nutrient availability in regulating root architecture, Curr Opin Plant Biol 6(3):280-287

Maltais-Landry G (2015) Legumes have a greater effect on rhizosphere properties (pH, organic acids and enzyme activity) but a smaller impact on soil P compared to other cover crops. Plant Soil 394(1-2):139-154

Masciandaro G, Ceccanti B, Benedicto S, Lee HC, Cook HF (2004) Enzyme activity and C and N pools in soil following application of mulches. Can J Soil Sci 84(1):19-30

Marschner H, Marschner P (2012) Marschner's mineral nutrition of higher plants. Academic press

Meier U (1997) BBCH-Monograph. Growth stages of plants – Entwicklungsstadien von Pflanzen – Estadios de las plantas – Développement des Plantes. Blackwell Wissenschaftsverlag, Berlin and Wien, p. 622

Mengel K, Kosegarten H, Kirkby EA, Appel T (2001) Principles of plant nutrition. Springer, Netherlands

Murphy J, Riley J (1962) A modified single solution method for the determination of phosphate in natural waters. Anal Chim Acta 27:31-36

Nain L, Rana A, Joshi M, Jadhav SD, Kumar D, Shivay YS, Paul S, Prasanna R (2010) Evaluation of synergistic effects of bacterial and cyanobacterial strains as biofertilizers for wheat. Plant Soil 331(1):217-230

Nakagawa S, Schielzeth H (2013) A general and simple method for obtaining R2 from generalized linear mixed-effects models. Methods in Ecology and Evolution 4:133-142

Nash DM, Haygarth PM, Turner BL, Condron LM, McDowell RW, Richardson AE, Watkins M, Heaven MW (2014) Using organic phosphorus to sustain pasture productivity: A perspective. Geoderma 221–222:11-19

Nuruzzaman M, Lambers H, Bolland MD, Veneklaas EJ (2005) Phosphorus uptake by grain legumes and subsequently grown wheat at different levels of residual phosphorus fertiliser. Crop Pasture Sci 56(10):1041-1047

Oberson A, Joner EJ (2005) Microbial turnover of phosphorus in soil. In: Turner BL, Frossard E, Baldwin DS (eds) Organic phosphorus in the environment [papers presented at the Organic Phosphorus Workshop, held July 2003, Ascona, Switzerland]. Wallingford, CABI, pp. 133-164

Oberson A, Pypers P, Bünemann EK, Frossard E (2011) Management Impacts on Biological Phosphorus Cycling in Cropped Soils In: Bünemann EK, Oberson A, Frossard E (eds.) Phosphorus in Action. Springer Berlin Heidelberg, pp. 431-458

Oehl F, Oberson A, Tagmann H, Besson J, Dubois D, Mäder P, Roth H-R, Frossard E (2002) Phosphorus budget and phosphorus availability in soils under organic and conventional farming. Nutr Cycl Agroecosys 62:25-35

Oelmann Y, Richter AK, Roscher C, Rosenkranz S, Temperton VM, Weisser WW, Wilcke W (2011) Does plant diversity influence phosphorus cycling in experimental grasslands? Geoderma 167-68:178-187

Ohm M, Paulsen HM, Eichler-Lobermann B, Rahmann G (2013) Development of phosphatase and dehydrogenase activities in soils of annual cropland and permanent grassland in an organic farm. In: Løes A-K, Askegaard M, Langer V, Partanen K, Pehme S, Rasmussen IA, Salomon E, Sørensen P, Ullvén K, Wivstad M (eds) Organic farming systems as a driver for change, NJF Report Nr. 9(3): 123-124

Ohm M, Schuler M, Fystro G, Paulsen HM (2015) Redistribution of soil phosphorus from grassland to cropland in an organic dairy farm. Landbauforschung 65(3-4):193-203

Pätzold S, Hejcman M, Barej J Schellberg J (2013) Soil phosphorus fractions after seven decades of fertilizer application in the Rengen Grassland Experiment. J Plant Nutr Soil Sci 176:910-920

Paulsen HM, Köpke U, Oberson A, Rahmann G (2016) Phosphorus - The predicament of organic farming. In: Schnug E, De Kok LJ (eds.) Phosphorus-100% Zero, Springer Netherlands, pp. 195-213

R Core Team (2014) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Redel YD, Rubio R, Rouanet JL, BorieF (2007) Phosphorus bioavailability affected by tillage and crop rotation on a Chilean volcanic derived Ultisol. Geoderma 139(3):388-396

Requejo M, Eichler-Löbermann B (2014) Organic and inorganic phosphorus forms in soil as affected by long-term application of organic amendments. Nutr Cycl Agroecosyst 100:245 – 255

Richardson AE, Simpson RJ (2011) Soil microorganisms mediating phosphorus availability update on microbial phosphorus. Plant Physiol 156:989-996

Schaub D, Paulsen HM, Böhm H, Rahmann G (2007) Der Dauerbeobachtungsversuch Trenthorst-Konzeption und Versuchsaufbau. In: Zikeli S, Claupein W (eds) Zwischen Tradition und Globalisierung, Band 1, Berlin, 2007, pp. 33-36

Schüller H (1969) Die CAL-Methode, eine neue Methode zur Bestimmung des pflanzenverfügbaren Phosphates in Böden. Z Pflanz Bodenkunde 123:48-63

Simpson M, McLenaghen RD, Chirino-Valle I, Condron LM (2012) Effects of long-term grassland management on the chemical nature and bioavailability of soil phosphorus. Biol Fertil Soils 48:607-611

Simpson RJ, Oberson A, Culvenor RA, Ryan MH, Veneklaas EJ, Lambers H, Lynch JP, Ryan PR, Delhaize E, Smith FA, Smith SE, Harvey PR, Richardson AE (2011) Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems. Plant Soil 349(1-2):89-120

Simpson RJ, Richardson AE, Nichols SN, Crush JR (2014) Pasture plants and soil fertility management to improve the efficiency of phosphorus fertiliser use in temperate grassland systems. Crop Pasture Sci 65:556-575

Steinshamn H, Thuen E, Bleken MA, Brenøe UT, Ekerholt G, Yri C (2004) Utilization of nitrogen (N) and phosphorus (P) in an organic dairy farming system in Norway. Agric Ecosyst Environ 104(3):509-522

Stutter MI, Shand CA, George TS, Blackwell MS, Dixon L, Bol R, MacKey R, Richardson A, Condron L, Haygarth PM (2015) Land use and soil factors affecting accumulation of phosphorus species in temperate soils. Geoderma 257, 29-39

Tabatabai MA, Bremner JM (1969) Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol Biochem1:301-307

Talgre L, Lauringson E, Roostalu H, Makke A (2014) Phosphorus and potassium release during decomposition of roots and shoots of green manure crops. Biol Agric Hortic 30(4):264-271

Thalmann A (1968) Zur Methodik der Bestimmung der Dehydrogenaseaktivität im Boden mittels Triphenyltetrazoliumchlorid (TTC). Landwirtsch Forsch 21:249-258

Tóth G, Guicharnaud R-A, Tóth B, Hermann T (2014) Phosphorus levels in croplands of the European Union with implications for P fertilizer use. Eur J Agron 55:42-52

Whitehead DC (1970) Carbon, nitrogen, phosphorus and sulphur in herbage plant roots. Grass Forage Sci 25(3):236-241

5 General discussion

Phosphorus is an essential element for all living organisms, but P is a non-renewable resource (c.f. Chapter 1.2). The demand for fertilizer P import into the reference farming system is foreseeable (Study 3). However, the use of mineral fertilizer in organic agriculture is restricted. Because soil P balances in organic systems are often negative, and because especially P fertilization is often neglected due to sufficient soil reserves, organic farms are increasingly at risk for nutrient deficits. One possibility to avoid limiting growth might be the transfer of soil P from grassland with high soil P reserves to arable land via stable manure. To quantify this potential, different research areas need to be considered: After developing methods to calculate the grassland yields (Study 1), the P flows on an organic dairy farm in northern Germany was calculated and imaged (Study 2). Then the development of parameters for P supply for twelve years after converting to organic farming was analyzed (Study 3). As a result, the P supply situation of the research station and the potential of grassland as a P source can be evaluated.

5.1 Key findings and uncertainties

5.1.1 Study 1

A practical method to estimate grazing yields in practice is presented in the first study. The measurements with a rising plate meter showed a good correlation between height and dry matter yield for the organic dairy farm in northern Germany. The measured data are used to calculate grassland-related P flows in Study 2. Those measurements at pasture plots also provide data to improve grazing and pasture management.

Because these measurements are the basis of assessment in Study 2, the accuracy of the presented method should be discussed. According to Hoppe et al. (1995), rising plate meter measurements are a suitable method to estimate the daily growth rate and yields after adapting a site-specific correlation, as done in Study 1. The rising plate meter method is an easy alternative to yield estimations by directly dry matter biomass sampling due to adequate results and a much lower expenditure of time (Ohm et al. 2013). Analyzing the daily growth rate of grazed pastures is more complex. A movable-cage method is suggested to avoid the problem that the effect of herbivores on daily growth rate is biased against detecting any increases in production (McNaughton et al. 1996). In the recent work, the potential biomass regrowth is estimated due to the inclusion of neighboring, currently ungrazed plots. The growth rate is considered with this modified method, but the common, labor intensive work with exclosure cages is redundant. Smit et al (2005) recommend another technique to estimate the herbage intake of grazing cows using the ratio of dosed even-chain synthetic n-alkane (C_{32}) and a naturally occurring n-alkane (C_{31} or C_{33}) in the herbage and feces. This method might give more precise results, but is disproportionately high in cost as compared to the estimations of grazing intake to calculate farm specific nutrient flows.

The estimated grazing yields were used to compare the effects from grazing and farm-own feed conserves (silage) from arable land (clover grass) on green-house-gas emissions in milk production. By means of life-cycle assessment based on material flows for the whole farm, it was shown that substituting clover grass silage by improved grazing management reduces the global warming potential of milk by 1.5 % per kg energy-corrected milk. In a broader view, extensified and organic grassland farms compared to intensive farms (use of mineral P-fertilizer, unlimited in purchasing fodder) could reduce negative effects in the life cycle assessment (LCA) impact categories: energy use, global warming potential, and water eutrophication (Haas et al. 2001). Nevertheless, common life cycle assessments do not address all impacts of grazing that are relevant for farming success. Positive effects on animal welfare (cf. Chapter 1.4), labor conditions or cultural benefits are neglected. But greenhouse gas emissions can be avoided by improved sward and grazing management as deduced in the analysis of this study. So the system service of grassland can be improved by proper management.

In conclusion, the presented method is seen as suitable to estimate grassland-related P flows for field and farm studies analyzing nutrient flows. Management improvements and yield effects can be based on these regular measurements in grassland and thereby reduce greenhouse gas emissions in milk production.

5.1.2 Study 2

The inner P flow of an organic dairy farm was calculated over a three-year period in the second study. The P balance of the farm showed an obvious mining of 1,105 kg soil P per year on 116 ha. According to the cultivation, the average mining of grassland was 7.9 kg P ha^{-1} a^{-1} and 10.9 kg P ha^{-1} a^{-1} in arable land. The grassland accounts for 29.2 % of the P entering the stable with feedstuff. Because of high P reserves in soil, negative field balances of P do not yet endanger the soil fertility, especially in grassland.

The estimation of farm flows has a modelling character. In this context the following aspects will be discussed (1) inclusion of small amounts (like atmospheric deposition and losses) in the farm balance, (2) use of farm specific data and the finding of a suitable level for data acquisition, and (3) support of internal P flows for improving management and its transferbility.

Including small P amounts in the farm balance

There are different studies about farm P balances. While some include atmospheric deposition and losses by leaching, surface run-off, and erosion (Aarts et al. 2000, Modin-Edman et al. 2007, Rotz et al. 2005), others do not take this nutrient flow into account (Steinshamn et al. 2004, Haas et al. 2007, Nesme et al. 2012). In Study 2 these nutrient flows are included in the farm balance, even if atmospheric sources of P are generally small (< 1 kg P ha^{-1}) (Rotz et al. 2005). For the region under study in this thesis (0.2 kg ha^{-1} a^{-1}, LLUR 2014), the input factor is low, but should be considered for calculations because variations between regions and over time can be found in the literature. The P input from the atmosphere has severely reduced in the last decades in Germany. Bernard et al. (1978) estimated for German conditions a mean value of 0.4 kg P ha-1 a-1 with an assumed mean precipitation of 800 mm a-1. Similar amounts are still common in other regions as found in a Swedish study (Modin-Edman et al. 2007), and are close to the average values for the UK, with a deposition of 0.3 kg ha-1 a-1 (White 2006). These amounts differ from the Netherlands where a P deposition of 0.9 kg ha-1 a-1 was used for the calculation of P flows (Aarts et al. 2000).

Also minor losses of P from the soil by leaching had been considered for farm land (Cooke und Williams 1973, White 2006). Low P losses through run-off were anticipated in Trenthorst due to the plain nature of the area, the loamy texture of the soils, and watchful farm practice. Therefore P losses by leaching and run-off from the soil are estimated with 0.3 kg P ha^{-1} a^{-1} according to the Swedish study (Modin-Edman et al. 2007) and are in line with estimated losses from German soils (Scheffer and Schachtschabel 2010). In sum, total minor natural losses of 0.1 kg P ha^{-1} were calculated for the farm under study. Nonetheless, this small amount should also be taken into account since it allows a complete view on all sources (Figure 1.1). This is important because the relevance of P as a non-renewable resource is high and P losses in that dimension are of great importance for the surface water (LLUR 2014). Further research should also try to obtain farm specific values for deposition and losses instead of only official values.

Also, it would have been preferable if the P amount of the drinking water of the cows was considered. But the P content was below the ordinary detection level of the water works and therefore not included in the analysis. If concentrations were set to a threshold of 1 mg L^{-1}, 3,000 m^3, drinking water for the cows would account only for 3 kg P yr^{-1}. For the 116 ha farmland this would lead to a marginal P input of 0.03 kg P ha^{-1} yr^{-1}. Nevertheless, this amount and the natural depositions and losses complete the farm flow.

Use of farm specific values

Typically, different plant species show variations in P acquisition and in P export (Daroub et al. 2001, Eichler-Löbermann et al. 2008, Gahoonia and Nielsen 2004, Jungk and Claassen 1986). Also, the P concentration varies within one species or species mix. For example, at the research farm the grass-clover silage of the arable land showed a range in the P concentration between 2.7 and 3.6 g kg^{-1} P in DM (mean 3.1 ±0.30, n=10, 2010-2012). This high variation between the values is similar to other analyses of grass-clover silage. A sum of 752 samples from German organic farms showed a mean value of 3.4 g kg^{-1} P in DM (range 2.1 - 4.9) between 1996 and 2002, with no distinction between perennial and annual systems (Leisen and Heimberg 2003). This is similar to the regional specific value of 3.5 g kg^{-1} P in DM for grass-clover silage for organic farming (Kape et al. 2008). The German standard (KTBL 2009) recommends P concentration values of 1.6 – 2.4 g kg^{-1} P in DM and 4.1 – 4.7 g kg^{-1} P in DM for extensive grassland and for intensive grassland in conventional farming, respectively. In contrast, a Swedish study uses a divergent mean value of 2.8 g kg^{-1} P in DM for silage (Gustafson et al. 2007). Vegetation samples from permanent grassland in the current study resulted in higher P concentrations (3.9 g kg^{-1} P in DM ±0.62, n=17, 2012). So, the results for permanent and annual grassland in the current study have a wide range of P concentrations and fit well to the range found in literature. Similarly P contents of maize at harvest also had high variability (Table 3.3). Maize had the highest biomass yield per ha and its mean P content was 2.8 g kg^{-1} P in DM ±0.4 with a range between 2.4 and 3.3 g kg^{-1} P in DM. Likewise P analyses of 74 maize silage samples from German organic farms showed a mean value of 2.5 g kg^{-1} P in DM, with a wide range between 0.17 and 0.36 g kg^{-1} P (Leisen and Heimberg 2003). P concentrations have important effects on the estimated P flows, especially in high yielding crops.

Because of the high variations of P export between the years, P contents and biomass yields, annual calculation of soil P balances for 2010, 2011 and 2012 resulted in ranges from -6.2 to -9.3 kg P ha^{-1} a^{-1} in grassland and -1.5 to -17.7 kg P ha^{-1} a^{-1} in arable land (Ohm et al. 2015). Therefore, it is reasonable to analyze farm specific samples during different years to get a better view of mean P flows on farms following the differing crop yields and milk yield for the use in optimization of nutrient flows and environmental aspects. This result is similar to Schüler et al. (2016, submitted), who analyzed the variation of greenhouse gas emissions of the farm. They show significant variations between the years following the differing crop and milk yields. In sum, the assessment of longer time periods and farm specific values leads to more representative results for the use in optimization of nutrient flows and environmental aspects, e.g., greenhouse gas emissions.

Internal P flows as support for management decisions and its transferability

Due to calculation and visualization of farm-specific P flows, nutrient transfer between segments of the system, differences in P uptake between species and years, and P imports and outputs across the system boundaries became obvious. High yearly yields and P uptake show that P levels in soils are still sufficient. Enhancing the P cycle with high biomass yields seems still possible. Also the observed variation in year-specific distribution of P can give suggestions for improvements. A detailed view on manure distribution showed imbalances between the years and plots. For example there was no fertilization with stable manure on the arable land in 2012. The visualization of detailed P flows allows the targeted management of P flows to desired farm areas. In brief, calculations and visualization of farm specific P flow show year and plot specific improving potential.

The transferability of the results is provided in different terms. On the one hand the research farm shows an example of an organic dairy farm with low P input. As organic farms are characterized as low external input systems, negative P balances can often be found at the farm-gate level (Haas et al. 2007). Even if organic mixed farms, such as those in Austria, show balanced or positive P balances mainly due to fodder imports (Lindenthal 2000), the problem of nutrient export might only be shifted out of the farm system boundaries. If system boundaries expand to all organic production areas with different balance deficits in P, there must be a deficit, at least in the level of the exported products, when no additional fertilizers are imported. Therefore the topic of negative nutrient balances is relevant and should be included when insisting on closing P cycles.

On the other hand, the farm can be seen as an example of a farm with potential P reserves in the soil. Soil P reserves from previous high fertilization (Barberis et al. 1995, Schröder et al. 2011, Tóth et al. 2014) can be reduced without endangering soil fertility for a limited time. Even more, there is a need to reduce the status of many over-fertilized soils to a level that is environmentally acceptable (c.f. Chapter 1.2), while still being adequate for crop production

(Barberis et al. 1995). Nevertheless, for the farm under study, the slowly decreasing amount of inorganic available P contents in top-soils under negative P balances links to the necessity of addressing this problem in the near future. Biochemical aspects must be better understood to predict the duration times of soil P in organic crop rotations.

To sum up: (1) even small P amounts should be taken into account for inner farm P cycle, (2) farm specific and year specific values should be preferred to conclude on farm-specific optimisation, (3) detailed P flows show yearly and plot specific improvement potential and provide an opportunity to guide P flows within the farm. The results provide an example for organic dairy farms with low P input and potential P reserves in soil.

5.1.3 Study 3

After twelve years organic farming without external P fertilizer, no significant deficiency in P characteristics of plants and soils was noticeable on the farm under study. Despite reduced levels of plant available P (CAL) and labile inorganic P forms (Hedley fractionation) in soil, P (CAL) contents remain above the organic farming thresholds. According to high P (CAL) values, plants still profit from soil reserves. Especially grassland shows a high P supply and therefore will not suffer deficits in the next years. Moreover, grassland shows significantly higher enzyme and microbial activities than arable land and therefore might have an improved potential for P uptake from soil reserves by plants. This knowledge could support bridging the P gap at arable land by nutrient transfer from grassland to arable land, as shown in Study 2.

Study 3 deals with complications with the statistical analysis. The long-term experiment did not consist of real replications concerning the cash crop and dairy crop rotation. Each rotation consists of six plots with different crops (c.f. Chapter 1.7). The two crop rotations consist of 12 plots with 12 different treatments, defined by crop rotation and species. These 12 treatments are only done at one plot each year and therefore the number of replications is one. The problem of the design is that in an analysis of variance one cannot separate the effect of 'field' and 'crop'. The four GPS-located sample points per plot are only random samples of one treatment. The four samples describe the variance of the plot, but not between the plots. Nevertheless, taking multiple measurements from each experimental plot increases the sensitivity of the experiment by increasing the precision with which properties of each treatment are estimated (Hurlbert 1984). The variance between the plots would be necessary to have a valid experimental error, to divide between crop effects and effects of plots.

One solution for this problem would be a replication of the treatment. The problem of on-farm experiments is that the cultivated area should not be too small. Otherwise the cultivation is far from practical conditions and the operating expenses are much higher. This is especially important if complex research questions like the effects of different crop rotations are focused upon. The statistical approach was not taken primarily into account in designing the research area. According to Piepho et al. (2011), in general on-farm experiments have an increased practical relevance and validity compared to on-station experiments, but the precision might be lower within the larger heterogeneity of the experimental area. In terms of the heterogeneity, it should be pointed out that soil type at the experimental area is relatively homogenous and the plots are mostly located close to each other (c.f. Chapter 1.7). This might lead to a better precision than for other on-farm experiments.

Nonetheless, pseudo-replication, defined as "use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated (though samples maybe) or replicates are not statistically independent" (Hurlbert 1984) is a risk. According to Hulbert, the design of the research area is at risk of simple-temporal pseudoreplication. Millar and Anderson (2004) describe this as the failure to acknowledge the sequential measurement of multiple observations on the same treatment replicate. To avoid pseudo-replication, only results from two exemplary arable fields and two exemplary grassland plots were compared by pairwise t-test or, if data were not normally distributed, by Wilcoxon signed ranks test. The development of soil P (CAL) contents between 2001 and 2013 was analyzed using linear mixed effects models (LMM). As the data were not normally distributed, data were log-transformed. For the data from the different systems of arable land (dairy, stockless) the LMM was set up with year, farming system and the interaction of these two as fixed effects and LTM-point (Figure 1.6) nested within LTM-plot and crop as random intercept effects. For the grassland data, the model used year as fixed effect and LTM-point nested within LTM-plot as random intercept effect. With this setting, the plot effect is included in the analysis. This is useful if whole crop rotations are considered, but comparison is still problematic in the short run.

In brief, the on-farm experiment has an increased practical relevance. Statistical calculations have to consider that the crop rotations do not consist of replications.

5.2 Soil P as nutrient reserve

Soil P reserves from previous intensive fertilizer application can be a source of nutrient supply (Study 2). The farm under study mobilized 1,105 kg P a^{-1} from soil reserves from 116 ha (corresponding to 9.5 kg P ha^{-1} a^{-1}). As underlined by the results of Study 3, this negative balance does not yet endanger plant growth, especially in grassland. Likewise, White (2006) estimates that soil P contents range from 500 to 2,500 kg P ha^{-1}, of which 15-70 % may exist in strongly adsorbed or inorganic forms. Stutter at al. (2012) evaluated the soil P for Germany to 15 cm depth with more than 3000 kg P ha^{-1}. Many soils in Germany are in high or oversupplied categories (Figure 1.2), especially regions with a high density of animals (c.f. Chapter 1.1). A reduction of high P amounts could also reduce the risk of P losses to surface water (c.f. Chapter 1.2). These soil reserves could be a nutrient source for organic farms due to biomass transfer. This idea fits to the requirements of Shapley et al. (2015). They call for an efficient use of areas with large P accumulations by inducing negative P balances for several decades, until soil P concentrations are reduced. Also Svanback et al. (2015) identifies ‘phytomining’, creating a negative P balance by crop harvests, as a strategy to lower soil P levels and prevent P losses in landscapes.

Furthermore Simpson et al. (2011) suggest P efficient plants to improve P availability to other crops by intercropping or introducing them in rotations. Particular grain legumes like white lupine (*Lupinus albus L.*, Gardner and Boundy 1983, Cu et al. 2005) or faba bean (*Vicia faba L.*, Li et al. 2007) show the ability to mobilize sparingly-available P. In addition to this, the authors suggest that plant breeding should focus on P uptake und P-efficiency to reduce P accumulation in soil by enhancing extraction from, or interception of P destined for accumulation in the sparingly available P pools. Study 2 shows that significant amounts of P could be mobilized from soil reserves with organic crop rotations. In general, high biomass harvests led to high P uptake from soil. Maize (30.5 kg P ha^{-1} a^{-1}), grass-clover (23.9 kg P ha^{-1} a^{-1}) and mixed faba bean and oats (19.8 kg P ha^{-1} a^{-1}) had the highest P uptake in cropland. At grassland, on the analyzed farm the highest yield of 23.4 kg P ha^{-1} a^{-1} were taken up by grazing and harvesting. Additionally in grassland a high turn-over activity is expressed by enzymatic indicators of biological soil activity (Study 3, c.f. Chapter 5.3).

Managing soil fertility near the critical threshold value is expected to maximize efficiency of nutrient use (Simpson et al. 2011). But a decline of P supply to insufficient amounts would be contrary to the IFOAM health principle which includes healthy soils. Nevertheless, the standard threshold values for soils are developed for yield levels of systems with intensive fertilization. They might be too high for organic farming. For organic crop rotations this might implicate a higher tolerance to lower P levels (Study 3) and a sustained reliance on P mining from soil reserves might be allowed. In consequence Kolbe (2001) generally suggests available nutrient contents in soils ranging in Category B as optimum for organic farming, whereas for conventional farming Category C is preferred. Further scientific research is needed to find a system-specific optimal P level for organic agriculture needs. The question of whether soil microbiological and rhizosphere effects on P mobilization from soil reserves will be more pronounced due to diminishing P contents with losses in plant available P over long periods is still open, as is the question of the reliability of these mechanisms for the farmer. Also further biological mechanisms not addressed here, like mycorrhiza, might improve. It will be necessary to find a site-specific fertilizer application rate to balance P extraction by plants with the supply available from soils and fertilizers.

In short, soil P reserves (e.g., from historical fertilizer input) are veritable P sources for plants, also at the farm under study. In general, soils with a high nutrient supply can be seen as a P resource for farming. Different species show varying P uptakes from soil and therefore P mobilization potential. The reliability standard values for sustainable P supply in soils of organic farming and the reliability of biological mobilization mechanisms should be discussed further.

5.3 Grassland in the P cycle

Grassland might be a nutrient source for arable land via stable manure for P in the farm under study (Study 2). Here P accumulations from former grazing and fertilization occur frequently (c.f. Chapter 1.6, Study 3). Significantly higher contents of inorganic P fractions and total P were found compared to arable sites (c.f. Table 4.4). Mining of soil P does not yet endanger soil fertility on the site under study for a foreseeable time period (Study 3). Moreover, grassland showed significantly higher activity of acid and alkaline phosphatases in soil. On the one hand, this is an indicator for biological activity and indicates a high P turnover in the organic pathway (Frossard et al. 2016). On the other hand, this might promote the plant availability of soil P compared to arable land with annual crops. Inorganic P from biological turnover processes might be in excess for take-up by plants and can be transferred to arable land to support nutrient supply. In this case study, arable land was supplied directly with 64 kg P a^{-1} from soil reserves of grassland (correspond to 1 kg P ha^{-1} a^{-1}) (Study 2). In animal housing periods, like winter-time or night-time, the fodder supply could be composed of high proportions from grassland to increase this P transfer. In the view of the farm P-balance, grazing animals reduced the pressure of the forage production on arable land. This indirectly relieves arable land of 627 kg P a^{-1} (10.1 kg P ha a^{-1}) compared to hypothetic scenarios solely producing forage crops in arable rotations.

Actually, the regularly included grassland showed high differences in the DM intake of grazing cows (Study 1). This indicates a potential for a future improvement of swards, grazing management, and storage food yields and would mean an intensification of production and the related P flows. A higher proportion of grassland in the food ration due to intensive management and increased yields would force the mining of soil P in grassland. This scenario seems suitable for grassland soils with high plant available P, as analyzed in this case study.

Another aspect for improving P-efficiency is the use of mineral P fertilizers in organic grassland. Mineral fertilizer use in organic farming is mainly restricted to rarely soluble rock phosphates (c.f. Chapter 1.3). Due to its intensive P cycle (c.f. Chapter 1.3, Study 3) and lower pH values (Figure 1.7, Table 1.1), in grassland, P from phosphate rock should be mobilized to plant available forms more efficiently than in arable land. So, phosphate rock might be preferably placed on grassland to be transferred in the arable farm cycle via manures from silage and fresh forage (Mengel et al. 2001, Möller 2009). In a holistic farming approach it seems to be effective to reallocate stable manure mainly to N demanding crops on arable land. Due to its mobilization potential, mineral P (and also K) fertilizer could be placed mainly on permanent grassland (for later transfer) while high legume percentage might cover N-demands here. In this way nutrient ratios in different fertilizers, different nutrient demands and nutrient turnover on different sites should be actively addressed to increase the effectiveness of fertilization (Möller 2009).

In the long run, additional P import will be needed, even though the nutrient supply of 34 % of the German grassland caused by former over-fertilization is categorized as high or very high (Scheffer und Schachtschabel 2010) (c.f. Chapter 1.1). Phytomining on those sites reduces the risk of negative environmental effects due to nutrient losses (c.f. Chapter 5.2). As 209,600 ha of permanent grassland are currently unprofitable or abandoned in Germany (Federal Statistical Office, 2014) there is a potential to use this land to substitute other fodder sources for ruminants, which also might be (re-) addressed as P source (if soil reserves are sufficient). Also biomass out of nature conservation areas should be actively used. This biomass might need to be removed to achieve nature protection targets (Diacon-Bolli et al. 2012, Isselstein 2003, Isselstein et al. 2005, Sutherland 2002). Soil fertility reduction can be recommended in conservation practices, e.g., by phytomining, in order to promote and sustain species-rich vegetation (Jouany et al. 2011). Materials from these areas are also discussed as substrate for bio-energy generation in biogas plants (Richter et al. 2011, Wachendorf et al. 2009), but the potential for nutrient transfer was not yet in focus. Also due to the fact that feed and energy demand of dairy cows changes throughout lactation, grassland of very different quality could more actively be integrated in farm nutrient flows. For example, extensively managed grassland, neglected so far, can be a fitting fodder source in the first phase of the dry period of dairy cows (Figure 5.1, Brinkmann et al. 2012) , thus avoiding malnutrition-caused diseases. Its use relieves the pressure of forage production from arable land or high quality pastures and provides nutrients.

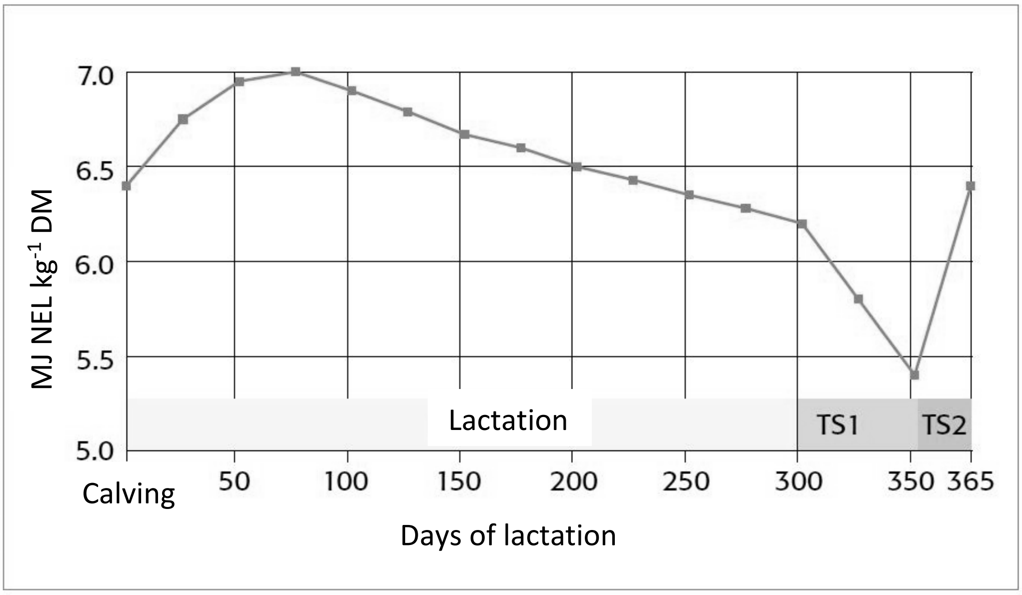

Figure 5.1 Energy demand of dairy cows in the lactation. NEL=Net energy lactation, DM=Dry matter, TS=Dry period (Brinkmann et al. 2012).

The energy content of the grass varied widely between the plots (minimum of 4.8, and maximum of 7.5 MJ kg^{-1} NEL). A few grassland plots in Trenthorst are influenced by high groundwater tables, like plot 1106, 1107, and two remote plots with nature protection targets. A high level leads to air deficiency in the root zone and reduces the feed quality (Klapp 1971). These areas might be preferred for feeding cows in dry period and could be more actively integrated into the grassland management by site specific grazing.

To summarize the function of grassland: (1) farm own grassland can be used as a direct or indirect nutrient source to improve the P supply of arable land; (2) grassland might transfer P from phosphate rock to plant available P more efficiently than arable land; (3) additional grasslands, for example from nature protection areas, can be used as fodder sources in special phases of dairy nutrition or as substrate for biogas production and could be seen as unexploited new P sources in the farm cycles, if soils are sufficiently supplied. Diverging sustainability goals in land management should not be forgotten while seeking P, as these measures obviously address productivity increase partly with consequences for biodiversity.

5.4 Phosphorus in relation to other nutrients

Phosphorus reserves will end within the foreseeable future, although the remaining timespan is still being discussed (Chapter 1.2). But focusing just on P as an essential nutrient is inadequate. Deficits of other macro- and micro nutrients can also limit plant growth. These nutrients differ from P in their solubility and movement in soils, in their availability for plants, and have different accumulation patterns in soil.

Nitrogen is a renewable resource as air consists to 78 % of N. Nonetheless N often limits plant growth in organic farms. Especially high quality, protein rich food is extremely dependent on the availability of sufficient N (Vance 2001). Plants acquire N from soil, through fertilizer, manure or mineralization of organic matter, and from the atmosphere through symbiotic N_2 fixation (Vance 2001). In organic agriculture, legumes and their biological nitrogen fixation are crucial and replace mineral fertilizer (c.f. Chapter 1.1). By the way, the production of mineral N fertilizer requires excessive energy consumption and today requires about one liter oil for each kg N fertilizer (Schubert 2011).

Sulfur is one of the more common constituents of the Earth´s crust and is available in different sources, but the cost of recovery is high (Fixen und Johnston 2012).

Potash contains a variety of K-bearing minerals and economic exploitation is possible in sedimentary salt beds from ancient inland seas, salt lakes or natural brines (Fixen und Johnston 2012). Potash reserves of the world have a reported reserve life of 235 years (based on 2007-2008 production) and a reserve base exceeding 500 years (Fixen und Johnston 2012). In contrast to P, Germany belongs to the four countries with the highest amount of natural K reserves (Fixen und Johnston 2012). Similarly to K from crude salt, Mg fertilizers are also generated (Schubert 2011). Liming focuses primarily on the improvement of soil fertility, thereby fertilization with Ca and Mg is a side effect (Schubert 2011). In this context it should be added that in Study 3 the Mg content of wheat in 2003 and 2013 was below the target values for plant tissue suggested by Bergmann (1993). Also the Mg value of grassland undercut the target value a little in 2013. For K in wheat grains from the stockless crop rotation, threshold values were undercut in 2003 and 2013. In the dairy crop rotation it was below the critical value only in 2013 (c. f. table 4.5). The K supply of the grassland was in the same range. Whether the target values for these nutrients are appropriate for the conditions of organic farming should be discussed based on a wider data basis and is not aim of this study.

Also, it has to be mentioned that farm-specific P flows provide suggestions for improved P management and for closing site-specific P gaps (Study 2). Other nutrient flows could also be addressed with the presented model based on complete mass flows. The inclusion of other nutrients may lead to further improved management decisions.

5.5 Solutions for sustainable P flows

Current farming practice calls for P fertilization to avoid a decline in soil fertility. Since 2001, no external P fertilizer was received at the farm under research. As shown, for a limited time period P reserves in soil can be addressed and distributed on the farm via livestock manure (Chapter 5.2, Study 2). Currently, neglected grassland could be increasingly focused upon as a nutrient source for nutrient transfer (Chapter 5.3).

At the end a comprehensive perspective can help to find recommendations for restructuring P-flows from the food chain back to agriculture. Europe is not only facing problems of nutrient deficits and the search for suitable fertilizers in organic farming. Regional nutrient overflows by feedstuff and food imports are also prominent. So, Europe has to deal with excessive use of worldwide P reserves, improper P distribution (c.f. Chapter 1.1 and 1.2) and inefficient use of imported P (Ott and Rechberger 2012). Withers et al. (2015) defined a “**5R**” stewardship to reduce Europe´s dependence on P imports:

1) **Realign P inputs** to match requirements.
2) **Reduce P losses to water.**
3) **Recycle in bioresources** more effectively.
4) **Recover P** from wastes.
5) **Redefine P in food systems.**

Realign to match requirements (Point 1) primary focus on production systems with excess of P supply (c.f. Chapter 1.1 and 1.2). In conventional farming, amounts of inorganic P currently added to soil are in excess of actual requirements (Withers et al. 2015). In contrast, organic farming suffers mostly from nutrient deficits (Chapter 1.3). Therefore, suggested lower P inputs do not concern the organic system. Nevertheless, the use of phosphate rock should be discussed in the context of matching the requirements of the plants. Phosphate rock has a limited P availability in arable land (cf. Chapter 1.5). To realize a balanced P fertilization in organic farming, Schnug et al. (2003) recommend the granulation of low soluble forms of P (rock phosphate or bone ashes) with elementary sulfur and the release of sulphuric acid during microbial sulfoxidation to enhance P availability to plants. Otherwise phosphate rock is added in soil but will not become plant available in acceptable time spans, leading to low P efficiency. Nevertheless, phosphate rock cannot be a sustainable solution for improved P flows because of its non-renewability (Chapter 1.2).

As seen by the reduction of P losses to water (Point 2), organic farming is not responsible for the excessive P accumulation in soil, as in regions of intensive animal husbandry (cf. Chapter 1.1). This over-fertilisation leads to high nutrient losses in water bodies (cf. Chapter 1.2). But of course, organic farms should also take action against erosion and run-off (Lindenthal 2000). In contrast to the detrimental accumulation of P in many agricultural soils, organic agriculture profits from historically accumulated soil reserves. Thereby nutrient mining could reduce P losses to water (Chapter 5.2).

Points 3) and 4) may provide P for conventional and organic agriculture. Recycling bio-resources more effectively (Point 3) suggests returning crop residues, animal manures, bone meal, and nutrients from wastewater bio-solids to the field. The largest amount of recyclable P in Europe is livestock manure, representing 1.6 Tg P a^{-1} (Withers et al. 2015). A transfer of manure from areas with a high nutrient supply (intensive animal husbandry) to areas with a low nutrient supply (cash crop rotations) is suggested to reduce environmental burdens (LANUV 2009). This manure management will be profitable for conventional farming. But conventional manure input is generally not allowed in organic farming. In contrast, in Denmark it is common practice to transfer manure from conventional to organic farms. But this practice defeats the principles of organic farming, if it supports industrial animal husbandry. The use of grassland as a bio-resource for P acquisition from soils is already discussed in Chapter 5.3. Besides common biomass, other sources, such as algae and duckweed from neighboring water bodies could be a P-containing biomass source. In other studies, duckweed from domestic wastewater (Oron 1994), algae from dairy manure treatment (Mulbry et al. 2005) or compost of marine algae like seaweed (Eyras et al. 1998, Zahid 1999) and green tides (Mazé et al. 1993) showed appropriate characteristics as fertilizer and may serve as a new P source, especially for organic farming. Hence, the removal of nutrients from waterbodies may also reduce environmental burdens and close the P cycle in a broader way (c.f. Chapter 1.2).

Recovered P from wastes (Point 4) focus on the 0.6 Tg P a-1 contained in wastes from domestic, agriculture, and in industrial residues which are not used because of logistical, economical, contamination, or hygienic reasons (Withers et al. 2015). Recycled waste provides a sustainable source of P and a step towards closed nutrient cycles (cf. Chapter 1.2 and 1.3). Already early theories of organic farming included nutrient P flows from human food consumption waste streams back to agriculture (Rusch 1968, Howard and Wad 1931). Also regional cycling of nutrients is still a principle of organic farming (IFOAM, 2015). But due to toxic components, the application of sewage sludge is not permitted here and the removal of toxic components is an expensive measure hindering an introduction in times of low prices for fossil P reserves (Van Vuuren et al. 2010). Nevertheless, at least due to the shortage of P reserves, the extraction of P from waste water steams and use as fertilizer will become increasingly important, e.g., the P-containing struvite from waste water cleaning that is suitable for agriculture application (Huang et al. 2016, Bilbao 2014, González-Ponce et al. 2009, Kern et al. 2008). The use of certified household composts is generally allowed in organic farming as fertilizer source (Commission Regulation (EC) No 889/2008). Its use is under debate in private organic grower associations. Future recycling concepts for P should include this source under strict quality control and special inclusion of composts from nearby collection points to fulfil regional nutrient transfer and enable a socially controlled quality management.

Above all, if P fertilizer includes ingredients which might endanger human health, this would not provide a preferable solution for organic farming, even if official critical values are undercut. Many consumer decisions for organic food rely on more healthiness due to less harmful substances than in conventional farming (Brunner 2009). This is underscored by stringent directives for fertilizers in organic farming (cf. Chapter 1.3) and lower critical values for many substances. But innovations in technology may also help to provide secure P from contaminated bio-resources. That is appropriate to the principles of organic farming.

The last point 5) aimed at human diets. One possibility to conserve P resources is the reduced consumption of animal products. Livestock production is less efficient than plant production, e.g., in energy efficiency, and includes nutrient losses during food production and in excrements. Globally meat production accounts for 72 % of the average P food print (average amount of mined P required to produce food consumed per capita per annum) (Metson et al. 2012). Decreasing meat consumption could play an important role in sustainable P management strategies (Cordell et al. 2009), and has synergies with other health and environmental sustainability priorities (Metson et al. 2012). Another aspect is the reduction potential in domestic waste. In the German food production chain nearly one third of the food produced (18 Tg food a^{-1}) is wasted and more than half of the losses are avoidable. At the consumer level, 7.2 Tg food a^{-1} is wasted, and the potential to reduce food losses is estimated to be 70 %. Therefore this chain link is of specific relevance (Noleppa and Cartsburg 2015). A reduction of wastage would improve overall P efficiency (Withers et al. 2015).

Above all, consumption of organic food can also conserve P resources. Low-P farming systems provide environmental (lower P losses) and efficiency (less P accumulation) benefits (Simpson et al. 2011). According to negative P balances often found in organic farms (c.f. Chapter 1.4) the theoretical P efficiency of organic products is even more than 100 %. Also lower P (CAL) levels in soil can lead to lower P concentrations in crops (Study 3). This leads to lower P concentrations in vegetable food and in livestock products (Wu et al. 2001). Following this idea, a decreased level of P in human foods to concentrations that ensure quality and growth of plants and products would lower food chain P flows and reduce P losses to the environment. Therefore, the consumption of organically produced food promotes a more sustainable utilization of non-renewable P sources, reduces environmental burdens, and improves P efficiency. In brief, society can reduce its P footprint by a reduced consumption of animal products, avoiding food wastes, and consuming organic products.

Realigned P inputs and reduced P losses to water are necessary for sustainable P flows. But organic farming is less responsible for these points than conventional farming. Bio-resources and wastes could be suitable P sources and their use would support closing the P cycle further. Also changes in the diet will be an important part in closing leaks in global P cycles.

5.6 Conclusions and future perspectives

Grassland plays an important role for fodder supply (29.2 % of the P) for the dairy cows at the examined mixed farm. The rising plate meter is a useful tool to monitor development of grassland yields and growth in order to take informed management decisions. Improved sward management will induce more storage feed, decrease feed production demands on arable land and improve related P flows between grassland and arable land. In addition, it can reduce the global warming effects of milk production (Study 1). Therefore improved grassland management should be more focused and part of practice.

The farm under study still profits from P soil reserves from former farming periods. Despite twelve years of nutrient mining without external P supply, no limit of plant growth is evident as soil P supply is still sufficient (Study 3). Biological soil activity, especially in grassland, is expected to play an important role for P cycling and activation. Whether increased biological activity in soils allows a sustained reliance on P mining from soil reserves is still unclear. Finding a system-specific optimal P level in soils and plants for the yield levels and crop rotating in organic farming, and defining suitable fertilization strategies, needs further scientific research.

Modelling the P flows of the farm under study was a suitable tool to identify gaps as well as to show potentials for improvements. Easy models to calculate and visualize farm-specific P flows should be developed for farmers. These models should prefer farm- and year-specific values. In searching for improvements, differing P mobilisation potential of species should also be taken into account when composing crop rotations. But also here research to derive practical advice is still necessary. Models of inner farm P flows can help improve the forcing of biological P cycling to prevent P fixation and keep rapid P-turn-over in soils upright. They can help to integrate grassland in a suitable way, and to manage nutrient flows.

Therefore, the meaning of grassland should be highlighted in a new context. Beside its several ecosystem services, also the mobilisation function of soil P reserves should be seen as a public good. On a regional scale, an assessment of potential nutrient transfer from over-fertilized areas, as well as from neglected grassland areas, to farms with nutrient demand should be done. Knowledge transfer is necessary to bring these ideas into practice. Attention to the presented topic should be generated by articles, consultants, in universities, vocational schools, and in professional development.

Forcing biological P cycling on farms and integrating grassland P in fertilizing strategies might be part of a solution until efficient and resource-friendly fertilizer systems are installed. Finally, it is essential to find adequate P fertilizers which close the P cycle for human waste streams back to agriculture. It is necessary to develop and implement fitting technologies for P recycling and detoxification of materials. Therefore, the awareness of the society about essential and non-renewable resources needs to be raised. The antipathy against waste, and especially sewage sludge, has to be transformed into view towards the value of waste as a nutrient source. Societal and political education will be the key for a better relationship to human waste and may lead to a more sustainable handling of our resources. Also, people can make their contribution to more efficient nutrient cycles and reduce environmental burdens by choosing meatless and organic diets and avoiding wastes.

5.7 References

Aarts HFM, Habekotté B, van Keulen H (2000) Phosphorus (P) management in the 'De Marke' dairy farming system. Nutr Cycl Agroecosys 56(3):219-229

Barberis E, Marsan FA, Scalenghe R, Lammers A, Schwertmann U, Edwards A, Maguire R, Wilson M, Delgado A, Torrent J (1995) European soils overfertilized with phosphorus: Part 1. Basic properties. Fert Res 45(3):199-207

Bergmann W (1993) Ernährungsstörungen bei Kulturpflanzen. 3. Auflage, Gustav-Fischer-Verlag, Jena Stuttgart

Bernhard H, Amberger A, Berth P, Grim J, Hamm A, Hüser R, Kandler J, Keune H, Koppe P, Malz F, Sarfert F, Schwertmann U, Wagner R, Werner W (1978) Phosphor-Wege und Verbleib in der Bundesrepublik Deutschland-Probleme des Umweltschutzes und der Rohstoffversorgung. Bernhardt, H. (Hrsg.) Verlag Chemie, Weinheim, New York

Bilbao J (2014) Phosphorus Recovery from Wastewater Filtrates through a Novel Electrochemical Struvite Precipitation Process. Berichte aus Forschung und Entwicklung IGB, Vol 64, Fraunhofer IGB (ed), Fraunhofer Verlag, Stuttgart

Brinkmann J, Schumacher U, Weidmann G (2012) Euter- und Stoffwechselgesundheit bei Biomilchkühen. FiBL-Merkblatt 1580, 1. Auflage

Brunner (2009) Nachhaltiger Konsum: Am Beispiel des Essens. Sozialwissenschaftliche Studiengesellschaft: SWS-Rundschau 49:29-49

Cooke GW, Williams RJB (1973) Significance of man-made sources of phosphorus: Fertilizers and farming. The phosphorus involved in agricultural systems and possibilities of its movement into natural water. Water Res 7(1–2):19-33

Cordell D, Drangert JO, White S (2009) The story of phosphorus: Global food security and food for thought. Global Environ Chang 19(2):292-305

Cu S, Hutson J, Schuller KA (2005) Mixed culture of wheat (*Triticum aestivum L.)* with white lupine (*Lupinus albus L.*) improves the growth and phosphorus nutrition of the wheat. Plant Soil 272:143-151

Daroub SH, Ellis BG, Robertson, GP (2001) Effect of cropping and Low-Chemical Input Systems on Soil Phosphorus Fractions. Soil Sci 166(4):281-291

Diacon-Bolli J, Dalang T, Holderegger R, Bürgi M (2012) Heterogeneity fosters biodiversity: Linking history and ecology of dry calcareous grasslands. Basic Appl Ecol 13(8):641-653

Eichler-Lobermann B, Kohne S, Kowalski B, Schnug E (2008) Effect of catch cropping on phosphorus bioavailability in comparison to organic and inorganic fertilization. J Plant Nutr 31(4):659-676.

Eyras MC, Rostagno CM, Defossé GE (1998) Biological evaluation of seaweed composting. Compost Sci Util 6(4):74-81

Federal Statistical Office (Statistisches Bundesamt) (2014) https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/LandForstwirtschaftFischerei/FeldfruechteGruenland/AktuellGruenland2.html;jsessionid=D65B94E75E9AAD6F8DB8190653CFB9DC.cae2 (accessed 14.4.2014)

Fixen PE, Johnston AM (2012) World fertilizer nutrient reserves: a view to the future. J Sci Food Agr 92(5):1001-1005

Frossard E, Bünemann EK, Gunst L, Oberson A, Schärer M, Tamburini F (2016) Fate of Fertilizer P in Soils—The Organic Pathway. In: Schnug E, De Kok LJ (eds) Phosphorus in Agriculture: 100% Zero. Springer Netherlands, pp. 41-61. doi: 10.1007/978-94-017-7612-7_4

Gahoonia TS, Nielsen NE (2004) Root traits as tools for creating phosphorus efficient crop varieties. Plant Soil 260:47-57

Gardner WK, Boundy KA (1983) The acquisition of phosphorus by Lupinus albus L. IV. The effect of interplanting wheat and white lupine on the growth and mineral composition of the two species. Plant Soil 70:391-402

Gonzàles-Ponce R, López-de-Sá EG, Plaza C (2009) Lettuce response to phosphorus fertilization with struvite recovered from municipal wastewater. HortScience 44(2):426-430

Gustafson GM, Salomon E, Jonsson S (2007) Barn balance calculations of Ca, Cu, K, Mg, Mn, N, P, S and Zn in a conventional and organic dairy farm in Sweden. Agr Ecosyst Environ 119(1–2):160-170

Haas G, Wetterich F, Köpke U (2001) Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agr Ecosyst Environ 83(1–2):43-53

Haas G, Deittert C, Kopke U (2007) Farm-gate nutrient balance assessment of organic dairy farms at different intensity levels in Germany. Renew Agr Food Syst 22(3):223-232

Hoppe T, Weissbach F, Schmidt L (1995) Kontrolle des Weidemanagements durch Bestandshoehenmessung. VDLUFA-Schriftenreihe No. 40, Germany

Howard A, Wad YD (1931) The waste products of agriculture. Their Utilization as Humus. Oxford University Press

Huang H, Zhang P, Zhang Z, Liu J, Xiao J, Gao F (2016) Simultaneous removal of ammonia nitrogen and recovery of phosphate from swine wastewater by struvite electrochemical precipitation and recycling technology. J Clean Prod 127(20)

Hurlbert SH (1984) Pseudoreplication and the design of ecological field experiments. Ecol Monogr 54(2):187-211

IFOAM (2015) Principles of Organic Agriculture. http://www.ifoam.bio/sites/default/files/poa_english_web.pdf (accessed 29.12.15)

Isselstein J (2003) Erhaltung und Förderung der Pflanzenvielfalt auf dem Grünland aus landwirtschaftlicher Sicht. Nova Acta Leopold 328:99-111

Isselstein J, Jeangros B, Pavlu V (2005) Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe–a review. Agronomy Research 3(2):139-151

Jouany C, Cruz P, Daufresne T, Duru M (2011) Biological Phosphorus Cycling in Grasslands: Interactions with Nitrogen. In: Bünemann EK, Oberson A, Frossard E (eds.) Phosphorus in Action. Springer, Berlin Heidelberg pp. 275-294

Jungk A, Claassen N (1986) Availability of phosphate and potassium as the result of interactions between root and soil in the rhizosphere. Z Pflanz Bodenkunde 149(4):411-427

Kape H-E, Wulffen von U, Roschke M (2008) Richtwerte für die Untersuchung und Beratung zur Umsetzung der Düngeverordnung in Mecklenburg-Vorpommern. Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern. http://www.lms-beratung.de/upload/59/1294212632_30690_19228.pdf (accessed 10.8.2015)

Kern J, Heinzmann B, Markus B, Kaufmann AC, Soethe N, Engels C (2008) Recycling and assessment of struvit phosphorus from sewage sludge. Agriculture Engenieering International: CIGR Journal, Manuscript number CE 12 01. Vol. X

Klapp EL (1971) Wiesen und Weiden. Parey, Berlin

Kolbe H (2001) Anleitung zur P-, K-, Mg-und Kalk-Düngung im ökologischen Landbau [Instructions for phophorous, potassium, magnesium and lime fertilisation in organic agriculture.]. SÖL-Berater-Rundbrief (3):3-9

KTBL (2009) Faustzahlen für die Landwirtschaft. Döhler H (ed) 14. Auflage, Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. KTBL, Darmstadt

LANUV Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westphalen (2009) Biomasse aus Abfällen. Gibt es ein optimales Stoffstrommanagement? Tagungsband. LANUV-Fachbericht 18 https://www.lanuv.nrw.de/uploads/tx_commercedownloads/30018.pdf (accessed at 1.8.2016)

Leisen E, Heimberg P (2003) Milchviehhaltung. Dokumentation 10 Jahre Leitbetriebe in Nordrhein-Westfalen. Schriftreihe des Lehr und Forschungsschwerpunktes Umweltgerechte und Standortgerechte Landwirtschaft Nr. 105. Landwirtschaftliche Fakultät der Rheinischen Friedrich-Wilhelms-Universität Bonn pp. 159-180

Li L, Li S, Sun J, Zhou L Bao X, Zhang H, Zhang F (2007) Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. Proc Natl Acad Sci 104:11192-11196

Lindenthal T (2000) Phosphorvorräte im Boden, betriebliche Phosphorbilanzen und Phosphorversorgung im Biologischen Landbau - Ausgangspunkte für die Bewertung einer großflächigen Umstellung ausgewählter Bundesländer Österreichs auf Biologischen Landbau hinsichtlich des P-Haushalts. Dissertation, Universität für Bodenkunde, Wien.

LLUR Landesamt für Landwirtschaft und ländliche Räume S-H (2014) Nährstoffe in Gewässern Schleswig-Holsteins Entwicklung und Bewirtschaftungsziele. Schriftreihe LLUR SH- Gewässer, D 24

McNaughton SJ, Milchunas DG, Frank DA (1996) How can net Primary Productivity be Measured in Grazing Ecosystems? Ecology 77(3):974-977

Mengel K, Kosegarten H, Kirkby EA, Appel T (2001) Principles of plant nutrition. Springer Netherlands

Millar RB, Anderson MJ (2004) Remedies for pseudoreplication. Fish Res 70(2-3):397-407

Mazé J, Morand P, Potoky P (1993) Stabilisation of 'Green tides' Ulva by a method of composting with a view to pollution limitation. J Appl Phycol 5(2):183-190

Metson GS, Bennett EM, Elser JJ (2012) The role of diet in phosphorus demand. Environ Res Lett 7(4):044043

Modin-Edman A-K, Öborn I, Sverdrup H (2007) FARMFLOW—A dynamic model for phosphorus mass flow, simulating conventional and organic management of a Swedish dairy farm. Agr Syst 94(2):431-444

Möller K (2009) Inner farm nutrient flows between arable land and permanent grassland via the stable in organic cropping systems. Eur J Agron 31(4):204-212

Mulbry W, Westhead EK, Pizarro C, Sikora L (2005) Recycling of manure nutrients: use of algal biomass from dairy manure treatment as a slow release fertilizer. Bioresource Technol 96(4):451-458

Nesme T, Toublant M, Mollier A, Morel C, Pellerin S (2012) Assessing phosphorus management among organic farming systems: a farm input, output and budget analysis in southwestern France. Nutr Cycl Agroecosys 92(2):225-236

Noleppa S, Cartsburg M (2015) Das grosse Wegschmeissen. Vom Acker bis zum Verbraucher: Ausmaß und Umwelteffekte der Lebensmittelverschwendung in Deutschland. Study on behalf of WWF Germany

Ohm M, Felix J, Schüler M, Paulsen HM (2013) Eignung von Methoden zur Ermittlung des Massenaufwuchses von Grünland am Beispiel eines ökologischen Milchviehbetriebes Kongressband VDLUFA 2013 Berlin:342-349

Ohm M, Schüler M, Paulsen HM (2015) Phosphor-Bodenbilanzen von Grünland- und Ackerflächen auf einem ökologischen Milchviehbetrieb. In: Häring AM, Hörning B, Hoffmann-Bahnsen R, Luley H (eds) Beiträge zur 13. Wissenschaftstagung Ökologischer Landbau "Am Mut hängt der Erfolg: Rückblicke und Ausblicke auf die ökologische Landbewirtschaftung" pp. 276-279

Oron G (1994) Duckweed culture for wastewater renovation and biomass production. Agr Water Manage 26(1–2):27-40

Ott C, Rechberger H (2012) The European phosphorus balance. Resources, Conservation and Recycling 60:159-172

Piepho H-P, Richter C, Spilke J, Hartung K, Kunick A, Thöle H (2011) Statistical aspects of on-farm experimentation Crop Pasture Sci 62(9):721-735

Richter F, Graß R, Wachendorf M (2011) Energetische Nutzung extensiver Grünlandflächen in Überschwemmungsgebieten von Fließgewässern im Rahmen des Verbundprojektes KLIMZUG Nordhessen. 11. Wissenschaftstagung Ökologischer Landbau, Gießen, 16.-18. März 2011

Rusch HP (1968) Bodenfruchtbarkeit: Eine Studie biologischen Denkens. Heidelberg: Haug

Rotz CA, Taube F, Russelle MP, Oenema J, Sanderson MA, Wachendorf M (2005) Whole-farm perspectives of nutrient flows in grassland agriculture. Crop Sci 45(6):2139-2159

Scheffer F, Schachtschabel P (2010) Lehrbuch der Bodenkunde. Spektrum Akademischer Verlag, Berlin, pp. 412-420

Schnug E, Rogasik J, Haneklaus S (2003) The utilisation of fertiliser P with special view to organic farming. Landbauforsch Volk 53(1):1-11

Schubert S (2011) Pflanzenernährung: Grundwissen Bachelor. Ulmer, Stuttgart

Schüler M, Paulsen HM, Berg W, Prochnow A (2016, submitted) Accounting for inter-annual variability of greenhouse gas emissions from dairy farming. Received by the International Journal of Life Cycle Assessment (28.7.2016)

Schröder J, Smit AL, Cordell D, Rosemarin A (2011) Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use. Chemosphere 84(6):822-831

Shapley AN, Bergstöm L, Aronsson H, Bechmann M, Bolster CH, Börling K, Djodjic F, Schoumans OF, Stamm C (2015) Future agriculture with minimized phosphorus losses to waters: Research needs and direction. Ambio 44(2):163-179

Simpson RJ, Oberson A, Culvenor RA, Ryan MH, Veneklaas EJ, Lambers H, Lynch JP, Ryan PR, Delhaize E, Smith FA (2011) Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems. Plant Soil 349(1-2):89-120

Smit HJ, Taweel HZ, Tas BM, Tamminga S, Elgersma A (2005) Comparison of techniques for estimating herbage intake of grazing dairy cows. J Dairy Sci 88(5):1827-1836

Steinshamn H, Thuen E, Bleken MA, Brenøe UT, Ekerholt G, Yri C (2004) Utilization of nitrogen (N) and phosphorus (P) in an organic dairy farming system in Norway. Agr Ecosyst Environ 104(3):509-522

Stutter MI, Shand CA, George TS, Blackwell MS, Bol R, MacKay RL, Richardson AE, Condron LM, Turner BL, Haygarth PM (2012) Recovering phosphorus from soil: a root solution? Environ Sci Technol 46(4):1977-1978

Sutherland WJ (2002) Conservation biology: Openness in management. Nature 418(6900):834-835

Svanback A, Ulen B, Bergstrom L, Kleinman, K (2015) Long-term trends in phosphorus leaching and changes in soil phosphorus with phytomining. J Soil Water Conserv 70(2):121-132

Tóth G, Guicharnaud R-A, Tóth B, Hermann T (2014) Phosphorus levels in croplands of the European Union with implications for P fertilizer use. Eur J Agron 55(0):42-52

Vance CP (2001) Symbiotic nitrogen fixation and phosphorus acquisition. Plant nutrition in a world of declining renewable resources. Plant Physiol 127(2):390-397

Van Vuuren DP, Bouwman AF, Beusen AHW (2010) Phosphorus demand for the 1970–2100 period: A scenario analysis of resource depletion. Glob Environ Change 20(3):428-439

Wachendorf M, Richter F, Fricke T, Graß R, Neff R (2009) Utilization of semi-natural grassland through integrated generation of solid fuel and biogas from biomass. I. Effects of hydrothermal conditioning and mechanical dehydration on mass flows of organic and mineral plant compounds, and nutrient balances. Grass Forage Sci 64(2):132-143

White RE (2006) Principles and practice of soil science: the soil as a natural resource. Fourth Edition, Blackwell Publishing, Oxford

Withers PJ, van Dijk KC, Neset T-SS, Nesme T, Oenema O, Rubæk GH, Schoumans OF, Smit B, Pellerin S (2015) Stewardship to tackle global phosphorus inefficiency: The case of Europe. Ambio 44(2):193-206

Wu Z, Satter LD, Blohowiak AJ, Stauffacher RH, Wilson JH (2001) Milk Production, Estimated Phosphorus Excretion, and Bone Characteristics of Dairy Cows Fed Different Amounts of Phosphorus for Two or Three Years. J Dairy Sci 84(7):1738-1748

Zahid PB (1999) Preparation of organic fertilizer from seaweed and its effect on the growth of some vegetable and ornamental plants. Pak J Biol Sci 2(4):1274-1277

6 Summary

6.1 Summary

Phosphorus (P) is an essential element to all forms of life and thus, for plant growth. Resources of P are non-renewable and limited and, as P is not consequently recycled from the food chain to agriculture, the P cycle is broken. Due to decades of over-fertilization, areas with intensive agriculture in Europe show high P accumulation in topsoil. In contrast, organic agriculture restricts fertilizer use and negative nutrient balances need to be equalized. The aim of the study is to analyze the role of grassland in P flows in mixed organic farms.

Structures for comparisons of farming systems at the research farm of the Thünen Institute of Organic Farming, Trenthorst, located in northern Germany were used for the analyses. The farm converted to organic farming in 2001 and had no P-fertilizer import. It is a representative example of an organic farm with high nutrient supply from the outset. Grassland-related P flows (by grazing and harvesting) were estimated with a specific method using a calibrated rising plate meter. Inner farm nutrient cycles were calculated with farm specific data for the dairy farm system for the years 2010 - 2012 based on a complete material flow model. The development of soil P characteristics of grassland and arable land after twelve years of organic farming without external P supply was determined by P fractions, and the activities of phosphatases and dehydrogenase in the soil.

- Measurements of the variable feed offer at pasture plots with a rising plate meter provide a data basis to calculate farm specific P flows ($DM = 100.41 \times h + 1$ ($r^2=0.7549$; $n=396$)). On the explored pasture plots, high differences (more than 30 %) were found in the dry matter intake of the cows between plots, and might indicate a potential for the improvement of grazing and pasture management.
- Optimizing pasture yields, e.g., by sward improvements and grazing management, offers chances to reduce environmental burdens. At daily milk yields of 20 kg ECM per cow and day, the GWP can be reduced by 15 g CO_2 eq. per kg ECM (= 1.5 %) by substituting 1 kg DM grass silage by 1 kg DM intake from pasture. It cannot be concluded that pasture based systems perform better than other systems, but that a well-run pasture provides a great opportunity to avoid greenhouse gas emissions.
- The 116 ha sized farm showed deficits of 1,105 kg P yr^{-1} (7.9 kg P ha^{-1} a^{-1} in permanent grassland and 10.9 in arable land) which were supplied from soil P reserves. Maize (30.5

kg P ha^{-1} a^{-1}), grass-clover (23.9 kg P ha^{-1} yr^{-1}) and mixed faba bean and oats (19.8 kg P ha^{-1} a^{-1}) had the highest P uptake in cropland. At grassland, grazing intake by livestock was 15.9 kg P ha^{-1} a^{-1} (± 2.7, min. 9.5, max. 20.7).

- Grazing and feed conserves from grassland accounted for 29.2 % of the P supply for the dairy cows and directly fed arable land with 64 kg P (average 1 kg P ha^{-1} yr^{-1}).
- If critical situations are avoided based on evaluation of soil and plant analyses, forced and controlled P mining on grassland sites with P contents over the agricultural optimum and redistribution to arable land could be a component of sufficient P management. Optimizing grassland management might improve this positive loop.
- Generally, the inclusion of unexploited grassland sites with high soil P contents in farm nutrient flows (via feed conserves for livestock or biogas) would address unused soil P reserves for redistribution.
- In arable land plant available P-contents in topsoils (0-30 cm) of the analyzed farm were still sufficient, but had decreased since converting to organic farming due to negative P balances. The content of plant available P (CAL) in topsoils generally reduced from 65 mg kg^{-1} over twelve years to 61.3 mg kg^{-1}. Also the labile P fractions H_2O P (7.8 to 5.1 mg kg^{-1}) and resin P (60.3 to 47.4 mg kg^{-1}) were lower in 2013 compared to 2001.
- In grassland between 2001 and 2013 the P (CAL) values reduced from 132.0 to 107.1 mg kg^{-1}. Also the P fraction H_2O (14.1 to 9.6 mg kg^{-1}), Resin P (141.2 to 90.6), $NaHCO_3$ (169.8 to 104.3), NaOH (431.3 to 279.3) and total P (1365.5 to 951.0) decreased (0-30 cm). Above all, soil P mining has not yet endangered soil fertility, according to high P (CAL)-contents in the soils. Therefore, it might further serve as P reserve in the farm cycle for a limited time period.
- In arable land the alkaline (144.9 to 149.4 µg p-Nitrophenol 1 g DM $soil^{-1}$) and acid phosphatase activity (140.9 to 158.2 µg p-Nitrophenol 1 g DM $soil^{-1}$) increased between 2001 and 2013 (0-30 cm). Nevertheless, reduced nutrient supply of P over the past twelve years might have led to a higher phosphatase activity in arable land.
- Dehydrogenase as indicator for general microbial activity did not show any significant effect. In relation to neighboring conventional fields, microbial activity is seen to be below its potential and should be stimulated by inputs of organic matter and reducing C/N rations to intensify the nutrient cycling in soil.
- In grassland phosphatase activity did not change significantly over time but dehydrogenase activity reduced significant reduced when 2001 (133.0) and 2013 (81.4 µg TPF 1g DM $soil^{-1}$, 0-30 cm) were compared.

- Obviously, neither in arable land nor grassland is the biological mobilization of P from organic and recalcitrant soil reserves high enough to stop losses in plant available P over the analyzed period. Mechanisms and balances of biological activation of P from soil reserves must be analyzed and quantified in more detail to derive practical recommendations, this especially at further declining contents in soil.

Looking to the future, imports of nutrients – here P – will become necessary to avoid plant growth deficits. Forced biological P cycling on farms and integration of grassland P in fertilizing strategies might be part of a solution until safe systems of P recycling from the food chain in agriculture are installed, not only in organic farming. Knowledge transfer into practise and societal awareness for non-renewable resources – like P – needs to be raised. Also people can make their contribution to more efficient nutrient cycles and reduce environmental burdens by choosing meatless and organic diets, and avoiding waste.

6.2 Zusammenfassung

Phosphor (P) ist unverzichtbares Element für alle Lebewesen und somit auch essentiell für das Pflanzenwachstum. Die weltweiten geogenen P-Reserven schwinden, da P nicht konsequent recycelt wird. Über Jahrzehnte hat sich in Regionen mit intensiver Landwirtschaft P im Oberboden angereichert und kann als potentielle P Reserve dienen. Im Gegensatz zur konventionellen Landwirtschaft sind die Möglichkeiten der P-Düngung im ökologischen Landbau eingeschränkt. Das Ziel der vorliegenden Studie ist es, die Bedeutung von Grünland für die Phosphorversorgung ökologischer Milchviehbetriebe zu quantifizieren. Die vorliegende Studie wurde innerhalb eines Versuchsansatzes mit verschiedenen landwirtschaftlichen Bewirtschaftungssystemen am Thünen-Institut für Ökologischen Landbau, Trenthorst (Östliches Hügelland, Schleswig-Holstein), durchgeführt. Der Versuchsbetrieb wurde 2001 von intensiver konventioneller Landwirtschaft auf ökologischen Landbau umgestellt. P-Dünger wurde seither nicht importiert. Seitdem profitiert der Betrieb von P-Bodenreserven. Für die Berechnung von grünlandbezogenen Massenflüssen wurde eine Methode mit Hilfe eines Höhenmessgerätes etabliert. Innerbetriebliche Phosphorkreisläufe wurden für den Zeitraum 2010-2012 auf Basis eines Massenflussmodells berechnet. Die Entwicklungen von P-Versorgung (P-Fraktionen) und von Indikatoren für die biologische Aktivität und den enzymatischen P-Aufschluss (Aktivität von Dehydrogenase und Phosphatase) in Oberböden von Grünland und Ackerland wurden zwischen 2001 und 2013 analysiert.

- Zur Bestimmung der Grünlanderträge der beweideten Flächen wurde ein Verfahren etabliert, bei dem umliegende, nicht beweidete Flächen analog zum Weidekäfig als Referenz für den Aufwuchs dienen. Mit dem Gras-Höhenmessgerät (FARMWORKS) konnte auf den ökologisch bewirtschafteten Weideflächen ein guter linearer Zusammenhang zwischen der ermittelten Bestandshöhe und dem Ertrag abgeleitet werden (Trockenmasse = 100,41 x Höhe + 1 ($r^2 = 0{,}7549$; n = 396)). Die Ertragsdaten dienten später der Berechnung von innerbetrieblichen Stoffströmen.
- Die Erträge schwankten zwischen den einzelnen Grünlandflächen um mehr als 30 %. Diese Unterschiede lassen auf Standortunterschiede schließen, weisen aber auch auf Optimierungspotential beim Weidemanagement hin.
- Durch eine Erhöhung der Trockenmasseaufnahme, z.B. durch die Verbesserung der Grasnarbe oder des Weidemanagements, können negative Umwelteffekte verringert werden. Bei einer Leistung von 20 kg energiekorrigierter Milch pro Kuh und Tag konnte

rechnerisch das Treibhauspotential um 15 g CO_2 eq. pro kg ECM (= 1,5 %) reduziert werden, indem 1 kg Grassilage mit 1 kg Futteraufnahme auf der Weide substituiert wurden.

- Der analysierte Milchvieh-Versuchsbetrieb (116 ha) zeigte jährliche Bilanzdefizite von -1.105 kg P a^{-1} und profitierte von Boden-P-Reserven. Dabei fielen auf das Grünland Defizite von -7,9 und auf Ackerland von -10,9 kg P ha^{-1} a^{-1}. Die höchste P-Abfuhr zeigten Mais (30,5 kg P ha^{-1}), Kleegras (23,9 kg P ha^{-1}) und der Mischfruchtanbau von Hafer und Bohnen (19,8 kg P ha^{-1}). Die durchschnittliche P-Aufnahme der Tiere mit dem Futter auf der Weide betrug 15,9 kg P ha^{-1} a^{-1} (± 2,7, min. 9,5, max. 20,7).
- 29,2 % der P-Versorgung der Kühe wurde vom Grünland abgedeckt. Die Ausbringung von Wirtschaftsdüngern führte zu einer Umverteilung von 64 kg P a^{-1} (1 kg P ha^{-1} a^{-1}) vom Grünland in Richtung Acker.
- Wenn kritische P-Versorgungszustände im Boden verhindert werden, könnte die Verwendung von P aus Bodenreserven des Grünlands für die Versorgung von Ackerschlägen eine aktiv anzusteuernde Komponente des P-Managements auf dem Betrieb sein. Durch Optimierung des Grünlandmanagements kann dieser Effekt erhöht werden.
- Generell kann durch gezielte Intensivierung der Biomasseabfuhr von Grünlandflächen (z.B. mit hoher P Versorgung oder wenig genutzt) P aus Bodenreserven über Futter für Tiere oder Biogasanlagen umverteilt werden.
- Auf den Ackerflächen sank der mittlere pflanzenverfügbare P (CAL)-Gehalt im Oberboden (0-30 cm) über zwölf Jahre von 65 mg kg^{-1} auf 61,3 mg kg^{-1}. Die labilen P-Fraktionen H_2O P (7,8 auf 5,1 mg kg^{-1}) und Resin P (60,3 auf 47,4 mg kg^{-1}) waren 2013 geringer als in 2001. Auf den Ackerflächen lag die P-Versorgung, trotz negativer P-Bilanzen, auch nach 12 Jahren deutlich über den Grenzwerten für den Ökologischen Landbau.
- Zwar nahmen die P (CAL)-Gehalte in Grünland im Untersuchungszeitraum von 132,0 auf 107,1 mg kg^{-1} im Oberboden ab (0-30 cm), befinden sich aber immer noch in Versorgungsstufe D. Daher könnte das Grünland auf dem analysierten Standort befristet als P-Reserve für den Gesamtbetrieb dienen. Auch die folgenden P-Fraktionen haben abgenommen: H_2O (14,1 auf 9,6 mg kg^{-1}), Resin P (141,2 auf 90,6), $NaHCO_3$ (169,8 auf 104,3), NaOH (431,3 auf 279,3) und Total P (1365,5 auf 951,0).
- Auf den Ackerflächen nahmen die Aktivitäten der basischen Phosphatase (144,9 auf 149,4 µg p-Nitrophenol 1 g DM $soil^{-1}$) und der sauren Phosphatase (140,9 auf 158,2 µg

p-Nitrophenol 1 g DM soil^{-1}) im Vergleich der Jahre 2001 zu 2013 zu. Dies kann mit einem verringerten Angebot an löslichem P im Boden zusammenhängen.

- Die Dehydrogenaseaktivität als Indikator für biologische Aktivität zeigte keine signifikanten Veränderungen und lag im Vergleich zu angrenzenden konventionell bewirtschafteten Flächen niedriger. Ein höherer Input an organischer Substanz und eine Verringerung des C/N-Verhältnisses könnte die biologische Aktivität steigern.
- Die biologische Mobilisierung von P aus organischen und schwer löslichen Bodenreserven reichten auf Ackerflächen und Grünland nicht aus, eine Reduktion der pflanzenverfügbaren P-Gehalte über den untersuchten Zeitraum von 12 Jahren zu kompensieren. Die biologische Aktivierung von P-Bodenreserven muss detaillierter analysiert und quantifiziert werden, um hieraus Empfehlungen für die Praxis ableiten zu können; insbesondere bei weiter absinkenden Gehalten in Böden.

Eine Forcierung des biologischen Phosphor-Kreislaufes und die Integration von Grünland in die P-Versorgungsstrategien von landwirtschaftlichen Betrieben kann Teil einer Lösung sein, bis nachhaltige Systeme zur P Versorgung, nicht nur für den Ökologischen Landbau, etabliert sind. Ziel müssen Phosphordünger sein, die Nährstoffe aus der Nahrungsmittelkette zurück in die Landwirtschaft bringen und damit den P-Kreislauf schließen. Für den nachhaltigen Umgang mit der Ressource P spielt neben dem Wissenstransfer in die landwirtschaftliche Praxis auch das gesellschaftliche Bewusstsein eine Rolle. So kann beispielsweise durch eine fleischarme, biologische Ernährung und die Vermeidung von Abfällen jeder Mensch einen Beitrag zu effizienteren P-Kreisläufen und niedrigeren Umweltwirkungen leisten.

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Erklärung

„Hiermit versichere ich, dass ich die vorliegende Dissertation selbstständig, ohne unerlaubte Hilfe Dritter angefertigt und andere als die in der Dissertation angegebenen Hilfsmittel nicht benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder unveröffentlichten Schriften entnommen sind, habe ich als solche kenntlich gemacht. Dritte waren an der inhaltlich-materiellen Erstellung der Dissertation nicht beteiligt; insbesondere habe ich hierfür nicht die Hilfe eines Promotionsberaters in Anspruch genommen. Kein Teil dieser Arbeit ist in einem anderen Promotions- oder Habilitationsverfahren verwendet worden.“

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Galmsbüll, den 23.7.2017

Magdalena Ohm