SYNTHESIS

Ecological consequences of conventional dairy farming

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Throughout this thesis, I have explored how dairy farm practices (earth) influence earthworms (worms) and their availability for predators such as meadow birds (birds). The underlying question was whether agricultural intensification affected earthworms in the same way as it did other organisms. Several previous studies (Edwards & Lofty 1982b, Muldowney et al. 2003, Atkinson et al. 2005, Curry et al. 2008) had suggested that today’s current dairy farming systems, rather than having negative impacts on earthworm populations had positive effects.

As populations of meadow birds, for which earthworms are a staple food, strongly declined throughout Western Europe (Busche 1994, Donald et al. 2001, Vickery et al. 2001, Donald et al. 2006, Kentie et al. 2016), the possibility remained open that agricultural intensification negatively affected earthworm availability for these predators. We indeed found this to be the case. In chapters 4, 5 and 6 we show that the impact of agricultural intensification is ecogroup-specific, with the surfacing detritivores being negatively affected, and the subsurface-living geophages not being affected (Postma-Blaauw et al. 2006, van Eekeren et al. 2008). Because of their surfacing behaviour, detritivores are of special importance for higher trophic levels as they then can be caught by visually hunting predators, e.g. Lapwings Vanellus vanellus (chapters 2 and 3).

Now, having the chance for extended synthesis, I would like to move a step further. Earthworms are not only prey for predators, but also provide crucial ecosystem services (Lavelle 1997, Lavelle et al. 2006). In this thesis we showed the negative effect of intensive agriculture on detritivorous earthworms, but did this also affect the important role of earthworms in the dairy farmland ecosystem?

Darwin (1881) already noticed the positive effect of earthworms on plant growth and later many studies have indeed showed this (Curry & Boyle 1987, Lavelle 1997, Scheu 2003, van Groenigen et al. 2014). Earthworms improve the structure and the aeration of the soil and increase decomposition rates by incorporating litter into the soil, ingesting and fragmenting it and by excreting nutrient-rich faeces, this all provides favourable conditions for microbial activity and eventually accelerates the release and uptake of nutrients for plants (Edwards & Fletcher 1988, Lavelle 1997). It is the detritivores, not the geophages, which perform this latter function (Postma-Blaauw et al. 2006) and thus play a crucial role in rotating the dairy farmland ecosystem wheel faster (Fig. 7.1). So, although total earthworm densities may increase under intensification, their positive role in the dairy farmland ecosystem might diminish as detritivores decline.

To study the effect of detritivore earthworms in differently managed grasslands, we collected data during two studies in 2013 and in 2015. In both studies, intact sods were collected in the field and placed in a greenhouse. This allowed us to measure ecological relevant responses, and by placing them under controlled conditions and adding or excluding earthworms and or manures, we studied the effect of
earthworms on sward productivity. In 2013 we examined, with the help of master student Siwen Tang, whether earthworms from one site can accelerate the production faster as they are adapted to their own system, the so called home-field advantage (Rashid et al. 2013). We compared sods from the extensively managed dairy farm of Murk Nijdam in Wommels, Fryslân with sods from a naturally grazed grassland in the Oostvaardersplassen, Flevoland. Native earthworms and dung were exchanged with earthworms and dung from the other site and productivity of the sward was measured.

We chose to use sods from the Oostvaardersplassen as it is one of the few natural grasslands in The Netherlands that is grazed throughout the year. Furthermore, it is an ecological interesting area as this very young area (it is located in a polder that was reclaimed from a freshwater lake in 1968) and is home to a population of 4555 (2016 count) freely roaming large herbivores (Heck Cattle *Bos taurus*, Konik Horses *Equus ferus caballus* and Red Deer *Cervus elaphus*) in an area of less than 1600 ha of grassland (Cornelissen 2017). Compared with conventional dairy farming, the number of large grazers per hectares is 1.5 times higher and for organic dairy farming it is even 3 times higher (Fig. 7.2). Furthermore, large flocks of 1000s to 10,000s of geese (Greylag Goose *Anser anser*, Barnacle Goose *Branta leucopsis* and White-fronted Goose *Anser albifrons*) also use this area for grazing. The primary productivity of this grassland must be high to support such high numbers of herbi-

![Figure 7.1](image-url)

**Figure 7.1**: Graphical illustration of how dairy farmland ecosystem is driven by the interaction between earthworms that process cattle dung into nutrients for grass which is grazed by cows which then produce dung again. Earthworms (especially detritivores) play a crucial role in rotating this wheel faster as they accelerate the step between dung and grass.
vores without any supplementary feeding or intervention. Earthworms might thus play a crucial role in this system which can give valuable insights for dairy farming systems.

The productivity of an ecosystem is highly variable and is defined by multiple factors, both biotic and abiotic (Bardgett 2005). Previous studies already showed significant differences on soil productivity depending on the land historical use (Olff et al. 1994). The Oostvaardersplassen is much younger than the centuries old marine clay landscape where the farm of Murk Nijdam is situated. As this might influence the results of this experiment, in 2015 with the help of two master students, Eduard Mas and Aaron te Winkel, we conducted a similar experiment as in 2013, but now with sods only from Flevoland close to the Oostvaardersplassen. This time, the sward production with different earthworm and/or dung treatments of the Oostvaardersplassen was compared with grasslands from the biodynamic dairy farm ‘Zonnehoeve’ in Zeewolde and from the conventional intensive used dairy farm of Jeroen van Maanen next to the Zonnehoeve. In this experiment only native earthworms were used.

For this synthesis, we only selected from both experiments those sods that had native earthworms and or dung and sods that received neither earthworms nor dung (control), in total thus four treatments. Unfortunately, we ended up with only three sods per treatment per location, which is too low to find significant differences, but might give interesting patterns.

**Figure 7.2:** Grazing pressure in terms of number of large grazers per hectare for organic and conventional dairy farming in The Netherlands and for the Oostvaardersplassen. Grazing pressure for the dairy farms is calculated by dividing the total number of cows with the total area of grassland from data obtained from CBS.
Methodological intermezzo

Study sites
Two datasets from 2013 and 2015 are used. In 2013 we compared a natural grassland with an extensive managed dairy farm. The natural grassland is located in the Oostvaardersplassen nature reserve (N52°25’11; E5°21’5). In this area there is a part with open water and reed beds (3600 ha) and a drained, dry area, consisting mainly of short-grazed grassland (1600 ha). It was originally designated for industrial and agricultural use before the surprise emergence of several endangered breeding birds in the wettest part, after it was decided that it became a nature reserve. Since then three populations of large grazers were introduced to the area: 35 Heck Cattle in 1983, 27 Konik Horses in 1984 and 54 Red Deer in 1992–93. The number of herbivores are not controlled by culling, no supplementary feeding is given during winter and no management intervention is implemented to maintain vegetation. This management resulted in an enormous increase of large grazers. In 2016 180 Heck Cattle, 975 Konik Horses and 3400 Red Deer were counted. The area of short grazed grassland also increased at the expense of shrubs and trees (Cornelissen et al. 2014). The grassland is dominated by Lolium perenne, Poa trivialis and Trifolium repens.

The other grassland in 2013 was located at Murk Nijdam’s dairy farm in Wommels, Fryslân (N53°5’30; E5°33’51). This grassland is fertilized once a year at the end of March by spreading farmyard manure on the surface. Mowing occurs in June, after which grazing occurs until October/November. The grassland has a diverse plant community including Agrostis stolonifera, Alopecurus geniculatus, Cardamine pratensis, Lolium perenne, Poa trivialis, Ranunculus repens, Rumex acetosa and Taraxum officinale.

In 2015, the same grassland in the Oostvaardersplassen was compared to a biodynamic and a conventional dairy farm close to the Oostvaardersplassen. The biodynamic grassland was located 13 km south of the Oostvaardersplassen (N52°18’22; E5°22’55) at the mixed-farming biodynamic company ‘De Zonnehoeve’. The fields used for this experiment are part of a crop-rotation regime, with cereals and legumes alternated with grass-clover every three years. At the time of our sampling, the grasslands were two years old. The dominant species were Lolium perenne, Trifolium repens and Trifolium pratense. From spring to autumn, dairy cattle grazed on the grasslands and fertilized the fields. No other form of fertilizer was used, and neither were antibiotics used to cure sick cows. The conventional grassland was located 1.3 km to the south of the biodynamic grassland (N52°17’38; E5°22’44) and is part of the intensive dairy farm of Jeroen van Maanen. This grassland was also part of a rotation regime with tulips and during sampling this field was two years old. This grassland was a monoculture of Lolium perenne which are
not grazed by cattle, but is mown 4–5 times a year, from which the harvest is fed to
the cows in the stable. The grasslands are fertilized with slurry manure and artifi-
cial fertilizer in February and after each mowing.

We also measured soil organic matter content as it is an important factor in the
nutrient cycling and the distribution of earthworms (Riley et al. 2008, Crittenden et
al. 2015). We randomly took 15 soil samples of approximately 5 g from upper 10
cm of the soil per location. We also collected 1 sample per site from 10 – 20 cm
depth. These soil samples were first mixed thoroughly before 1 g was oven-dried at
60 °C for 24 h. After drying, the samples were weighed again to calculate soil mois-
ture content as a percentage of weight loss and then burned in a muffle furnace at
440 °C for 4 hours. The cooled samples were weighed again and the percentage
organic matter was calculated based on the weight difference. These measurements
were only performed in 2015.

The sods were collected by using a corer with a diameter of 19 cm that was
pushed slowly into the soil to a depth of 10 cm (Photo 7.1A). Then the corer with
the sod was carefully excavated and the sod was placed inside a fitting PVC ring
within a square plastic basin (Photo 7.1B). All sods were collected on two days in
October 2013 and over 5 days in October 2015.

**Greenhouse experiment**

The sods were grown in a greenhouse at the University of Groningen. The tempera-
ture was kept at approximately 20 °C and water was given daily. Before the treat-
ments were applied to the sods, all earthworms inside the sods were removed. We
did this by first watering the sods and then sending electrical pulses through it for
10 minutes. Earthworms were chased out of the sod and could be collected easily. In
this way, the sod remained intact and did not had to be destructed, which would
influence the microbial community in the sod. After all sods were treated with elec-
tricity, we clipped the vegetation to 3 cm height and applied earthworms or dung
according the treatment schedule. In 2013, the worm treatments received 10
*Lumbricus rubellus* earthworms (total biomass on average 4.36 grams) at the start
of the experiment and another 5 (total biomass on average 2.18 grams) 40 days
later to replace any escaped earthworms. In 2015, the worm treatments received
only at the beginning 13–16 (approximately 3 grams) *Lumbricus rubellus* earth-
worms. We chose to use only *Lumbricus rubellus*, as it is a detritivore and therefore
feeds on organic material which is pulled into the soil. Furthermore, this species
was found on every location. Each worm-sod received earthworms from its own
location to avoid detrimental effects of changing habitat type.

In 2015 the application of dung was standardized by applying Pokon™ organic
dried dung pellets to all dung treatments. These pellets are made of a mixture of
chicken and cattle dung and without any other additives. Before applying to the
sods, the pellets were processed by moistening it with water to create slurry and to allow microbial growth. This slurry was left in the greenhouse and kept moist for a week before 15 g was applied to the dung-sods. The dung and worm-sods received the same amounts of earthworms and dung as the worm and dung treatments. The control received nothing.

After a habituation period of one month, the experiment in 2013 started on 12 December and lasted 13 weeks until 13 March 2014. The sods were clipped at 13 January and 13 February. Frequent clipping was needed to maintain growth. In 2015, the experiment started on 2 November and lasted 10 weeks until 11 January 2016. The sods were clipped twice at 26 November and 21 December. During a clipping event, all sods were clipped at 3 cm height and the harvest was dried in a stove at 70 °C for 24 hours after it was weighed to the nearest 0.001 gram. The growth rate was determined by dividing the total dry weight of a sod by the number of days since the previous clipping.

Statistics
The two datasets were analysed separately. For both years, the data of the last clipping was used and analysed with a Two-way ANOVA in R (R Development Core Team 2017). Sward production was entered as the response variable, with an interaction between location and treatment as explanatory variables. The logarithm of sward production was used for the 2015 dataset. A stepwise backward procedure was followed to find the Minimal Adequate Model (MAM) in which terms were deleted in order of decreasing $P$-value (Quinn & Keough 2005). Soil moisture and soil organic matter data were analysed with a General Linear Model using a quasi-binomial family structure as proportions were used.
**Results & discussion of these exploratory experiments**

In the comparison between the natural grassland of the Oostvaardersplassen and the extensively managed dairy farmland of Murk Nijdam in 2013, there was no significant effect of treatment on biomass production (Two-way ANOVA; $F_{3,19} = 2.828$, $P = 0.067$), but production was almost twice as high in the natural sods than in the dairy farmland sods (Two-way ANOVA; $F_{1,22} = 20.982$, $P < 0.001$). The interaction between location and treatment was not significant (Two-way ANOVA; $F_{3,16} = 2.112$, $P = 0.139$) and there were also no statistical differences between treatments within locations (Fig. 7.3). The treatment earthworms plus dung increased the production with 70% for the extensive dairy farm sods and 40% for the natural sods.

In 2015, the conventional intensive dairy farm sods showed the lowest biomass production (Two-way ANOVA; $F_{2,30} = 4.124$, $P = 0.026$). Treatment had an overall

![Figure 7.3](image)

**Figure 7.3:** Biomass production in milligram dry weight per day of grassland sods and receiving either only earthworms, only dung, dung and earthworms, or nothing (control). In 2013 extensive corresponds to the extensively managed dairy farm of Murk Nijdam in Wommels, Friesland and natural is the Oostvaardersplassen, Flevoland. In 2015, all locations were in Flevoland. Each bar represents the average growth rate of three sods with error bars representing SE.
significant effect (Two-way ANOVA; $F_{3,30} = 6.310, P = 0.002$), with highest production in sods with earthworms and dung. The interaction between location and treatment was not significant (Two-way ANOVA; $F_{6,24} = 0.467, P = 0.826$) and there were also no statistical differences between treatments within locations (Fig. 7.3). Nevertheless, production in the earthworms plus dung treatment was 47%, 39% and 98% higher for conventional, biodynamic and natural sods respectively.

Compared to the two grasslands used for dairy farming, the Oostvaardersplassen grassland had a threefold higher soil organic matter content in the upper 10 cm of the soil compared to the two dairy farm grasslands (GLM; $F_{2,42} = 597.08, P < 0.001$, Fig. 7.4A). This effect disappeared at lower soil layers (GLM; $F_{2,6} = 1.601, P = 0.277$, Fig. 7.4A). The high soil organic matter content is also reflected in 150% higher soil moisture content in the Oostvaardersplassen (GLM; $F_{2,42} = 169.64, P < 0.001$, Fig. 7.4B).

**Figure 7.4:** (A) Soil organic matter content of the Flevoland grasslands in 2015. (B) Percentage of moisture in the top 10 cm of the soil. 15 samples were taken at 0 – 10 cm depth and 3 at 10 – 20 cm depth. Error bars represent SD.
The method of collecting and using intact sods showed that the functioning of a grassland can be measured experimentally while maintaining ecological relevant functions. With only 3 repeats per treatment the statistical power of the test was rather low, but even with such low sample sizes, the experiment in 2015 showed a significant overall effect of treatment. Furthermore, in both years, there was a clear trend of increasing production in sods with earthworms and dung. However, the big disadvantage of this method is that it is unknown how many earthworms were in the sod. The best method of extracting earthworms from the sods without destructing it and affecting other organisms, is the use of electricity. However, it was uncertain how successful this method would be, as probably not all electrically paralysed earthworms would be able to crawl out the sod (Caja et al. 2008, Pelosi et al. 2009). When in 2013 the sods were hand-sorted after the experiment, earthworms were still found in most of the sods, including the non-earthworm treatments. Although these were mainly geophagous A. caliginosa, it still could have blurred the pattern. To eliminate this in the clearly necessary, and clearly promising, future studies, sods could be collected in periods when earthworm activity is low, i.e. when they have migrated to deeper soil layers during drought or frost.

The difference in biomass production between the natural grassland of the Oostvaardersplassen and the two dairy grasslands in 2015 was striking. This difference is likely to be a reflection of the soil organic matter and soil moisture values in the top 10 cm of the soil which are for the Oostvaardersplassen extremely high. This ‘peat-on-clay’ soil type is formed by high input of organic material and low soil disturbance. The area is now grassland, but was first dominated by reed and shrubs of mainly Black Elderberry Sambucus nigra (Cornelissen et al. 2014), which resulted in high input of litter. No earthworms occurred in the freshly reclaimed soil of Flevoland, and after a few years litter accumulated at the surface and formed a thick slowly decomposing layer (Hoogerkamp et al. 1983). Soon after earthworms were introduced, soil fertility improved as litter was incorporated into the soil (Hoogerkamp et al. 1983). The same occurred in New Zealand, where fast growing European grasses also created a thick mat of litter, which quickly was incorporated into the soil after European earthworms were introduced (Stockdill 1982).

Since the Oostvaardersplassen became a nature reserve in 1974 (but probably already since their reclamation in 1968), the soil has never been tilled. This must have helped the maintenance or build-up of soil organic matter. Soil organic matter is important as it provides a primary food source for soil biota. When micro-organisms only need carbon to meet their energy needs (organic matter with low C:N ratio), the excess nitrogen is released in a form that is available to plants (mineralization), this is a key process for an ecosystem because it determines the productivity of plants (Bardgett 2005). The addition of earthworms to this system, animals which fragment and mix organic input with the soil, accelerated the decomposition
by micro-organisms and thus quicker availability of nutrients for plants. The high soil organic matter content of the Oostvaardersplassen sods enhances the cycling of nutrients leading to very high productivity when the crop of herb-rich grass is continuously harvested.

The experiments showed that earthworms play an important role, but the conditions of the soil are of paramount importance as this will influence earthworm populations. Undisturbed permanent grasslands contain much higher number of earthworms than fields that are regularly disturbed by tillage (Evans & Guild 1948, Parmelee et al. 1990, Paoletti 1999). Especially detritivorous earthworms are negatively affected (Nuutinen 1992, Ernst & Emmerling 2009, Crittenden et al. 2014, Pelosi et al. 2014a). Edwards & Lofty (1982a) also found a negative effect of tillage on the deep-burrowing species such as Lumbricus terrestris (a detritivore), but not on shallow working species such as Aporrectodea caliginosa (a geophage).

Scaling up

As we have shown in chapter 5, dairy farmland fertilized with slurry manure only has much lower densities of detritivores than farmland fertilized with farmyard manure. Although the lower quality of the manure for these earthworms compared to farmyard manure is likely to be involved (Edwards & Lofty 1982b, De Goede et al. 2003, van Eekeren et al. 2009, Bertrand et al. 2015), these slurry fertilized fields were also more often disturbed than the farmyard fertilized fields. Fertilizing by slit-injection, reseeding and ploughing are all practices that occur regularly in intensive managed dairy farmland. As already mentioned in the introduction of this thesis, grasslands that have never, or at least not for decades, experienced these disturbing farming practices are rare. In the province of Fryslân, only grasslands managed by nature organizations such as it Fryske Gea, Staatsbosbeheer and Natuurmonumenten now belong to these rare undisturbed soils, but comprise only 3.5% of the total grassland area (Fig. 7.5).

These farming practices are negatively acting on two essential factors for earthworms: water and food. The physical damage of soil disturbance not only destroys earthworm burrows, but also breaks down soil aggregates and fungal hyphae that are of importance in the water binding capacity of a soil (Beare et al. 1997, Franzluebbers 2002, Pulleman et al. 2003, Bronick & Lal 2005). Parmelee et al. (1990) showed that fungal biomass in untilled fields were higher than in fields that were regularly tilled and during a drought event earthworms populations were more resilient in untilled than in tilled fields. Drought events particularly harm detritivore populations (Eggleton et al. 2009), probably because geophages go into diapause by curling into a small knotted ball in the soil and form a protective coat-
ing of secreted mucus (El-Duweini & Ghabbour 1968, Edwards & Bohlen 1996). Experimentally measured drought tolerances for the detritivorous *Lumbricus rubellus* and the geophagous *Aporrectodea caliginosa* did not show differences between these species (A. Ooms & M.P. Berg, pers. comm.). Detritivores can increase the moisture content of the soil by collecting litter in the soil and at the surface, geophages, on the other hand, induce water runoff by their burrowing behavior (Ernst *et al.* 2009).

The negative effect of soil disturbance on earthworm food resources is mainly caused by declining amounts of surface litter, which is again detrimental for detritivores (Nuutinen 1992). Eventually, this will also lead to a decline in soil organic matter which is also negative for geophages which feed on it (Parmelee *et al.* 1990, Riley *et al.* 2008, Crittenden *et al.* 2015). So any soil disturbance is negative for earthworms, but more importantly, it is affecting the whole dairy farmland ecosystem as specifically detritivores are affected. Tillage changes the whole detritus food

![Figure 7.5](image-url)
web by favouring bacteria and potworms (Enchytraeidae) at the expense of fungi and earthworms (Hendrix et al. 1986, Wardle 1995, Wardle et al. 2004). Injection of slurry manure in dairy farmland probably has the same effect and by increasing bacterial biomass it promotes food conditions for geophages, but not for detritivores which generally prefer fungal degraded litter (chapter 5). This might be the reason why fungicides are also toxic to detritivores (Pelosi et al. 2014b).

The intensive land use of conventional dairy farming, will push aside the beneficial detritivores, and thus destroy the accelerating step in the dairy farmland ecosystem wheel between manure and grass production (Fig. 7.1). The use of inorganic fertilizer can take-over this step and indeed, increasing use of N inorganic fertilizer will decrease the positive effect of earthworms (van Eekeren et al. 2009, van Groenigen et al. 2014). The low biomass production in the sods from the conventional grassland, might be a result of this dependence on inorganic fertilizers. The loss of detritivores can lead to a deterioration of the soil structure as high abundances of solely geophages can result in sticky lumps that forms cement-like plates on the surface, a phenomenon that occurred in intensively used fields in Flevoland (Ester & van Rozen 2002).

Back-tracking the thesis

In chapter 1 we gave an overview of the ecological impact of agricultural intensification in Dutch dairy farmland and asked ourselves whether the availability of earthworms is negatively affected by agricultural intensification as it does not seem to harm earthworm abundances, in contrast to other organisms. For meadow birds, however, it is not about abundances, but about the detection and availability of earthworms (Zwarts & Wanink 1993). Therefore, we needed a method to measure earthworm availability properly. Taking soil samples will only give an estimation of earthworm availability, when taking the bill length into account, for tactile hunting meadow birds such as Black-tailed Godwit Limosa limosa. Visually hunting meadow birds such as Lapwings Vanellus vanellus, rely on surfacing earthworms and taking soil samples alone will thus give a biased estimation of earthworm availability.

In chapter 2 we described how surfacing earthworms could be counted by using a simple cart that is easy to perform and replicable. We have shown that only a small fraction of the total earthworms surface during the night and earthworm abundance does not predict the numbers of surfacing earthworms. Therefore taking soil samples will give no, or at least a biased, estimate of earthworm availability for a visually hunting meadow bird.

The method to count earthworms by using a cart was tested in a study to unravel the foraging strategy of Ruff Philomachus pugnax (chapter 3). With indoor feeding
experiments, we showed that Ruffs mainly use visual cues to detect earthworms. Although Ruffs only feed during the day, intake rates were strongly correlated with number of surfacing earthworms at night. This study illustrated that using the method described in chapter 2 gives indeed a good measure of earthworm availability for visual hunting meadow birds.

After we had developed a good method to measure earthworm availability we switched our focus to earthworms to understand what determines the surfacing behaviour and thus earthworm availability. In chapter 4 we studied the effect of surface-applied farmyard manure on the availability of earthworms for meadow birds. This traditional way of fertilizing is generally thought to promote food conditions for meadow birds, however, it reduces the availability of earthworms for meadow birds in the short term. From an earthworm view, this is not surprising, as it surface to collect food. To avoid being food itself, it remains in the soil when it is satiated.

The long-term effect of fertilizing with different types of manure was studied in chapter 5, where earthworms were collected on differently managed dairy farmland. This showed, that fertilizing with farmyard manure will benefit detritivorous earthworms, and thus it will promote food conditions for meadow birds. However, perhaps the most important factor determining earthworm availability for meadow birds, is soil moisture. In chapter 6 we showed that not only the surfacing behaviour of earthworms stops when the soil desiccates, but also the penetrability of the soil decreases which is detrimental for tactile feeding meadow birds.

Final words: ‘Oil’ versus ‘worms’

The main question of this thesis was: How does dairy farm management affects earthworms and their availability for meadow birds? As I have shown throughout this thesis, detritivore earthworms are key organisms in the dairy farmland ecosystem, but they are also susceptible to agricultural intensification in several different ways. Food conditions for earthworm predators will deteriorate under intensification, not only because detritivores decline, but also because earthworms become less available due to desiccating conditions making the soil harder and earthworms less active (chapter 6). Furthermore, larger-sized earthworms are most severely affected (Wardle 1995, Postma-Blaauw et al. 2010, Tsiafouli et al. 2015) and therefore predators have to consume more smaller-sized earthworms to meet energy requirements (Box A).

To promote detritivorous earthworms, soil disturbance should be minimized and (coarse, i.e. high C:N ratio) organic material should be applied on the surface. The positive effect of earthworms on plant productivity is indeed larger when more
litter is applied (van Groenigen et al. 2014). These actions not only promote detritivores, but could also be the beginning of a self-reinforcing system where the input of organic material promotes detritivores and improves soil structure and soil organic matter cycling including the beneficial interactions with micro-organisms (Fig. 7.6) (Bertrand et al. 2015, Bender et al. 2016). In turn, soil moisture content increases, which keeps earthworms active and available to meadow birds and other predators, but it will also stimulate sward production (Fig. 7.5). The energy driving this system does not rely on oil fuelling the machines of the farmer, but on the green energy of some humble creatures living belowground.

Earthworms are not only prey for endangered species or agents for improving agricultural production, they are a fascinating group of organisms that is part of a complex food web and thus should be studied like any other organisms in a natural ecosystem. We believe that looking with an ecological, rather than an agricultural, perspective at the dairy farm ecosystem, will yield valuable insights to help the development of much more environmentally friendly dairy farming and the conservation of meadow birds and other farmland species (Tsiafouli et al. 2015, Bender et al. 2016, Erisman et al. 2016).

**Figure 7.6:** The dairy farmland ecosystem flywheel including the factors that boost rotating this wheel (soil organic matter and soil moisture) and will eventually also promote earthworm availability for other organisms.