MSc thesis

Introducing poultry in orchards to restore ecological relationships in agricultural production systems

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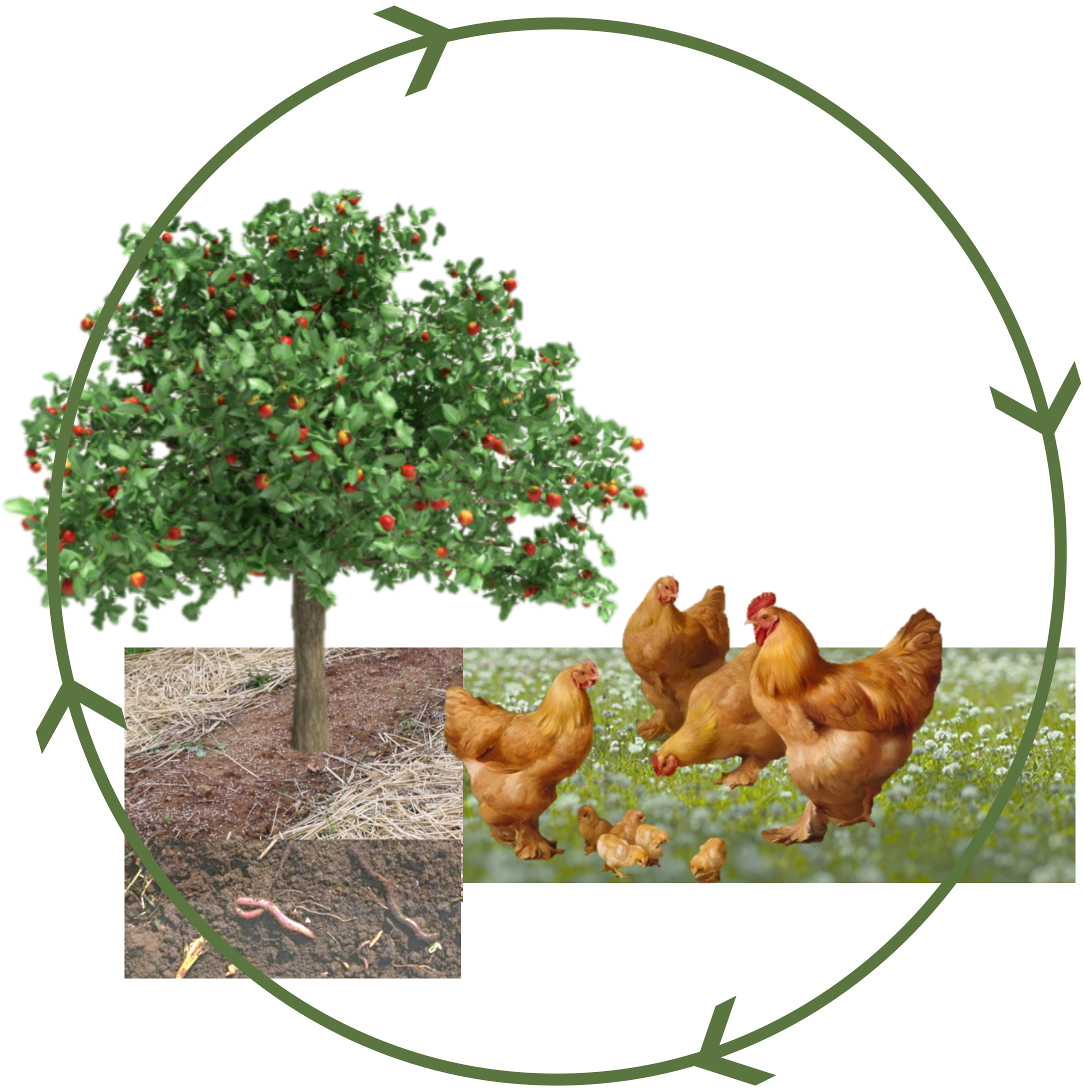

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Summary

Integrating poultry in orchards contributes to the re-establishment of natural living environments for chickens and thereby potentially enhances symbiotic relationships between poultry and orchards. The main objective in this study was therefore to evaluate system performance of redesigning poultry rearing, which included rearing poultry in orchards using mobile housing, altering diet, introducing maternal care and using dual-purpose poultry breeds. Key beneficial and adverse ecological relationships resulting from this practice were identified, comprising fertilization of the plant-soil system, foraging on macrofauna and animal behaviour. It was found that mobile housing results in a more even distribution of manure on the pasture (115 kg N ha^{-1} $year^{-1}$) at a density of 500 chickens ha^{-1}. Also, a lower vegetation pressure was found due to mobile housing compared to static housing systems. Furthermore, it was shown that due to forage opportunities in the orchard, the share of concentrates in the diet of hybrid laying chickens could be lowered to 50% while maintaining a similar laying percentage (84%) compared to hybrid laying hens in Dutch organic systems (85%). Feed conversion ratio was similar, 2.42 kg feed kg egg^{-1} compared to 2.30 kg feed kg egg^{-1}, suggesting higher energy requirements of chickens in orchards. The current type of management was proven to contribute to natural behaviour patterns with up to 46% of time spent on walking and foraging compared to deep litter (23%) and battery cage systems (1.3%). This behavioural pattern was adopted at an early life-stage when chicks where reared by mother hens in the orchard (43%) compared to chicks reared without mother hens in a stable (6%). Due to the cost-reducing practices resulting from the redesigned rearing system, a profitable model could be developed for the use of purebred dual-purpose breeds. However, without price premiums (i.e. 30 ct egg^{-1} rather than 25 ct egg^{-1} based on direct sales) the use dual-purpose breeds in orchards with on-farm propagation was 20% lower compared to the use of hybrid breeds integrated in orchards. This was mainly due to a lower laying percentage of dual-purpose breeds (65%) compared to hybrid breeds (84%). Nevertheless, it was concluded that the decision towards adopting purebred dual-purpose breeds in orchards with on-farm propagation is financially viable and practically feasible, especially for small-scale extensive farming systems aiming to increase diversity of products. Further research could focus on reducing predation risk of chickens, which was considered the main bottleneck in adoption of the studied system.

1. Introduction

1.2. Restoring ecological relationships in farming systems

The industrial era represents increasingly specialized, simplified and technological innovation dependent farming systems. Labour efficiency, yield increase and rely on control management were the principle objectives of modern farming systems to attain production, which were vigorously adopted to crop and animal production during the green revolution. The disconnection between the once interdependent plant and animal realms in agriculture resulted in efficient and highly productive farms, but it has been argued that this has led to less stable and resilient farming systems (Kirschenman, 2012; ten Napel et al., 2006). A high density of animals in artificial environments has resulted in animal welfare issues, thereby causing high impacts of improper management (Tilman et al., 2002) and large-scale monocropping practices in arable farming systems led to pest, weed and disease problems (ten Napel et al., 2006).

In response, alternative ways of practicing agriculture have been developed that aim to restore ecological relationships and to increase the use of natural resources in an on-farm closed cycle (Luttikholt, 2007). To achieve these objectives, understanding of ecological relationships and processes in farming systems is needed. Currently, farming systems are developing that reintegrate animal and plant production systems (Hermansen et al., 2004). One of such systems is the integration of poultry in orchards. Poultry in orchards contribute to the re-establishment of natural living environments for chickens and thereby potentially enhance symbiotic relationships between poultry and orchards (van Veluw, 1994). As a result, inputs to the system to control production can be minimized (ten Napel et al., 2006; Hermansen et al., 2004).

Over the last decades new rearing systems for chickens have been developed especially focussing on the improvement of animal welfare (Mollenhorst et al., 2005). However, since generally three different perspectives on the judgement of animal welfare exist, there are debates about what rearing system supports animal welfare (Fraser, 2003). Animal welfare can be understood as (1) promoting good biological functioning in the sense of health, growth and reproduction, (2) reducing animal suffering and (3) supporting living natural lives (Fraser, 2003). Within the organic sector, the focus is mainly on supporting natural lives, thereby including the possibility to perform natural behaviours, feed adapted to the animal's physiology and a natural living environment (Lund, 2006). This perspective can be understood from the underlying philosophy of organic agriculture (Luttikholt, 2007). The practice of introducing chickens in orchards converges with this perspective, because it has the potential to support living natural lives of chickens.

1.3. Potential benefits of poultry in orchard systems

However, the practice of introducing chickens in orchards has not gained much attention over the last few decades, but may provide solutions to challenges current practices face, especially those following organic standards. Therefore, this study focused on the main practical consequences and opportunities for the design of the integration of poultry in orchards, including housing conditions, feed provisioning, introduction of maternal care and use of dual-purpose breeds. These aspects were integrated on a farm and quantitatively analysed on their performance regarding fertilization, feed use efficiency, animal behaviour and output production. Thereafter, these results were evaluated using existing knowledge on current chicken rearing systems. As an outcome of this study, the main ecological relationships that shape the system of poultry within orchards were identified to further develop this practice.

1.3.1. Housing

Current chicken housing in regular rearing systems comprises static buildings. In organic agriculture a shift towards a more natural living habitat is aimed for (Lund, 2006) and an outdoor area of 4 m^2 per chicken is provided (SKAL, 2016). However, several studies have identified that chickens are not spreading homogeneously throughout the outdoor area and mainly concentrate close to the buildings (Rivera-Ferre et al., 2006). This often results in high vegetation pressure and therefore high nutrient leaching potential, especially nitrogen, in the areas close to the buildings (Rivera-Ferre et al., 2006). In orchards mobile housing systems could be used, thereby supporting the use of the outdoor area. This may lead to a reduction in vegetation damage and a more even distribution of manure compared to static housing systems, thereby resulting in a lower nutrient leaching potential.

1.3.2. Feed

In regular chicken rearing systems diets include nearly 100% concentrates and within such systems chickens are supplied wheat grains only to stimulate forage behaviour (Bestman et al., 2011). However, because of nutritious foraging opportunities already present in the orchard, chickens may gain a larger share of proteins for their dietary needs by feeding on macrofauna (e.g. insects, larvae and earthworms) and vegetation compared to regular chicken rearing systems (Walker & Gordon, 2003; Hermansen et al., 2004).

The share of concentrates in diets could, therefore, possibly be lowered when integrating chickens in orchards (Hughes & Dun, 1983). Not only this provides an effective way for reducing feed costs, insects may become even more available to chickens after tree strip cultivation, a recurrent procedure for uprooting weeds and aerating the soil around the fruit trees using a Tournasol. As a result, chickens may require even less from the provided feed and feed conversion ratio, expressed as kg feed/kg egg, can be reduced.

Introducing chickens in orchards might also be a solution for the EU legislative implementation end 2017 when organic chicken diets should consist of 100% organic ingredients (van Krimpen et al, 2015a). Currently, 5% of chicken feed comes from conventional origin because otherwise the essential amino acid methionine, being the first limiting amino acid (van Krimpen et al., 2015b), is lacking in the diet of organic chickens (van Krimpen et al., 2015a). A reduced methionine content in chickens' diets may result in lower laying performance (van Krimpen et al., 2015b). However, it has been reported that insects may contribute to a large extent to the methionine requirements (Wagenaar & Visser, 2006) and integrating chickens in an orchard may, therefore, resolve this issue.

1.3.3. Animal behaviour

The integration of chickens in orchards is assumed to provide a more natural living condition for chickens, but this assumption has thus far not been thoroughly tested according to animal behaviour patterns. Earlier studies have found that increased feather pecking incidence, an indicator for the association with stress (El-Lethey et al., 2000), was observed in battery cage systems compared to deep litter stables, caused by a lack of substrate for foraging and dustbathing (Mollenhorst et al., 2005; Blokhuis, 1986). Foraging and comforting behaviours that require more space, like dustbathing, were significantly less identified in battery cage systems compared to deep litter stables (Mollenhorst et al., 2005). On top of that, smaller flocks of chickens that are kept in an outdoor run introduced at a young age together with cockerels were found to express even lower feather pecking damage (Bestman & Wagenaar, 2003). A higher percentage of cover in a chicken run was found to increase outdoor run usage (Bestman et al., 2014), resulting in a high potential for improving poultry welfare in orchard systems, where fruit trees are abundant. Scoring animal behaviour can be an appropriate tool to assess whether a more natural behaviour pattern is actually observed. As a baseline, the behaviour pattern of the common ancestor of the domestic chicken red junglefowl (*Gallus gallu*s L.) can be compared to the observed patterns in the domestic chicken flock (Dawkins, 1989).

1.3.4. Maternal care

Another practice that supports natural living conditions for chickens is the introduction of maternal care. Influences of maternal care on chicks have been intensively studied and results indicate that the presence of mother hens during rearing of chicks has many benefits relating to the welfare of chicks (Bestman & Wagenaar, 2003; Rodenburg et al., 2009ab; Edgar et al., 2016). Besides, part of being a hen includes providing maternal care for chicks and withholding hens from being a parent can be seen as reducing animal welfare (Edgar et al., 2016).

Considering the welfare of chicks, it was found that the presence of a mother hen during rearing improves foraging and social behaviour (Rodenburg et al., 2009ab). Also, feather pecking and fearfulness of chicks were both reduced. In the study of Riber et al. (2007) it was found that chicks that were raised by a foster-mother hen performed more ground pecking, used perches more at a younger age and had a lower mortality compared to chicks grown up without a foster-mother hen. Conclusively, as Rodenburg et al. (2009ab) summarizes, positive effects of brooding should be translated for application in commercial systems. Their view is supported by Edgar et al. (2016), though it has been suggested that the positive cues should be *artificially* integrated since the biological way of rearing chicks is commercially not feasible. However, to date there has been no research done on rearing chicks by mother hens following the biological approach of maternal care in an orchard system. From a commercial perspective, this could be a more interesting model for rearing chicks by mother hens.

1.3.5. Dual-purpose breeds

Because of the increasing demand for animal welfare in extensive production systems, new traits continue to enter the selection matrix. Not only breeding for specific traits, but also different selection methods for breeding are used. For instance, group selection for a lower mortality rate has successfully shown to reduce propensity to develop feather pecking (Rodenburg et al., 2009ab). However, most developments aim to genetically improve the typical 4-line cross hybrid chickens. A more fundamental approach to improve animal welfare on the genetic level can be to reverse the differentiation of hybrids by developing purebred dual-purpose breeds (Damme & Ristic, 2003).

Dual-purpose breeds may be a solution for the redundancy of male chicks in hybrid dependent egg production systems (Nauta et al., 2003; Ellendorf et al., 2003) and for the fast-growing broilers in the meat industry with related physiological issues (Bessei, 2006). Currently, Stichting Biologische Fokkerij is developing a purebred dual-purpose poultry breed meant for both egg laying and meat production (Nauta et al., 2011) in response to the dependency of organic poultry systems on the conventional breeding supply. As Nauta et al. (2003, p.5) mentioned: *"Interest in breeding has increased because organic agriculture is expanding and as yet too little attention has been paid to the development of specific organic breeding programmes and associated legislation."* However, there is little knowledge on the practical implementation of dual-purpose breeds in production systems and their financial consequences. Within the report of Leenstra et al. (2014) a comparison on egg production with model calculations was made between conventional and organic production systems with hybrid layer hens, heavy layer hens and dual-purpose breeds. It was shown that dual-purpose breeds have higher feed costs for similar egg and meat production and the ecological food print is therefore larger. Yet, integration of chickens in orchards may provide effective cost-reducing ways to rear dual-purpose chickens, thereby providing a more ethical responsive way to rear chickens.

1.4. Research objectives, study location and hypotheses

Although for many of the potentially beneficial aspects regarding housing, feeding, maternal care and use of dual-purpose breeds it has been suggested they should be applied in practice (Rodenburg et al., 2004; Walker & Gordon, 2003; Hughes & Dun, 1983; Edgar et al., 2016; Nauta et al., 2011), to date there has been no study carried out on integrating them in a practical design. Consequently, how the combined practices affect ecological relationships within the poultry-orchard system remains unknown. Yet, using these relationships can contribute to on-farm closed cycles and reduce inputs to the system, while maintaining production levels and economic viability (ten Napel et al., 2006). Identifying relationships that can be beneficially influenced from a management perspective and that decrease use of inputs though sustain productivity may support the adoption of this type of practice. So, in this study *the main objective was to evaluate system performance of redesigning poultry rearing in orchards and identify key beneficial and adverse ecological relationships resulting from this practice.*

Within this research project a farm was studied that has been practicing rearing of poultry in an orchard for several years. Urban farm 'Fruittuin van West', located in Amsterdam Nieuw-West, comprises 6 hectares with over 20 fruit varieties and includes 250 Lohman Brown laying hens. The chickens are housed in mobile chicken coops measuring 8 m^2 each that are relocated daily through the pasture rows in the orchard. The chicken coops are only meant for sleeping and feed and water is provided in the orchard.
Furthermore, the farmer feeds the chickens with a diet of 50% concentrates (laying pellets) and 50% spelt grains, rather than the common supplied diet in regular chicken rearing systems of nearly 100% concentrates (Bestman et al., 2011). Tree strip cultivation, as explained before, is a recurrent practice on the farm.

For the present study the following sub objectives have been identified:

1. To quantify fertilization of the grass/clover swards by chicken manure as a result of using mobile chicken coops and to study trampling of vegetation.
2. To study laying performance, indicated by laying percentage and egg weight, of chickens in the orchard with the supplied diet and thereby indirectly determine the role of naturally provided protein-rich sourced forage opportunities by using tree strip cultivation.
3. To determine whether integration of poultry in orchards leads to more natural behaviour patterns compared to regular rearing systems.
4. To design a system for commercial implementation of rearing chicks by mother hens in an orchard and to determine the contribution of maternal care for the adoption of natural behaviour patterns by chicks.
5. To determine financial consequences for commercial integration of dual-purpose breeds in an orchard following the current type of management and applying the practice of maternal care.

These objectives have resulted in the following hypotheses:

1. Using mobile housing facilities of chickens results in an even distribution of manure throughout the orchard and leads to a reduced pressure on vegetation compared to static housing systems (Rivera-Ferre et al., 2006).
2. Feed conversion ratio of the imported feed to the system, expressed as kg imported feed/kg egg, was hypothesized to be lower in the 'Fruittuin van West' farm as a result of foraging on insects and vegetation. Due to foraging and tree strip cultivation, abundance of macrofauna in the soil within the fruit tree rows was hypothesized to be lower when chickens were present.
3. Chickens in the production system of 'Fruittuin van West' were hypothesized to exhibit a more similar natural behaviour pattern to the common ancestor of the domestic chicken red junglefowl (*Gallus gallus* L.) (Dawkins, 1989) compared to chickens in regular housing systems (i.e. battery cages and deep litter stables, Mollenhorst et al., 2005).
4. Chicks reared by mother hens in an orchard were hypothesized to sooner adopt a similar behaviour pattern to adult chickens in the orchard compared to chicks reared without a mother hen in the stable.
5. Regarding dual-purpose breeds, it was hypothesized that it is just as profitable to rear dual-purpose breeds in orchards by mother hens due to lower costs compared to hybrid breeds raised without mother hens.

2. Methods

2.1. Housing

For this study, measurements were taken following the current practice of chicken housing on the farm, as mentioned above. Three chicken coops (8 m^2 each) housing 250 birds in total were allocated to three separate rows next to each other in a fenced-off area of 0.5 ha on the farm (figure 1). The chicken coops were moved 4 m (i.e. one coop's length) per day through the rows throughout this area until the chicken coops had covered the whole area (figure 2). This would take about 8 weeks and, thereafter, all chickens were moved to another part of the orchard that was fenced-off.

Figure 1: Chicken coop in the orchard at Fruittuin van West

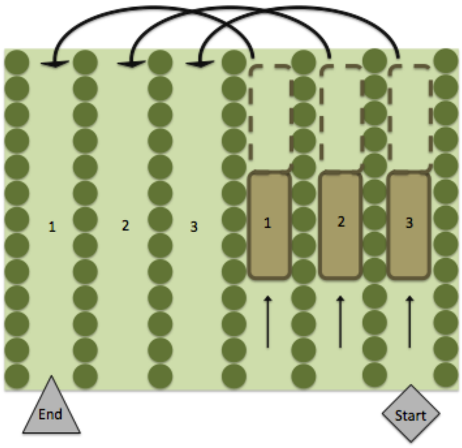

Figure 2: Schematic representation of relocation of mobile coops indicating starting position in the fenced-off location ('start') and end position before allocating chickens to the next fenced-off location ('end'). In reality, there are more rows between the start and end position. Chicken coops are indicated by the brown rectangles representing their number according to the observations. Every day the chicken coops are relocated 4 meters (i.e. one coop's length) (dashed lines) and at the end of a row chicken coops are relocated to new rows according to the figure.

The locations in which the chicken coops were allocated had no history of artificial or organic manure supply. For determination of manure distribution within one fenced-off area, all chickens were counted during five consecutive nights in their chicken coops. When chickens are on the perch at night, excreta will drop directly on the pasture, thereby contributing to fertilization. The fresh excreta was collected and weighed the next morning from each of the three chicken coops. The amount of manure was divided over the number of chickens in the concerning coop to get to an average of amount of excreta per chicken dropped on the pasture per night. This number was multiplied by the average total number of chickens per coop. Since every coop was replaced one coop's length (i.e. 4 m) every day through the rows in between the fruit trees, the chicken coop that was always closest to the final position in the particular area was denoted as ‘first’ and the chicken coop that followed was denoted as ‘second’. The chicken coop that was always closest to the starting position was denoted as ‘third’ (figure 2). Nitrogen content in chicken manure was retrieved from literature (Smith et al., 2000) to determine N fertilization per kg of chicken manure.

The effects of fertilization and forage pressure on vegetation stands (Koorn & Allmenröder, appendix 1) were analysed by harvesting biomass at three locations in the orchard. The first location was a fenced-off area where chickens had been present for 3 weeks at the time of measurements. The second location was a fenced-off area where chickens had foraged 9 months before for 8 weeks and a control measurement was taken in a location where chickens had never foraged. Dry weight was determined and grass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) biomass was weighed separately. Besides, chlorophyll content was measured (Koorn & Allmenröder, appendix 1) of the dominant species clover and grass using a SPAD chlorophyll meter to indicate N content. The SPAD meter uses LEDs to emit light and the transmitted light through the leaves is detected. The obtained value is compared to calibration values and converted into a numerical SPAD value. SPAD values are henceforth proportional to the amount of chlorophyll in the leaves, which is an indicator for N content (Konica Minolta, 2016).

2.2. Feed

Feed conversion ratio, expressed as kg feed/kg egg, was measured over a period of 24h. When the sun sets, chickens move to their perches in the chicken coops and quit feeding. After sun set, therefore, all 10 available feeding boxes were filled with 50% grains and 50% concentrates and subsequently weighed. Next day, eggs were collected, counted and a subsample of (n=10) eggs was weighed on a fine-scale balance and replicated 6 times, so N_{tot}=60 eggs. Individual egg weight was back calculated for the whole batch of eggs. All feeding boxes were weighed 24h after the initial weight measurement and total kg of feed consumed could be calculated. This was divided over the total weight of eggs to get the feed conversion. This procedure was carried out once a week over a period of 10 weeks, from February until May.

Laying percentage was also measured to compare laying performance with other Dutch organic chicken rearing systems (Leenstra et al., 2014). For this, all chickens were counted in their chicken coops for a total of 8 days and the number of eggs collected during the following day was divided over the number of chickens counted.

During three of ten feed conversion measurements, tree strip cultivation was practiced to detect whether feed conversion ratio would effectively decrease. For this, the area where chickens were present was cultivated (figure 3), thereby attracting chickens to forage on exposed high-protein sourced macrofauna. The feed conversion ratio measurement was performed similar to the other feed conversion ratio measurements.

Figure 3: Attraction of chickens after tree strip cultivation

For studying macrofaunal dynamics during foraging of chickens and as a response to tree strip cultivation (Teeuwen & Schramm, appendix 2), the number of earthworms was used as an indicator for soil macrofauna, because their large size makes them one of the major contributors to invertebrate biomass in soils (Edwards, 2004). Six soil samples were taken the day before tree strip cultivation, during the day when cultivation was practiced and nine days after cultivation. Another six soil samples were taken 16 days after cultivation, but only in the field where chickens were present at the time of measurements due to logistics at the farm. The fields where the measurements were taken for harvesting biomass included a location where the chickens were present at the time of measurements and a location where chickens had not foraged before (see section 2.1.). At each sampling site, a volume of 20x20x20 centimetres of soil was taken by digging vertically into the ground with a spade. Earthworms from each sample were sorted and counted by hand. Due to the large variability in earthworm size, weight of the total number of worms was determined per sampling site prior to tree strip cultivation. Average weight per worm was calculated by dividing weight per sample (g) with total number of worms per sample.

2.3. Animal behaviour

Analysing chicken behaviour patterns was performed following the instantaneous scan sampling method (Martin & Bateson, 2007) according to the study of Mollenhorst et al. (2005) with which the resulting behaviour patterns of the chickens in Fruittuin van West were statistically compared. For this, one person observed the chicken flock in three sessions of 30 min. each during one day for a total of 6 days. Cockerels were not included in the analysis, but the behaviour pattern of cockerels was analysed separately during 3 out of 6 days. Chicks grown up with and without mother hen (see section 2.4.) were analysed at three weeks of age for four days following the same instantaneous scan sampling method.

The area where the chickens were present was subdivided into four functional areas, i.e. the area around the eating and drinking facilities, the area close to the chicken coops and two distinct forage areas where chickens were present at that particular time. The sequence of observing in the four functional areas was randomly depicted each day of performing observations. Each session started with the observer to walk for 5 minutes to the functional area following an adaptation period of another 5 minutes. Next, all hens/cockerels/chicks present in an observation plot were observed every minute and behaviours were scored according to the ethogram (table 1).

Similar to the analysis of Mollenhorst et al. (2005), scan sampling data of all four functional areas within one observation day were summed into a total number of hens/cockerels/chicks performing each of nine behaviours. Rather than summarizing per session (Mollenhorst et al., 2005), the scan sampling data of the Fruittuin van West were summarized per day for all three sessions, because of the relatively heterogeneous behaviours of outdoor foraging chickens throughout the day (Bestman et al., 2011). Subsequently, for each observation day, the percentage of hens/cockerels/chicks performing each of nine behaviours was calculated.

Table 1: Ethogram of instantaneous scan sampling, adapted from Mollenhorst et al (2005)

Behaviour	Description
Stand	Standing idle, no body contact to floor
Sit	Sitting idle, body on floor
Walk	Locomotion from one place to another
Forage	Scraping over floor with feet, pecking on floor
Eat	Eating from feeding boxes
Groom	Cleaning with beak or feet, feather ruffling, preening
Drink	Drinking water from water nipples
Dust-/sunbath	Laying down in substrate and making fluttering movements
Rest	Laying down or sitting on perch with closed eyes

2.4. Maternal care

The design for raising chicks by mother hens was adapted from the current practice of chicken rearing in the Fruittuin van West. For this, one of the reserve chicken coops on the farm was reconstructed and allocated to a fenced-off site in the orchard. The chicken coop was meant to house mother hens for developing broodiness. Seven hens were introduced from the Orpington breed and were obtained from different hobby breeders. Similar to the current practice, feed and water was supplied in the orchard and hens were allowed to forage in the orchard during the day. Multiple nests with imitation eggs were provided for the hens in the chicken coop (figure 4). Once a hen would develop broodiness, the nest including the hen was relocated to another compartment within the chicken coop such to create an undisturbed environment for the hen to brood the imitation eggs.

Figure 4: Adapted chicken coop with laying nests (blue boxes) including imitation eggs provided to stimulate broodiness of hens

Once multiple hens had developed broodiness, an incubator was installed with a capacity for hatching a total of 500 eggs. The fertilized eggs were from the purebred dual-purpose breed of breeder Wytze Nauta (Stichting Biologische Fokkerij), called 'Vredelinger'. After 18 days of incubation, 3 days before hatching, eggs were sorted out that did not contain an embryo. Also, during this time, 15 fertile eggs were put under each broody hen and replaced the imitation eggs. Once the chicks hatched under the mother hen, the nest including hen and chicks was placed in a $1m^3$ wooden box with mulching material as ground cover and providing ad libitum starter's feed for chicks and water. The mother hens and chicks were given access to a fenced-off outdoor area of 15 m^2 during the day (figure 5). The eggs that did not hatch under the mother hens at day 1 were exchanged for 1-day-old chicks from the incubator until every mother hen had a total of 15 chicks. After three weeks, mother hens with their chicks were reintroduced in the orchard at the location where the mother hens were housed.

Figure 5: Wooden boxes in a fenced-off area on the farm for keeping mothers and their chicks

The remaining eggs were hatched in the incubator and 90 chicks were put in three wooden boxes measuring 1 m^3 each, similar to the boxes the mother hens and chicks were allocated to. Conventional heat lamps provided a comfortable temperature and food and water was provided ad libitum. After two weeks, chicks were allowed to forage in the entire stable measuring 30 m^2. After six weeks of age, chicks were moved to the orchard, but during these weeks no measurements were taken anymore because of time limit of the study.

Thus, chicks raised by mother hens were reared in the orchard and chicks raised without mother hens were reared in the stable. Any differences measured between the two treatments were not attributed to either presence/absence of mother hens or outdoor/indoor conditions, but attributed to the combined factors. The comparison as such was chosen because in the study of Edgar et al. (2016) it was argued that maternal care could not be introduced in regular systems due to large space requirements that the concerning rearing systems cannot offer. However, an orchard provides more space for raising chicks by mother hens. Yet, chicks raised without a mother cannot be raised in the orchard due to temperature stress. The aim of this part of the study was, therefore, to compare the rearing conditions at a higher level of integration to meet practical demands for implementation of the system.

Measurements included comparisons of hatchability of the incubator and by mother hens. During the experiment losses of chicks to predators or due to other causes were recorded. Furthermore, development of chicks was measured by weighing a total of n=6 chicks at the age of 1 week, 2, 3, 4 and 12 weeks. An equal number of cockerels (n=3) and hens (n=3) was taken for each measurement, but during the first weeks of age cockerels and hens could not yet be separated. Feed consumption was measured from 2 to 3.5 weeks of age for every half a week. For this, storage bags were separated for chicks with mother hens and chicks without mother hens. Feed boxes were equally filled up before every measurement and the difference in weight of feed storage bags before and after filling feeding boxes were an indicator for consumed feed. The difference in weight of feedbags was divided over the chicks according to rearing practice. During the course of these measurements, feed boxes of the chicks raised by mother hens were adapted for more efficient feeding by chicks such that spillage was reduced and the mother hens and other chickens had no access to the feed boxes. Lastly, as mentioned earlier, at three weeks of age behaviour assessment was performed (see section 2.3.).

2.5. Dual purpose breeds

To analyse whether the introduction of dual-purpose breeds in an orchard following the current type of management thereby using mother hens to rear chicks is profitable was evaluated using a financial model. A comparison of dual-purpose chickens (figure 6) and hybrid laying and meat chickens was therefore made. Parameters of the dual-purpose chickens 'Vredelinger' were based on records of breeder Wytze Nauta of his own flocks on laying percentage and meat production.

Figure 6: Picture of hens and cockerels of the dual-purpose breed 'Vredelinger'

Since there is no data available on feed consumption of dual-purpose breeds in orchards, the same feed consumption parameters were used as from the data acquired in this study. Parameters of productivity of hybrid chickens and feed costs and feed consumption were taken from the recorded data, but parameters for hybrid meat chickens on meat production were taken from literature. Furthermore, the practice of brooding chicks was taken into the calculation for the system with dual-purpose breeds and was compared to the rearing system using 1-day-old hybrid broiler chicks and hybrid laying chickens of 18 weeks of age. Depreciation of housing was estimated according to the data of the farmer of his stable and chicken coops. Total revenues, costs and net income were expressed per production cycle.

A production cycle takes 365 days, in which a total of 500 chickens were simulated for both the dual-purpose breed and for hybrid laying chickens and broilers. The number of chickens was based on the demand of the farmer to increase his flock size by two-fold for selling more eggs to the customers.

Cockerels of the dual-purpose breeds were modelled to be slaughtered at an age of 20 weeks at 1.8 kg dressed weight and at an age of 12 weeks at 1.8 kg dressed weight for the hybrid broilers. Furthermore, laying hens were simulated to produce eggs during the whole year at 65% laying percentage for the dual-purpose hens and at 84% for the hybrid laying hens (see section 3.2.). During the production cycle mortality, expressed as the share of the total flock, was included in the calculations. Mortality was based on the recorded data on the decrease in number of chickens in the orchard over a period of 17 weeks. The mortality for dual-purpose chicks reared in the orchard by mother hens was based on the data of the experiments.

Regarding propagation of the flock of the dual-purpose breed, the replacement rate of laying hens was set at 33% every year. So, laying hens of the dual-purpose breed are slaughtered at the age of 3 years. Thereafter, they are sold for meat. Because of a tougher meat quality, prices were modelled to be lower (€10,- kg^{-1} for meat of hens versus €12,- kg^{-1} for meat of cockerels). A consequence of propagation is that 50% of the new stock consists of cockerels. Since the total flock was set at 500 chickens, every year 125 hens and 125 cockerels were added to the flock and during the same year 125 hens and 125 cockerels were slaughtered. The same number of hybrid laying hens and hybrid broilers per year (i.e. 375 and 125 respectively) was used in the model to compare with dual-purpose breeds. For raising 250 chicks with 15 chicks per mother hen, 17 mother hens are needed for propagation of the flock. Price per mother hen was determined by multiplying the number of eggs the hen did not lay during the time of broodiness and raising chicks, in total 50 days per mother hen, with the price per egg. During the broody period (i.e. 21 days), a hen consumes a limited amount of feed only. Therefore, feed intake was assumed to be 42% (i.e. 21 divided by 50) lower compared to what a laying hen would consume when not broody.

For feeding the chicks of the dual-purpose breed, it was assumed that chicks would feed on starter's feed for two weeks before converting to a diet of 50% concentrates and 50% grain. Usually this period is much longer, until 6 months for regular indoor systems (Bestman et al., 2011), but it was assumed that the orchard provides sufficient proteins to account for the deficiency. For hybrid broiler chicks this period was set at four weeks, after which they are relocated from the stable to the orchard where they start on the diet of 50% concentrates and 50% grains.

2.6. Statistical analyses

The number of samples required for statistical significance between treatments was calculated according to the formula $n_{A,B} = \sigma_{A,B}^2 * ((z_\alpha + z_\beta)^2 / \Delta^2)$ with α (significance level) being 0.05 and β (statistical power) being 0.8. However, since most measurements were conducted for the first time and no literature could provide an estimate for σ (standard deviation of the population mean) and expected Δ (difference between treatments), number of observations was kept within practical limits (mostly n=6 per treatment).

Data was analysed using SPSS version 22.0. Data cases were split to compare measurements in the different areas on the farm (i.e. the location where chickens were present at the time of measurements, the location where chickens were present 9 months ago and the location where chickens had not been present). Prior to ANOVA using a GLM procedure, data were first examined for normal distribution by Levene's test and Q-Q plots. Data were presented as average and their standard deviation (SD).

3. Results

3.1. Housing

The number of chickens that were counted in each mobile chicken coop during (n=5) nights was consistently lower in the first chicken coop ($P<0.05$; 38, SD = 18) and higher in the third coop ($P<0.05$; 137, SD = 23) with the second coop in between ($P<0.05$; 92, SD = 25) (figure 7). The first chicken coop was always closest to the end position in the fenced-off location and the third chicken coop was always closest to the starting position (figure 2).

The average excreta added to the soil during the night was 47.5 gram per chicken per night (SD=3.15). This is the equivalent to 0.029 g N assuming 16 g N/kg excreta (Smith et al., 2000). Based on the area of the chicken coop (24 m^2) and multiplied by the average number of chickens (267) this is the equivalent to 36.5, 87.4, and 129.8 kg N/ha for the first, second and third chicken coop respectively.

The total amount of fresh excreta a chicken drops on the pasture per day was estimated to be 115 g (Smith et al., 2000). The amount of manure supplied to the pasture per chicken per day is therefore 115 – 47.5 = 67.5 g. Because the chickens in the orchard comprised an estimated density of 500 chickens ha^{-1} during 8 weeks per year per location, the total amount of manure supplied to the soil was calculated to be 2.02 tons. This is the equivalent to 30 kg N ha^{-1} $year^{-1}$.

Adding up this number with the average manure supplied at night (85 kg N ha^{-1} $year^{-1}$), the total manure addition of chickens with a density of 500 chickens ha^{-1} was calculated to be 115 kg N ha^{-1} $year^{-1}$ and (table 2).

When calculating the nitrogen excretion based on feed intake and N retention in eggs (Smith et al., 2000), total kg N ha^{-1} $year^{-1}$ was 135 (table 3), which is 20 kg N ha^{-1} $year^{-1}$ more compared to the calculation based on manure collection (table 2).

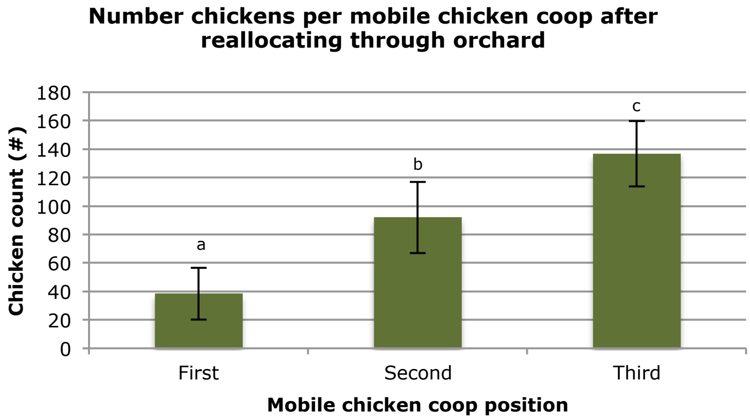

Figure 7: Average distribution of chickens in the three chicken coops counted at night when chickens were on the perch. ‘First’, ‘second’ and ‘third’ refers to the position of the coop in the location where chickens were allocated to (figure 2). Different letters indicate statistical significance at the 0.05 level.

Table 2: Modelled calculations of manure and nitrogen distribution under the chicken coops and within the fenced-off location where chickens were allocated to

	Night (under coop)	Day (whole pasture)	kg N/ha/year
# chickens	267	500	
Manure amount (g/chicken/day)	47.5	67.5	
g N/kg manure (Smith et al., 2000)	16	16	
Area (m2)	24	10000	
kg N/ha	85	30	115

Table 3: Modelled calculations of nitrogen excretion based on feed intake and egg production, data partly obtained from Smith et al., (2000)

	Amount	Unit
N intake (feed)	1100	g N bird^{-1} year^{-1}
N retention (egg)	311	g N bird^{-1} year^{-1}
N excretion	788	g N bird^{-1} year^{-1}
Average N fertilization	135	kg N ha^{-1} year^{-1}
Difference (table 2)	20	kg N ha^{-1} year^{-1}

Concerning the vegetation density, there was no significant difference in harvested total biomass of grass clover among the different locations (figure 8).

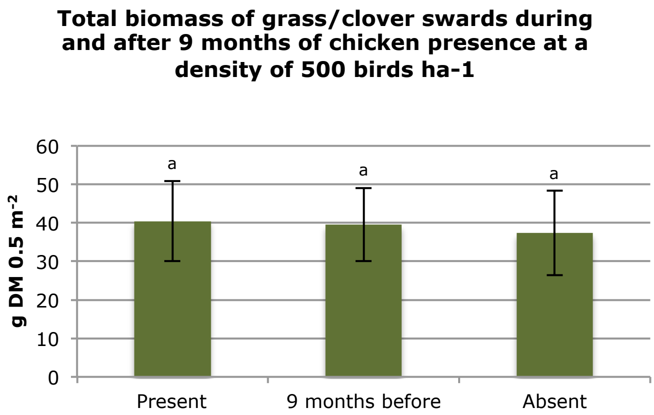

Figure 8: Biomass measurements of swards between the tree lines in three areas where (1) chickens were present at the time of measurements ('present'), (2) where chickens were allocated to 9 months ago ('9 months before') and (3) where chickens had never foraged before ('absent'). Different letters indicate statistical significance at the 0.05 level.

Chlorophyll content of grass and clover was higher in the location where chickens were present at the time of measurements compared to both locations where chickens were present 9 months before and where chickens had not been present ($P<0.05$). Chlorophyll tended to be higher in grass clover at the location where chickens were present 9 months before compared to where chickens had not been present ($P<0.10$). There was no significant difference in chlorophyll content between grass and clover (figure 9).

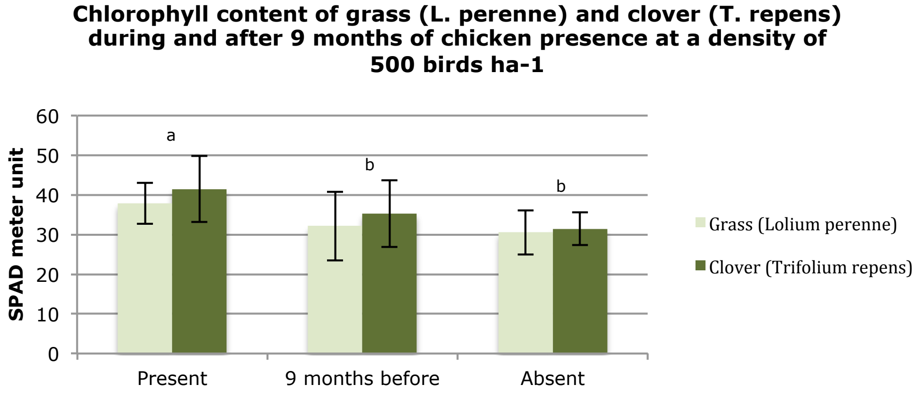

Figure 9: SPAD values of grass (light green) and clover (green), indicative for the N content of leaves, in the three measured areas where (1) chickens were present at the time of measurements ('present'), (2) where chickens were allocated to 9 months ago ('9 months before') and (3) where chickens had never foraged before ('absent'). Different letters indicate statistical significance at the 0.05 level.

3.2. Feed

Both feed conversion ratio and laying percentage of chickens in the Fruittuin van West were not significantly different from other Dutch organic chicken farms (Leenstra et al., 2014). The average feed conversion ratio of the Fruittuin van West farm was 2.30 (SD = 0.37) and from other Dutch organic farming systems 2.42 (SD = 0.11). Laying percentage was measured to be 84.4% (SD = 5.4) at the Fruittuin van West farm and 85.3% (SD = 3.5) on other Dutch organic farms (figure 10).

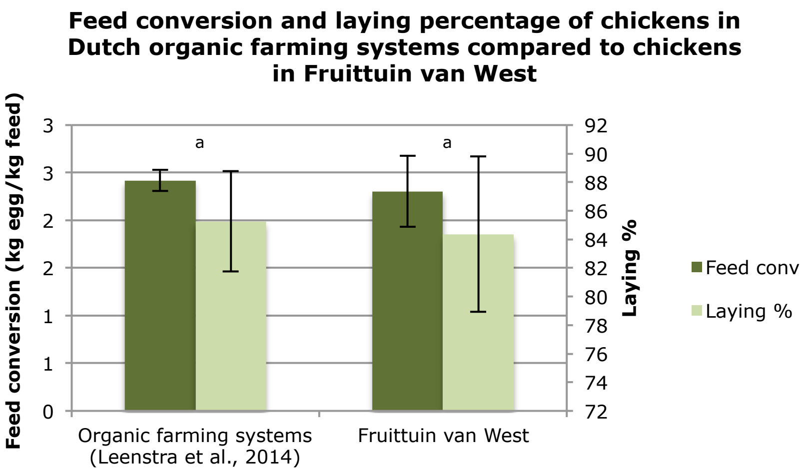

Figure 10: Comparison of feed conversion ratio (dark green, primary axis) and laying percentage (light green, secondary axis) between Dutch organic farming systems (Leenstra et al., 2014) and the Fruittuin van West. Different letters indicate statistical significance at the 0.05 level.

The average feed conversion ratio after tree strip cultivation was 2.03 kg egg/kg feed (SD = 0.38) and the average of the measurements without tree strip cultivation was 2.44 kg egg/kg feed (SD = 0.31). However, the decrease in feed conversion ratio after tree strip cultivation was not significant.

After analysis of the three tree strip cultivation events it became evident that the feed conversion ratio seemed to increase after every subsequent cultivation event, from 1.72 kg egg/kg feed (first measurement) to 1.92 kg egg/kg feed (second measurement; after 6 weeks) to 2.46 kg egg/kg feed (third measurement; after 8 weeks compared to the first) (figure 11).

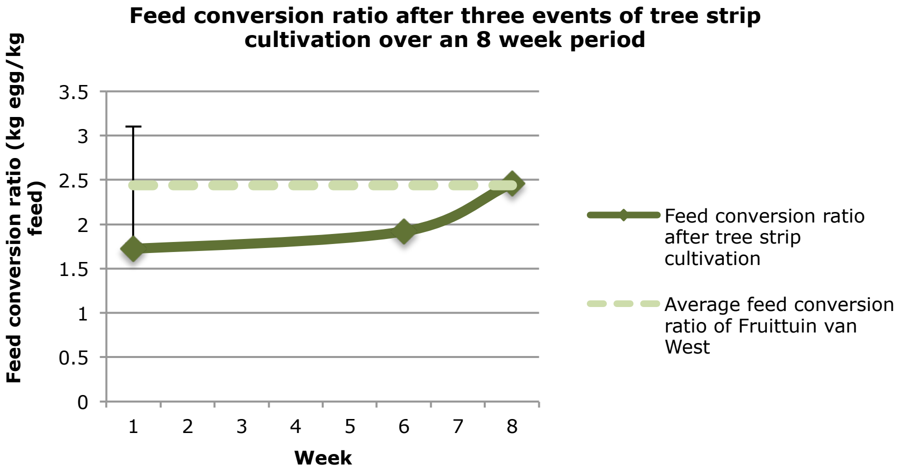

Figure 11: Feed conversion ratio after three recurrent tree strip cultivation events (week 1, 6 and 8) in one location in the orchard where chickens were present at the time of measuring (dark green line) with the average feed conversion ratio (dashed light green line) and its 95% confidence interval

Prior to cultivation, the number of earthworms was higher in the location where chickens were present at the time of measurements (25, SD = 7.7) compared to the location where chickens had not been present (14, SD = 6) ($P<0.05$). Yet, the average weight of earthworms in the location where chickens were present at the time of measurements was lower (0.24, SD = 0.05) compared to the average weight of earthworms in the location where chickens had not been present (0.33, SD =0.06) ($P<0.05$). When the average weight per worm was multiplied with the number of earthworms counted in every sample, earthworm biomass was not significantly different between the two locations, though there was a shift towards higher earthworm biomass in the location where chickens were present at the time of measurements compared to the location where chickens had not been present (figure 12).

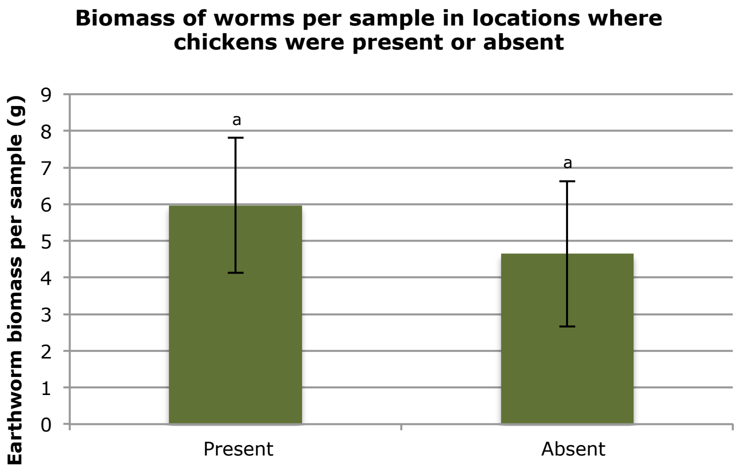

Figure 12: Average earthworm biomass per sample (20*20*20 cm soil sample) in the locations where chickens were present at the time of measurements ('present') and where chickens had not been present before ('absent'). Different letters indicate statistical significance at the 0.05 level.

After one day of tree strip cultivation, the number of earthworms in the location where chickens were present at the time of measurements tended to be lower (36%) compared to before cultivation (P<0.10). Contrarily to this finding, in the location where chickens had not been present, an increase of 56% of the number of earthworms was found after tree strip cultivation compared to before tree strip cultivation (P<0.05). Nine days after cultivation, the number of earthworms had not significantly changed in number for both groups compared to one day after cultivation. However, for the location where chickens were present at the time of measurements, earthworms showed a marginal recovery to their original number before tree strip cultivation was carried out. After sixteen days, the number of earthworms at the location where chickens were present at the time of measurements still had not increased significantly compared to one day after cultivation (figure 13).

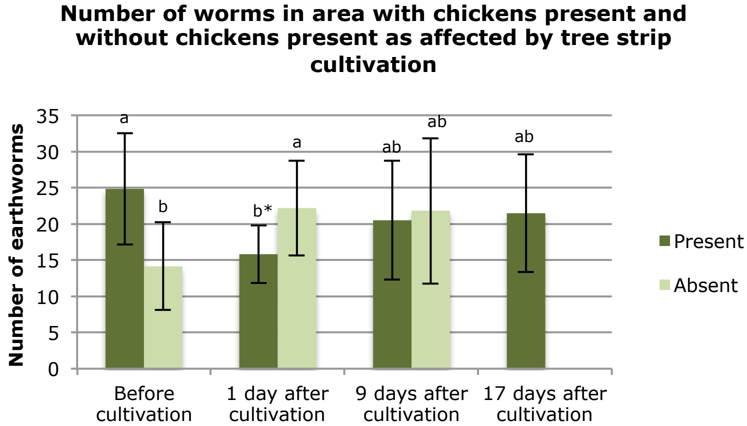

Figure 13: Changes in earthworm counts in areas where chickens were present at the time of measuring ('Present'); dark green bars) and where chickens had not been present ('Absent'; light green bars) 1 day before and 1, 9 and 17 days after tree strip cultivation. Different letters indicate statistical significance at the 0.05 level, (letter)* indicates significance at the 0.10 level.

3.3. Animal behaviour

Regarding behaviour patterns of chickens in the Fruittuin van West compared to both battery cage systems and deep litter stables (Mollenhorst et al., 2005), chickens in the Fruittuin van West spent less time on standing (P<0.05) and spent more time on foraging and comfort behaviours, including grooming, dust- and sunbathing and resting (P<0.05). Furthermore, chickens in the Fruittuin van West showed a higher degree of walking behaviour compared to battery cage systems (P<0.05), but not compared to deep litter stables. A reduction in eating behaviour was found for chickens in the Fruittuin van West compared to battery cage systems (P<0.05), but this was not found for deep litter stables (figure 14).

The most common noted behaviours for chickens in the Fruittuin van West were foraging, walking and grooming, combining to 60% of the total time observed. For battery cage systems most common observed behaviours are standing and eating (94% combined) and for deep litter stables standing and walking (64% combined).

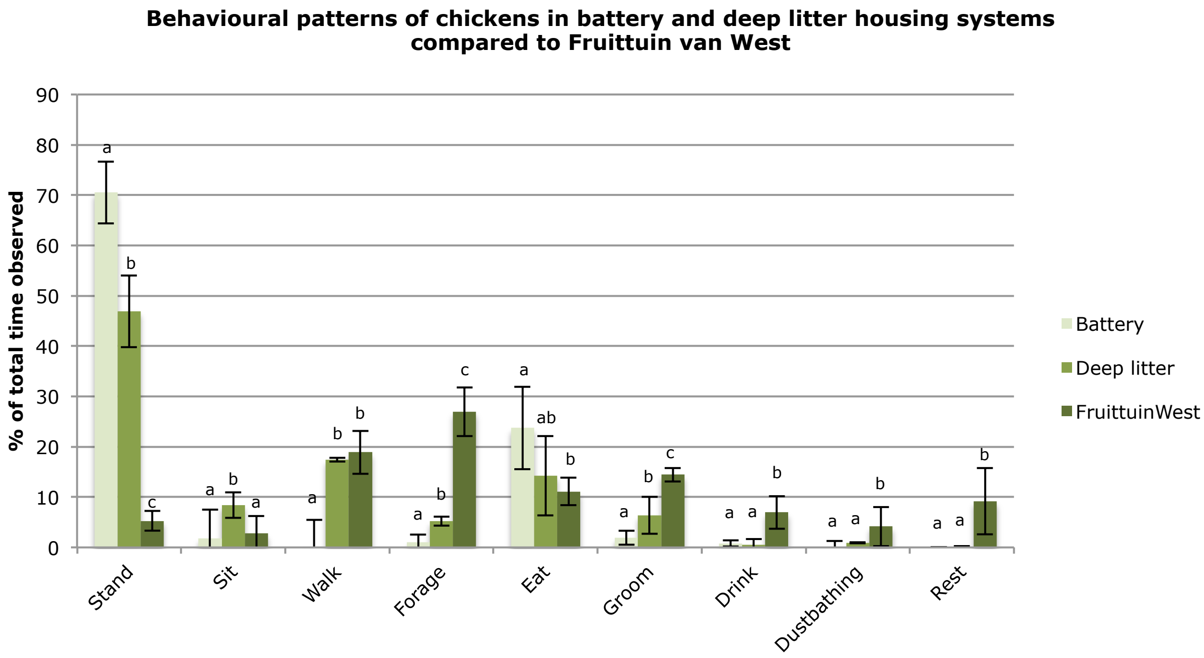

Figure 14: Graphical representation of time spent on common behaviours by chickens in battery (light green), deep litter stable systems (darker green) (Mollenhorst et al., 2005) and the Fruittuin van West (dark green). Different letters indicate statistical significance at the 0.05 level for each behaviour.

Chicks raised in the orchard by mother hens showed to have similar behaviour patterns compared to the general behaviour pattern of chickens in the Fruittuin van West. Chicks raised by mother hens were only found to spend more time on resting (P<0.05; 24% versus 9% respectively). Compared to chicks raised without mother hens, chicks raised by mother hens spend more time on foraging (P<0.05; 24% versus 10%) and less on eating (P<0.05; 7% versus 22% respectively). Furthermore, chicks raised by mother hens tended to spend more time on walking compared to chicks raised without mother hens (P<0.10) (figure 15).

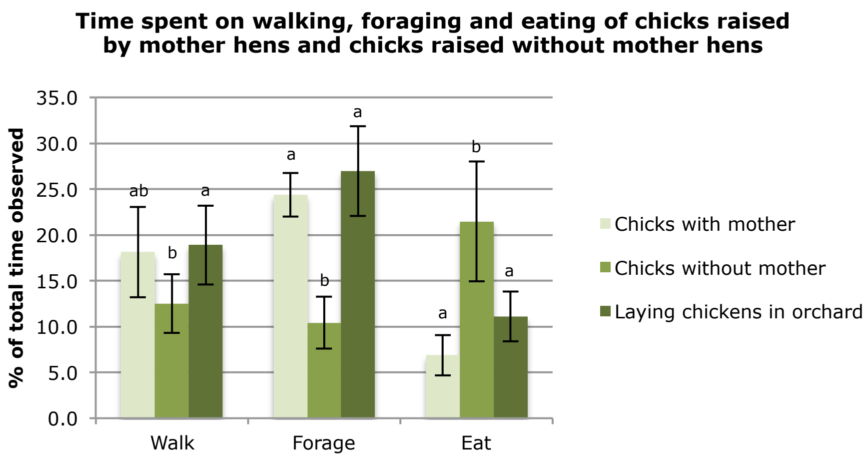

Figure 15: Graphical representation of time spent on walking, foraging and eating by chicks raised by mother hen in the orchard from 3 to 6 weeks of age (light green) and chicks raised without a mother in a stable of similar age (darker green) compared to the laying chickens already present in the orchard (dark green). Different letters indicate statistical difference at the 0.05 level for each behaviour.

3.4. Maternal care

From the seven introduced Orpington hens, a total of four got broody before the eggs hatched. The onset of broodiness for two out of four hens was at the first day when the eggs were put in the incubator. Therefore, these hens were broody for the entire 21 days before the eggs hatched. For the other two hens, onset of broodiness was at day 12 and at day 19, respectively (figure 16).

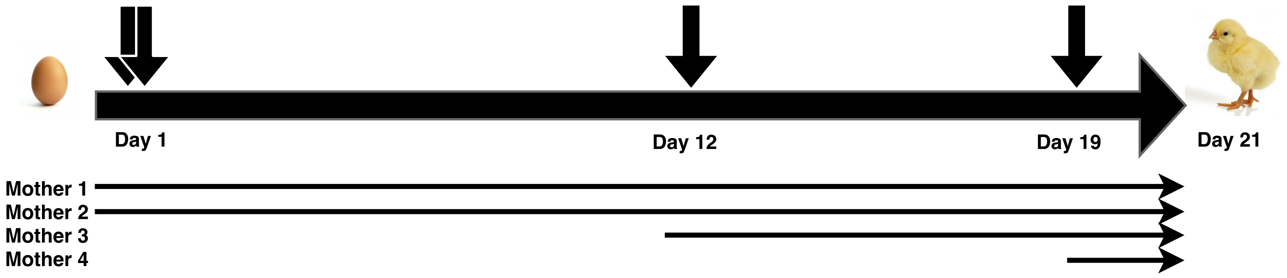

Figure 16: Onset of broodiness of four Orpington hens (thick vertical black arrows) during the time of incubating eggs until the chicks hatched (thick horizontal black arrow) and total length of broodiness period of each mother hen (thin horizontal arrows)

A total of 434 eggs out of 499 contained an embryo at 18 days of incubating. From the 434 fertilized eggs a total of 60 were put under the mother hens in their laying nests, leaving 373 eggs still in the incubator. From the 373 fertilized eggs 76% (284) hatched. From the 30 eggs put under the two mother hens that were broody for 21 days, hatchability was found to be 85%. From the other two mothers that were broody at 12 and 19 days, hatchability was only 13% and 7% respectively. All hens accepted 1-day-old chicks from the incubator after supplying to a total of 15 one-day-old chicks. The hen that got broody at 19 days after the incubator was installed did not yet show typical broody hen behaviours and vocalizations. Therefore, it was decided to provide this hen with a total of 10 chicks rather than 15 (figure 17).

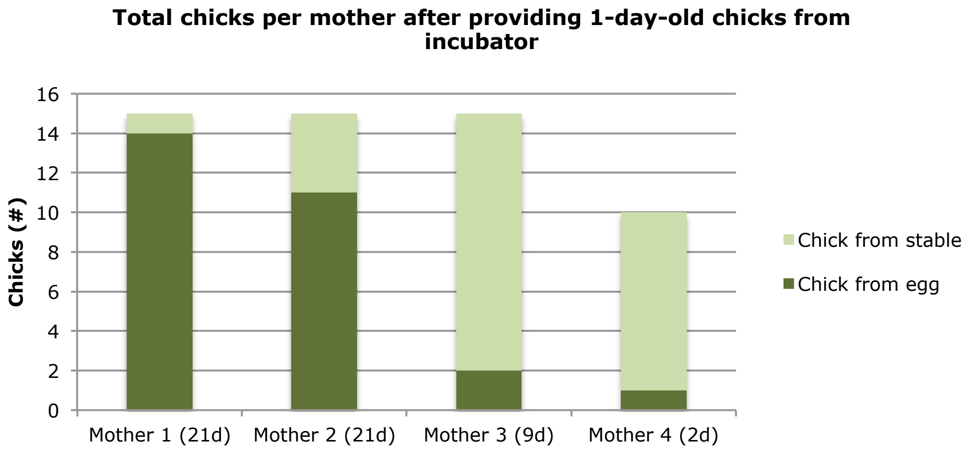

Figure 17: Hatchability for each of the four mother hens from 18-day-old fertilized eggs (dark green bars) with broodiness period between brackets and the number of 1-day-old chicks added from the stable (light green bars) until total number of chicks was 15, except for mother hen #4 (n=10)

During the time hens and their chicks were housed in wooden boxes a rat took a total of 25 chicks, reducing the total number of chicks to 30. After reintroducing the mother hens and their chicks in the orchard, another 5 chicks were taken but from an unknown cause. It might have been possible that the farmer's dogs took these chicks, since it was found to be a common issue that the dogs chased older chickens.

Feed consumption of chicks was found to be higher for chicks raised with mother hens before adapting feeding boxes to more efficient feeding (week 2: 40 g $chick^{-1}$ day^{-1} versus 15 g $chick^{-1}$ day^{-1}). After the first adaptations of the feeding boxes (week 2.5 and week 3), feed consumption was still higher for chicks raised by mother hens (Δ week 2.5: 9 g $chick^{-1}$ day^{-1}; Δ week 3: 11 g $chick^{-1}$ day^{-1}). Only after chicks were reintroduced in the orchard, at 3.5 weeks of age, and when feeding boxes were provided with a pellet on top to reduce consumption of starter's feed for chicks by older hens, chicks raised by mother hens were found to have a similar feed consumption compared to chicks raised in the stable without mother hens (69 g $chick^{-1}$ day^{-1} for both rearing systems) (figure 18).

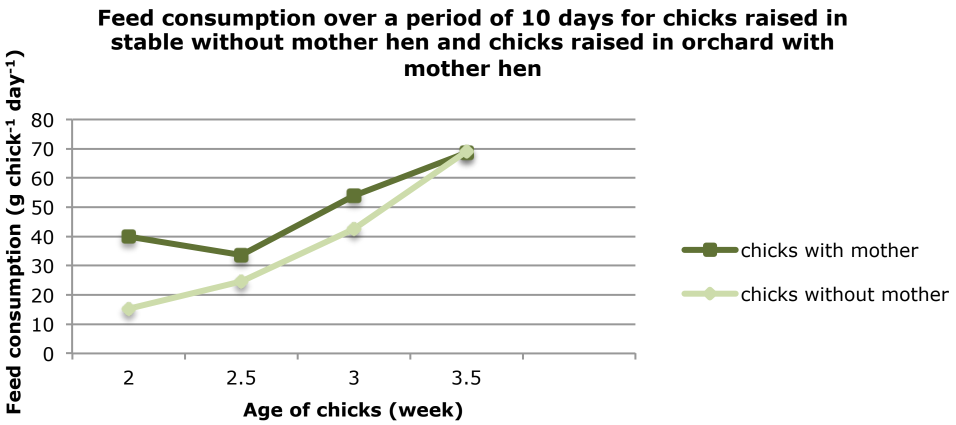

Figure 18: Feed consumption (g $chick^{-1}$ day^{-1}) of chicks raised by mother hens in orchard (dark green) and chicks raised without mother hen in stable (light green). Feed troughs for chicks raised by mother hens were adapted after 2 weeks, 2.5 weeks and 3 weeks of age.

Growth rate of chicks during the first weeks of age (week 1 to week 4) showed a tendency for chicks raised in stable without mother hens to be higher than for chicks raised in the orchard by mother hens. At 4 weeks of age, chicks raised in the stable without mother hens had a 21% higher weight ($P<0.05$) than chicks raised in the orchard by mother hens (figure 19). At 12 weeks of age, after all chicks had been introduced to the orchard for 9 weeks (chicks raised by mother hens in orchard) and 6 weeks (chicks raised in stable without mother hens), chickens showed no statistically significant difference anymore between the two groups.

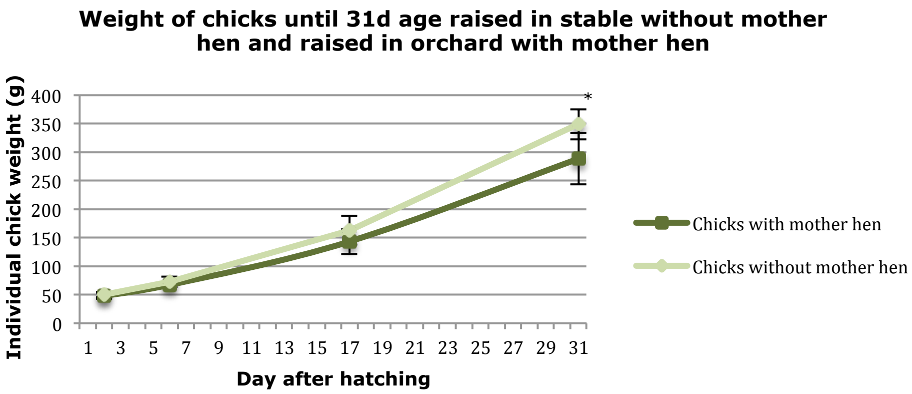

Figure 19: Weight increase of chicks (g) raised by mother hens in the orchard and raised without mother hens in stable from age day 1 until age day 31. * indicates statistical significance at the 0.05 level.

3.5. Dual purpose breeds

After modelling calculations, 500 chickens reared from the hybrid meat (n=125) and laying breeds (n=375) in a regular system resulted in a total turnover of €26,000.-. Within this calculation a mortality of 20% was taken into account based on the recorded data on the number of chickens in the orchard over a period of 17 weeks. Comparing the revenue of hybrid chickens to an equal number of dual-purpose chickens (n=500) raised by mother hens, this would result in a total turnover of €13,000.-. This calculation was based on 50% mortality, which was similar to the experimental findings on rearing chickens by mother hens. If mortality would be reduced by increasing the protection measures to a similar mortality of 20%, total turnover would be €21,000.-.

Total costs of the system where hybrid chickens were modelled were calculated to be €10,500.-, whereas for the system where dual purpose chickens raised by mother hens were modelled total costs were found to be €8,500.- if mortality was set at 20% for both systems. For the regular system with hybrid chicken breeds the costs were mainly covered by the purchase of chickens (€2,625.-) and feed (€5,000.-). For the system where dual-purpose chicks are reared by mother hens main costs were mainly covered by feed only (€5,000.-).

For both systems labour demand was expected to be similar and resulted in €2,500.- for the whole production cycle, based on 30 min of labour day^{-1} at an hourly cost of €10,-.

Net income was therefore found to be €15,500,- per production cycle for a regular system practiced at the Fruittuin van West using hybrid meat and laying breeds without rearing chicks. Regarding the rearing system in which dual-purpose chicks are raised by mother hens, net income was found to be €6,500,- if mortality was set at 50% and €12,500,- at 20% (table 4). Net income would be similar between the two systems if price per egg would be 30 ct for the dual-purpose system instead of 25 ct (appendix 3).

Table 4: Turnover, costs and net income rounded up to €500,- after model calculations of rearing systems with (1) dual-purpose breeds with maternal care and (2) hybrid layer and broiler breeds without maternal care as affected by mortality

	Mortality (%)	Turnover	Costs	Net income
Dual-purpose with maternal care	50	€13,000	€6,500	€6,500
Hybrid breeds without maternal care	20	€26,000	€10,500	€15,500
Dual-purpose with maternal care	20	€21,000	€8,500	€12,500

4. Discussion

In this study the main objective was to evaluate system performance of redesigning poultry rearing in orchards and identify key beneficial and adverse ecological relationships resulting from this practice. The redesigned system comprised integrating purebred dual-purpose breeds in an orchard using mobile housing facilities and included on-farm propagation of the flock. The main findings resulting from this practice included a more even distribution of manure and reduced trampling of vegetation compared to static housing systems (section 4.1); a similar feed conversion ratio but requiring a lower share of concentrates in the feed supplied to chickens compared to indoor systems (section 4.2); a more natural behaviour pattern that was adopted at an early life stage by chicks when raised by mother hens compared to indoor systems (section 4.3); a practically feasible method to propagate the flock by using mother hens, but which still needs to be optimized (section 4.4); and a financially profitable model for dual-purpose breeds when integrated in orchard systems (section 4.5). These main results will be elaborated on in the next sections. A synthesis part is included by which the interactions in the studied redesigned poultry rearing system are specified and further elaborated on.

4.1. Housing

Chickens were found to have a preference for spending their night in the chicken coop that was consistently closest to the starting position. This effect may be attributed to the natural behaviour of chickens to go back to their original sleeping location, though there is no literature supporting this hypothesis. Since chicken coops are relocated daily, this movement of their sleeping locations may therefore induce a higher number of chickens to sleep in the chicken coop that is always closest to the starting position in the fenced-off area. As a result, a heterogeneous manure deposition was found every other three rows in the orchard, ranging from an average of 36.5 to 129.8 kg N/ha at a density of 500 chickens ha^{-1}.

The amount of N in chicken manure was estimated to be higher in the calculation based on feed intake (table 3) compared to the calculation based on manure collection (table 2), but this difference was only 20 kg N ha^{-1} $year^{-1}$. In the calculation, feed intake was only based on provided feed (concentrates and spelt grains), but feed that was taken up due to foraging activities was not taken into account. It may be possible that the total protein:energy ratio is lower when feed intake from the pasture is taken into consideration (Hermansen et al., 2004), thereby lowering the N content of chicken manure based on feed intake. The reason for a lower protein:energy ratio compared to regular chicken rearing systems may be because of the fact that chickens in an outdoor pasture have a higher energy demand because of lower ambient temperatures and higher activity-related behaviours (van Krimpen et al., 2015b) (see section 4.2. and 4.3.). The calculation based on manure collection is probably a better estimate compared to the calculation based on feed intake, since feed intake from the pasture is hard to estimate (Walker & Gordon, 2003). For a more precise estimate, though, N content in chicken manure could be measured in future studies.

From the results it is assumed that biomass levels are equal among the measured locations. From the data it could even be deduced that biomass was slightly higher in the location where chickens were present at the time of measurements compared to where chickens were absent (figure 8). However, the number of observations in the present study was too low to get statistical significance and n=143 observations per location would be needed. This hypothesis is based on the fact that a higher chlorophyll content of vegetation stands was found during the presence of chickens compared to where chickens had not been present before (figure 9). This indicates that N uptake took place due to manure addition and since there was no history of fertilization of the pasture, a higher N uptake could be expected to lead to higher vegetation biomass.

Compared to static housing systems (Rivera-Ferre et al., 2006), using mobile chicken coops neither induces systematic trampling effects nor reduces vegetation biomass. Rather, using mobile housing systems results in lower nitrate leaching potential to the groundwater compared to static housing systems. The limitation of these measurements was that nitrate levels in the soil solution were not directly measured, but only an indirect indication was provided through increased chlorophyll content in leaves in the location where chickens were present compared to where chickens had not been introduced. Although this proves that there is N uptake by plants as a result of fertilization by chickens, the loss of nitrogen from the system remains unknown. Still, the density of chickens around a mobile chicken coop is much lower compared to static housing facilities (Rivera-Ferre et al., 2006; Anotinsen & Lantinga, unpublished) and due to a high degree of trampling in static housing systems, uptake of N is reduced and nitrate leaching potential is therefore higher.

Another limitation of these measurements was that the amount of manure deposited under the chicken coop was measured in early spring only. However, in early spring, the nights are still long compared to summer at the latitude of the Netherlands. Since the concentrated deposition of manure is mainly found under the chicken coop, in summer the total manure concentration under the chicken coops is expected to be lower compared to autumn. Because there is only limited uptake of nutrients in autumn by plants but temperatures are high enough for mineralization (Di & Cameron, 2002), the expected higher manure deposition is disadvantageous. Future studies should investigate how many chickens can be allocated to a chicken coop without exceeding legislative nitrate concentrations in the groundwater, thereby taking into account length differences of winter and summer nights. Possibly the size of chicken coops can be adapted to reduce the concentration of manure.

Introducing mobile chicken coops may be an interesting approach for increasing outdoor area usage and spreading manure more homogeneously around the pasture compared to static housing systems. However, the mobile housing systems used in this study were possibly too simplistic structures and led to mortality by predation to up to 20%, especially by foxes. On the farm, however, effective measures were taken during the study to eliminate foxes from entering the farm area through an electric fence. Therefore, before introducing this concept in other orchard systems, more protective measures are needed targeting the mobile chicken coops and/or around the farmland itself. This may increase the costs of using mobile chicken coops that have not been taken into consideration.

4.2. Feed

Feed conversion ratio in the Fruittuin van West was not found to be lower compared to other Dutch organic chicken farming systems. Yet, the feed provided to the chickens in the Fruittuin van West contained a 50% share of concentrates only, leading to a 36% reduction in feed costs (appendix 3) compared to a diet comprising 100% laying pellets.

Concentrates are often fed to nearly 100% of the chicken's diet in regular systems (Bestman et al., 2011) and feed costs account for a relatively large share of total costs in chicken rearing systems (Walker & Gordon, 2003), especially due to concentrates. It was shown that the laying performance (laying percentage (84%) and individual egg weight (64 g egg^{-1}) of the hens in the Fruittuin van West was similar to other Dutch organic farming systems (figure 10), but providing a diet of 50% concentrates only and 50% grains. This makes the strategy of integrating chickens in orchards a feasible option for the current challenges towards 100% organic ingredients in organic poultry feed (van Krimpen et al., 2015a), because the methionine requirements seem to be fulfilled from forage opportunities in the orchard.

It has been estimated in earlier research that concentrates can be reduced to up to a third of the diet provided to laying hens when integrated on pastures (Hughes & Dun, 1983). For producers this can be a risky strategy, given the fact that nutritional stress in high yielding genotypes may have serious implications on their welfare and production capacity (Hermansen et al., 2004). Besides, forage resources are not available constantly throughout the year, whereas hybrid laying hens are specifically bred to produce year-round. Yet, dietary requirements of chickens reared on pastures change over the season with relatively higher protein demand in summer and relatively higher energy demand in winter (van Krimpen et al., 2015b), synchronizing with the availability of forage resources. In this study, concentrates and spelt grains were mixed, but to assess changes in demand of protein and energy over the season, future studies could provide concentrates and spelt/wheat grains (i.e. relatively higher energy containing feed) separately to the chickens. Still, within this study it was found that average laying performance was similar to other Dutch organic chicken rearing systems (Leenstra et al., 2014). Feed inputs to the system can therefore be effectively reduced following the current type of management.

Total earthworm weight measured in summer was not higher in the area where chickens were present compared to where the chickens were absent (figure 12), but probably the number of observations was too low to statistically prove this ($n_{A,B}$ should be 27 at the found SD and difference). Reason for this hypothesis is that earthworms are attracted to organic amendments supplied to the soil surface (Edwards & Bohlen, 1996). When chickens fertilize the soil, earthworms are attracted as a result. However, at the same time, chickens are predating the worms and possibly the larger worms are preferred due to higher nutritious content. This creates a feedback, but the net result is probably that there are more earthworms attracted to the surface then chickens forage.

Within the present study, only earthworm dynamics were assessed. Yet, chickens may also forage on aboveground insects (Koorn & Allmenröder, appendix 1). Moreover, chickens can potentially serve as pest control to reduce damaging insects (Hermansen et al., 2004). However, in a study done on pest control of apply saw flies by chickens resulted in a lower number of saw flies but this had no effect on final fruit yield nor quality (Pedersen et al., 2002). Yet, only broilers were integrated in an orchard in the study, whereas when combining laying hens in orchards that stay during a whole year, the effect of pest control by chickens may be larger (Pedersen et al., 2002). Future studies could identify the impact of pest control by chickens, thereby especially focussing on the increasing pest problem in orchards of *Drosophila suzukii* (Cini et al., 2012), which was also identified by the farmer as a pest in his orchard.

Tree strip cultivation in this study reduced earthworm number even more after the first time of cultivation, though recurrent cultivation on the same location did not lead to a lower feed conversion ratio. This could be attributed to the low number of observations of measuring feed conversion ratio after tree strip cultivation (n=3). On top of that, after recurrent tree strip cultivation on the same location, a clear pattern of higher feed intake from the provided feed (concentrates and spelt grains) was found. Possibly, a lower amount of rewarding foraging opportunities (earthworms) was provided, because of recurrent cultivation on the same location. As a consequence, earthworms might not have been able to recover to their original number (figure 13) and the decreasing availability of nutritious feed from the tree strip cultivation practices may have caused chickens to increase their feed intake from the provided feed (concentrates and spelt grains). After allowing a resting period of 17 days after the first time of tree strip cultivation, there were some indications of recovery, possibly due to migration from below the pasture to the tree strip cultivated rows, because soil disturbance events attract earthworms (Edwards & Bohlen, 1996). This recovery is probably not a result from reproduction by earthworms, since their reproduction cycle takes about 10 weeks (Edwards & Bohlen, 1996).

Tree strip cultivation may only reduce the feed conversion ratio substantially when allowing sufficient resting periods. Therefore, tree strip cultivation may consequently not have a very high impact on reducing the average feed conversion ratio. To further assess the reduction of tree strip cultivation on the feed conversion ratio, follow-up experiments should allocate chickens to locations in an orchard that have had consistent tree strip cultivation histories and take recovery time of earthworms into account.

This study provided indications of effectively reducing the share of concentrates in the provided feed when chickens forage in the orchard. Tree strip cultivation may play a role to reduce the amount of concentrates even more, but their impact on the average feed conversion ratio may not be high because of a relatively long recovery time for earthworms. Future studies could supply grains and concentrates separately in order to quantify the uptake of concentrates relative to grains during different seasons.

4.3. Animal behaviour

From the behavioral patterns of chickens in the Fruittuin van West orchard, foraging and walking comprised the largest share of behaviours. Besides, a large share of comfort behaviours was noted, which is less found in regular laying hen systems (Mollenhorst et al., 2005). The behavioural pattern of chickens in the orchard is more similar to the common ancestor of the domestic chicken red junglefowl (*Gallus gallus* L.) (Dawkins, 1989) compared to battery cage and deep litter systems (Mollenhorst et al., 2005). In this respect, the current rearing conditions and management practiced at the Fruittuin van West contributes to supporting living natural lives, following the focus of the organic sector of animal husbandry (Lund, 2006).

Chicks raised by mother hens in the orchard adopted the typical behaviour pattern of adult chickens. This was not the case for chicks raised without mothers in the stable. In the stable there are less opportunities for foraging compared to the orchard. Besides, it was observed that the mother hen plays an important role in guiding the chicks throughout the orchard, something that was also apparent in other studies (Edgar et al., 2016). Walking behaviour was therefore more common among chicks raised by mothers compared to chicks raised without mothers in the stable. Probably because chicks spend more time on foraging, eating from the feeder was less observed, which was similar to adult chickens in the orchard.

These findings suggest that raising chicks by mothers in the orchard allows them to express more natural behaviours compared to chicks raised without mother hens in an indoor system. It has to be stressed that these findings are probably not found if chicks were to be raised by a mother hen in an indoor system. Although it was found that mother hens do promote foraging behaviour among chicks (Edgar et al., 2016), it is the combination of factors (i.e. raising by a mother hen and providing an orchard) that make chicks express a similar behaviour pattern as the adult chickens do and the present study provided the first evidence for this in a commercial-based chicken rearing system.

The limitation of these findings was that the improvement towards more natural behaviour patterns of chickens in the Fruittuin van West was compared with conventional battery cage systems and deep litter stables only. The difference between the behaviour patterns of chickens may be lower if the behaviour pattern of chickens in the Fruittuin van West would be compared to other organic chicken rearing systems. Yet, it could be hypothesized that chickens in the Fruittuin van West still show more similarities in their behaviour patterns to the red junglefowl compared to other organic rearing systems, because the chicken rearing management in the Fruittuin van West provides a relatively high share of cockerels in the flock, trees in the outdoor pasture and uses mobile chicken coops that allow chickens to make more use of the outdoor area (Wagenaar & Bestman, 2003). On top of that, the practice of rearing chicks by mother hens showed that chickens adopt this behaviour pattern at an early-life stage. Contrarily, current organic management practices introduce laying hens at the age of 18 weeks and during their raising period chickens are reared in conventional stables. Besides, organic broiler chicks also start their early-life period in indoor stables. Therefore, raising chicks by mother hens and implementing the management of the Fruittuin van West may contribute more to supporting living natural lives of chickens compared to current standard organic rearing systems.

4.4. Maternal care

Hatchability of eggs under the two mothers that were broody during the full period of 21 days (83%) was comparable to the incubator (76%). However, there was a large decrease in hatchability of eggs under the two mother hens that were broody for 9 and 2 days respectively (average hatching rate was 10%). This was thought to be due to the disruptive character of replacing imitation eggs for fertile 18-day-old eggs from the incubator, thereby stressing chickens resulting in trampling of eggs. Replacing imitation eggs by 18-day old eggs from the incubator or by one-day-old chicks in the night when broody hens are asleep, and thus more relaxed, can be a solution. Besides, smaller incubators can be used to improve synchronization of hatching eggs for each broody hen.

During the first weeks of rearing, chicks are highly vulnerable to many predators. In the present study this resulted in a decrease of almost 50% of the population due to a rat and the population was reduced even more by the involvement of a dog. Therefore, predation is regarded to be the main bottleneck for rearing chicks by mother hens in an orchard, as identified by the present study. On the contrary, Riber et al. (2007) found a reduction in mortality rate of chicks when raised by mother hens compared chicks raised without mother hens. However, in the present study chicks were reared in the orchard and within the study of Riber et al. (2007) chicks were reared in indoor stables. Therefore, regarding the practical implementation of raising chicks in an orchard, predation is an important bottleneck. Future studies should look for cost-effective measures to decrease losses to predators, thereby using firmly fenced-off areas where the mother hen and her chicks can be safely introduced.

Feed consumption of chicks raised without mother hens in the stable seemed to be lower compared to feed consumption of chicks raised by mother hens in the orchard. Spillage and consumption of feed by mother hens probably led to a high loss of feed meant for chicks only, because when feed was provided such that mother hens could not consume from this feed but only chicks could, feed consumption reduced. Therefore, to lower feed spillage when rearing chicks by mother hens, feed troughs should be adapted.

Chicks raised without mothers in the stable had a higher growth rate compared to chicks raised by mothers in the orchard. This is probably the result of both more activity-related observed behaviours and lower ambient temperatures in the outdoor chicks. This increased the energy requirements of chickens (van Krimpen et al., 2015b), and may have led to a lower weight gain among the chicks raised by mothers in the orchard. After 12 weeks of age for both groups, there was no significant difference in weight anymore. At 5 weeks of age, chicks raised without mother hens in the stable were also introduced in the orchard. Because of similar environmental conditions, growth rate was probably not different anymore between the groups.

Earlier studies have identified direct positive cues mother hens provide to raising chicks (Bestman & Wagenaar, 2003; Rodenburg et al., 2009ab; Edgar et al., 2016). This study took a more integrative perspective and introduced chicks with mother hens in orchards in order to provide more natural living conditions. Although this resulted in a more natural behaviour pattern shown by chicks raised by mother hens compared to chicks raised in the stable, allowing chicks in the orchard led to substantial losses of chicks due to predation. Therefore, to make the integrative approach of raising chicks by mother hens in orchards a viable alternative to regular practices in indoor stables, sufficient protection measures are required. Future studies should be aimed at finding methods to effectively reduce losses due to predation, thereby taken into consideration that the natural habitat should remain intact. Also, the practice of raising chicks by mother hens in orchards can still be optimized concerning replacement of fertile eggs or one-day-old chicks to improve hatching rate. Lastly, feed troughs can be adapted to decrease feed spillage and feeding of the more expensive chick feed by mother hens.

4.5. Dual purpose breeds

From the model calculations on profitability of rearing dual-purpose breeds using on-farm propagation compared to hybrid laying hens and broilers it was found that when mortality was equal between the two systems, using dual-purpose breeds resulted in 20% lower net income (table 4). This lower income was mainly because of a lower egg production of laying hens of the dual-purpose breed (65%) compared to hybrid breeds (84%). The number of eggs produced per year was consequently much higher for the hybrid laying hens compared to dual-purpose hens (appendix 3). Within the present study the relatively high mortality of chicks (50%) was unexpected. This caused net income to be much lower compared to when mortality would be 20%. If protection measures would be enhanced, mortality is expected to decrease, but still net income would then be 20% lower when integrating dual-purpose breeds with on-farm propagation compared to using hybrid breeds in orchards (table 4). However, when increasing the prices of direct sales of eggs of the dual-purpose breed from 25 cents to 30 cents, net income was modelled to be just as high. Prices therefore have a strong impact on the profitability of the system. This leaves the question whether the consumer is willing to pay the price. Consequently, this leads the discussion for rearing dual-purpose breeds more towards a value-based decision rather than an income-based decision (Gocsik, 2014).

In fact, any orchard system would already produce more outputs if chickens were integrated, because there is no extra land needed for rearing chickens and chickens can be readily introduced without major adaptations other than acquiring relatively simple sleeping, laying and feeding/drinking facilities. Besides, since there is an ethical call for finding alternatives to large-scale culling of one-day-old male chicks among laying breeds (Ellendorf et al., 2003) and physical development issues among fast-growing broilers (Bessei, 2006), rearing dual-purpose breeds may be more supported by the society and by farmers rearing organic poultry compared to rearing hybrid breeds (Nauta et al., 2003). Besides, as on-farm propagation and allowing adaptation of chickens to local conditions over generations is more in line with the values in organic agricultural systems (Luttikholt, 2007; Nauta et al., 2003; Lund, 2006), purebred dual-purpose breeds integrated in orchards with on-farm propagation may suit those systems better.

However, current initiatives to raise the cockerels of laying breeds for meat production seem promising (Lankerenhof, 2016). Besides, the physical development issues in slower-growing broiler breeds are already minimized compared to fast-growing broilers (Bessei, 2006). Therefore, dual-purpose breeds may not contribute substantially more to animal welfare than these implementations. On top of that, dual-purpose breeds still require a higher feed intake for the same meat or egg production compared to hybrid breeds, resulting in a higher environmental impact for rearing dual-purpose breeds (Ellendorf et al., 2003).

Yet, the present study has identified that the share of concentrates can be substantially lowered when rearing chickens in orchards and this finding is supported by other studies (Hermansen et al., 2004; Hughes & Dun, 1983). Therefore, if the comparison of feed use efficiency would be made on a more integral level between dual-purpose breeds and hybrid breeds, dual-purpose breeds may be more efficient. This is because hybrid breeds in indoor stables require a diet consisting of 100% concentrates (i.e. laying pellets). Chickens in orchard systems require only 50% concentrates, as identified in this study. Since high-protein containing ingredients and ingredients originating from a global market (esp. soy and palm oil) contribute more to environmental pollution compared to locally-grown grains (Nguyen et al., 2012), a life-cycle assessment for rearing dual-purpose breeds in orchards may result in a more positive outcome, because its impact is currently assumed for dual-purpose breeds in indoor stables (Ellendorf et al., 2013). Therefore, dual-purpose breeds integrated in orchards may be more efficient in the use of imported feed compared to hybrid breeds in indoor systems.

4.6. Synthesis

The present study has identified the main ecological relationships when introducing poultry in orchards following the management strategies of the studied farming system. First of all, an even fertilization of the soil-plant system by poultry litter is realized by using mobile housing. Furthermore, this housing type reduces disturbance of the soil-plant system and the natural habitat of chickens remains intact. This allows chickens to express their natural behaviours and on-farm propagation can be realised as a result. Provisioning of a natural habitat leads to higher foraging opportunities, including predation of earthworms and probably also predation of (damaging) insects (Hermansen et al., 2004; Koorn & Allmenröder, appendix 1). Concerning the latter, further research should be conducted to quantify the pest-control potential of chickens and the economical benefit as a result. The share of concentrates could effectively be reduced due to foraging opportunities (Hughes & Dun, 1983), which results in a lower environmental impact. Overall, introducing poultry in orchards increases production per unit of area, because in regular orchard production sward strips between the tree lines remain unused. The farming system produces more diverse products as a result. Predation of chickens by foxes and of chicks by rats was the main adverse ecological relationship in this study and is considered to be the main bottleneck for introducing this practice (figure 20).

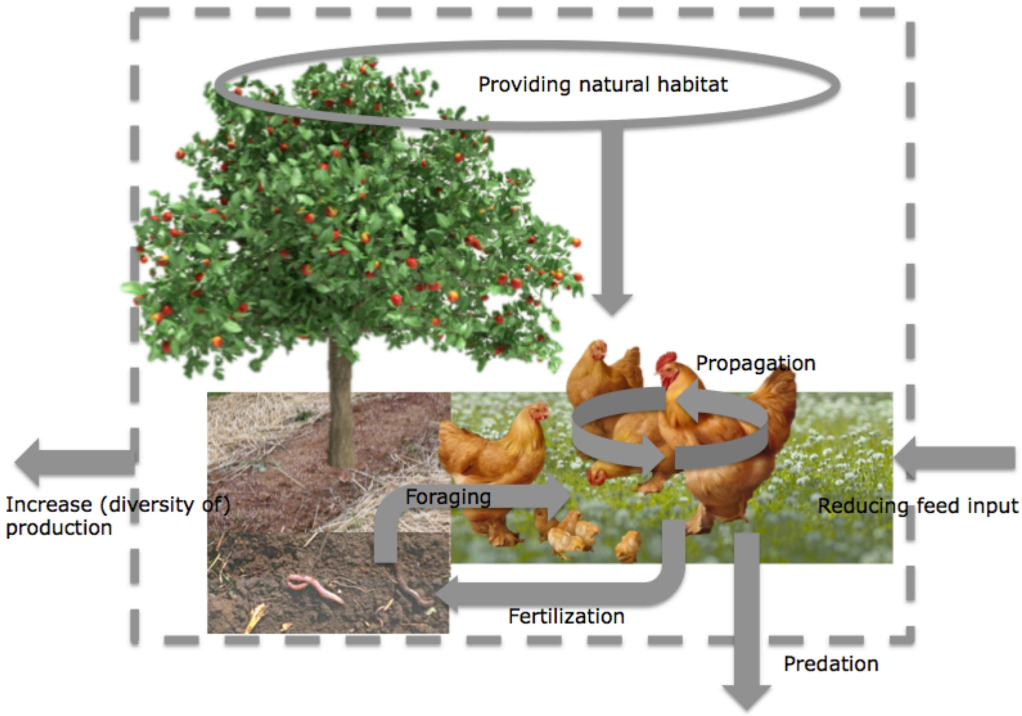

Figure 20: Overview of the main relationships when integrating poultry in orchards as found in the present study. Arrows indicate the relation to the (sub) system and the dashed square indicates the system boundary.

The position of the organic sector to focus on providing natural habitats has been criticized by disregarding other aspects of animal welfare (Lund, 2006), arguing organic chicken flocks tend to have higher mortality rates (Leenstra et al., 2012; Lervik et al., 2007; Hermansen et al., 2004). The present study confirmed this. However, if welfare would be understood as a concept in which chickens live natural lives (Fraser, 2003), then from this study it could be concluded that the welfare in an orchard system is higher compared to indoor systems. On top of that, allowing hens to become broody is part of their natural being (Edgar et al., 2016), making this system supporting the focus of organic husbandry even more compared to regular organic systems. Yet, animal welfare can also be understood as reducing animal suffering and good biological functioning (Fraser, 2003), where predation rates are decreased to a minimum level and production levels are maximised. In the latter case, raising chickens inside a protected housing facility meets the requirements better, since mortality is higher in outdoor systems (Leenstra et al., 2012).

For both outdoor and indoor systems to optimize welfare there are still challenges. Yet, often investments to improve animal welfare in indoor systems require price premiums before farmers are willing to adopt them (Gocsik, 2014). The middle-market segment gives therefore more interesting opportunities for farmers that have the motivation to increase animal welfare, because they are financially still attractive (Gocsik, 2014).

In an outdoor system, profitability of rearing dual-purpose chickens should be sought in diversifying the farming system such that it produces other outputs than chicken related products only. Integrating chickens in orchards using on-farm propagation provides a profitable basis for rearing dual-purpose breeds, because the system is not dependent on solely eggs or meat. This makes this practice suitable for farming systems aiming for diversification, which is one of the strategies for enhancing stable and resilient agriculture (ten Napel et al., 2006; Funes-Monzote et al., 2009). These aspects provide another profitable basis for rearing chickens by which animal welfare is enhanced, apart from the middle-market segment (Gocsik, 2014).

Yet, because of its extensive nature, poultry integrated in orchards has potentially a lower impact on increasing animal welfare in general compared to large-scale poultry production. In large-scale rearing systems any small improvement contributes more to animal welfare in general compared to transition-based small-scale rearing systems. Certain elements of the small-scale rearing system as postulated in this report can be identified and implemented in large-scale poultry production. For instance, provisioning of a more natural diet comprising of insect feed may lower the environmental impact of using concentrates (Wagenaar & Visser, 2006). Furthermore, a certain percentage of the cockerels of the laying breed can be introduced in the chicken flock and raised for meat production, which contributes to the ethical call for finding alternatives to one-day-old male chick culling (Ellendorf et al., 2003) and also contributes to reduced feather pecking (Wagenaar & Bestman, 2003). Also, as Edgar et al. (2016) already pointed out, artificial features of maternal care can be determined and implemented in large-scale rearing systems for raising chicks to improve their welfare, like dark brooders.

Still, there may be many farmers operating on an extensive small-scale basis that aim to diversify the farming system (van der Ploeg, 2000), making the practice of integrating dual-purpose chickens in orchards with on-farm propagation as presented in this study for those systems an interesting approach. Future studies could make an inventory of farmers that may be willing to adopt the practice of rearing dual-purpose breeds in orchards with on-farm propagation.

5. Conclusion

The practice of introducing chickens to orchards has not gained much attention over the last few decades, but may provide solutions to challenges current practices face, especially those following organic standards. This study focused on the main practical consequences and opportunities for the design of the integration of poultry in orchards, including housing conditions, feed provisioning, introduction of maternal care and the use of dual-purpose breeds. The main ecological relationships that shape the system of introducing poultry in orchards include an even fertilization of the soil-plant system by poultry litter. Furthermore, the integration of chickens in orchards leads to higher foraging opportunities, including predation of earthworms and possibly damaging insects. The share of concentrates in the diets of chickens could therefore effectively be reduced down to 50%. Integrating purebred dual-purpose chickens in an orchard system with on-farm propagation seems to be a promising approach for enhancing animal welfare from the perspective of living natural lives. Still, further research is needed to find options to reduce predation of chickens, which is considered the main bottleneck for implementing the redesigned chicken rearing system. Because of its extensive nature, poultry integrated in orchards has potentially a lower impact on increasing animal welfare in general compared to any small improvements implemented in large-scale poultry production. Such incremental improvements can be derived from the redesigned poultry rearing system as proposed in the present study. On the other hand, due to an increase in land and feed use efficiency, costs of integrating chickens in orchards are largely reduced. Therefore, integration of purebred dual-purpose chickens in orchards with on-farm propagation is suggested to be a promising approach for extensive small-scale farming systems aiming to increase diversity of products.

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Appendix 1

Assessing above ground dynamics of insect populations and vegetation after integrating poultry in orchards

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Introduction

Improving the sustainability of agriculture is becoming more important in cropping systems as well as in livestock production systems. Many of the current production systems are upscaled to reach maximum production, whereby the concentration of animals and plants are high and genetic diversity is low. This increases the impact of diseases or incidents tremendously (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). To maintain agricultural production levels following this paradigm, it is necessary to keep sources of disturbances on the system, like disease outbreaks or fluctuations in weather patterns away. For instance, by the exaggerated use of antibiotics and pesticides, that are extremely harmful to the environment and additionally boosts the evolution of immune disease strains. To create a system that is less susceptible to environmental variations but still economically attractive, it is important not to keep away the sources of variation, but reduce the impact of sources of variation by designing more robust agricultural systems (Napel, 2006).

An approach to do so is integrated farming. The aim of such combined systems is to both increase welfare of the animals by reducing animal densities and at the same time use beneficial characteristics of animals to reduce weeds and pests to acquire stable and high yields. As these systems are not very common in developed countries and are just evolving to prevent detrimental effects of current systems to increase (Edwards, 1987), very little research is done on its potential beneficial effects and interactions are still poorly studied. Mortality in biological farming is reported to be increased (Hermansen, Strudsholm, & Horsted, 2004), what makes it important to explore opportunities to counteract. There is evidence that integrated free-range poultry in fruit production increases welfare of chickens (B. O. D. Hughes, P., 1983), therefore integrated farming as such can have great potential, especially in biological systems, and should be further explored. Pedersen, 2004, showed that the presence of chicken leads to a reduction of apple sawflies, but there was no effect on production levels of the orchard. This agrees with an earlier research (Clark & Gage, 1996), where a reduction of the Japanese beetle, a pest in potatoes, was observed when chicken were present, but no beneficial nor detrimental effect on crop productivity was reported. These studies show that although pest suppression is successful, yields do not necessarily increase. But of course integrated farming means the integration of another system, with very often comes hand in hand with a new source of income. So total yield is likely to increase, based on different sources rather than on one.

According to Clark & Gage, 1996, chickens are not very effective against weeds, especially not at low densities, but this is not necessarily disadvantageous as weeds can provide space for beneficial organisms and natural predators (Lipecki, 2006) and are no real problem in fruit orchards as trees are not restricted by the growth of weeds. As long as the vegetation is supressed, a task that can be fulfilled by the chickens, competitive pressure will not play a role.

To draw conclusions about insect population dynamics and vegetation patterns as a result of foraging chickens in orchards, knowledge on the characteristics of chicken feeding behaviour is required. Being classified as omnivores chickens eat almost everything their beak can reach. The diet of jungle fowl and wild turkey poults consists of at least 50% insects (Klasing, 2005), which gives an idea of what domesticated chickens may eat.
To support such accusations and gain more knowledge about integrated poultry this study will evaluate the aboveground dynamics in a fruit orchard after introducing free-range chickens. The research will take place at the ''Fruittuin van West'', an organic fruit orchard in Amsterdam comprising 6.5 hectares. On the orchard twenty different kinds of fruit species are grown and 500 organic Lohmann Brown chickens are reared.
The chickens in the orchard are able to choose between provided feed and foraging on whatever they find in the orchard. An indication of how the hens feed themselves based on these two options is obtained by using a conversion factor which states how much kg of feed is used to produce one kg of eggs (Leenstra et al. (2014). The lower this value the higher the proportion of feed resulting from foraging. In an integrated free-range system this factor is suspected to be lower than in conventional systems, because the chickens use natural resources to fulfil their demands.
One effect of this natural feeding behaviour is the shaping of vegetation diversity and density on the strokes. Another aspect that is influenced by the chickens is pest suppression. Because the majority of pests in fruit trees live above ground (Samietz, Graf, Höhn, Schaub, and Höpli (2007), an indication of these effects can be identified through measuring insect abundance and vegetation patterns.
Based on this knowledge our hypothesis is as follows: We expect vegetation in areas where chickens were present to be more dense, because nitrogen supply is sufficient due to the manure. We also assume herb-like species to be dominant in areas where chicken are present, because it is likely that grass-like species are damaged worse by scratching. Insect populations are expected to be decreased and dominated by smaller insects, as we assume chickens to have a preference for large insects.

The aim of this research is to gain insight on the feeding behaviour of the chickens during foraging. This insight might contribute to determine optimal feeding ratios in organic systems, which lead to lower conversion ratios and thus more efficient feeding strategies. Additionally this knowledge can be used to explore the potential of chickens in Integrated Pest Management (IPM) and related opportunities to improve crop productivity.
This will be done by performing a series of experiments to answer the following questions:

1. Is the predator-prey relation between chicken and insects significantly influencing insect populations?

i. Chicken predate insects, do they prefer large ones? If so, would the ratio small/large insects increase in the orchard?

ii. Does the whole insect population in the orchard decrease?

2. In what way do chicken affect vegetation patterns?

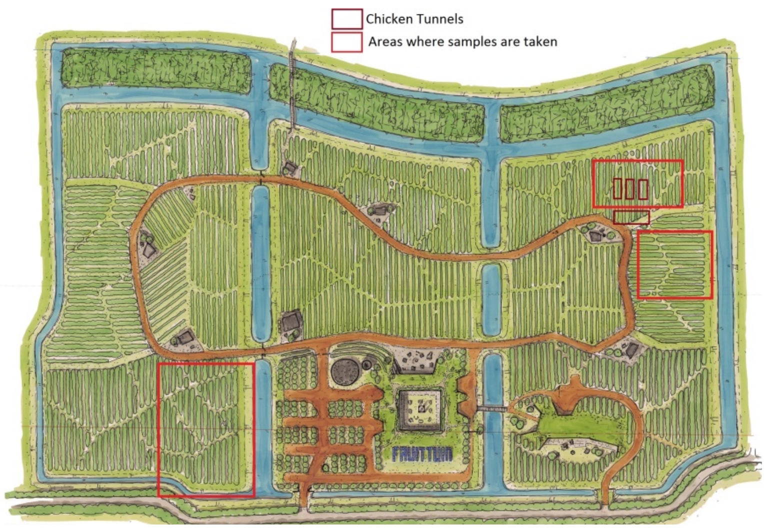
i. Does foraging result in rows more dense and richer in chlorophyll due to increased nitrogen availability by fertilization?

ii. Do bush-like vegetation species become dominant since they are less affected by scratching/grazing?

3. How can this knowledge be applied on optimal feeding systems?

Material & Methods

The measurements will be done in the orchard itself. The system is designed in a way that during the research there were three areas; one where chickens have foraged nine months ago, one that is free of chickens during our research and one where chickens are foraging during our research period. The red boxes in Figure 1, each in a different area, represent where most data is collected.



As stated in the introduction it is well known that chickens feed on everything they can find, so we split aboveground up in the two sub sections about insects and vegetation.

Insects

The aim of this study is to determine the dynamics of the insect population under the influence of poultry. Therefore an estimation of the absolute insect population is needed and will be derived based on sampling techniques as described by Landolt, Adams, & Rogg, 2012 and Southwood, 1978.
We will apply four different trapping methods that differ in selectivity and efficiency to get an indication of the insects present.
Besides this the traps are placed at different heights to catch flying as well as crawling insects. Insects normally pass different larvae and juvenile stages, that in most cases are cursorial, before reaching maturity. Chickens eat larvae and juveniles as well as adults, what makes it necessary to monitor all stages. This knowledge may also help to get insight on the dynamics of insect life cycles on the farm. The traps will be emptied one week after being placed.

Four methods used are:

1. Sweeping nets

This is a widely spread method, due to its simplicity and low costs. It will give an indication of insects present in the upper part of the vegetation and in the air.
Following the method of Rudd & Jensen, 1977, we decided to do 5 sweeps per measurement. In each area there were 4 randomly dispersed measurements in 5 rows, which in total meant 20 measurements per area.
Weather conditions have a great influence on this method and efficiency of this method, which were minimized by measuring when wind speed is low and shortly after it has rained (R. D. Hughes, 1955). The insects will be counted on the spot and released immediately afterwards.

2. Pitfall

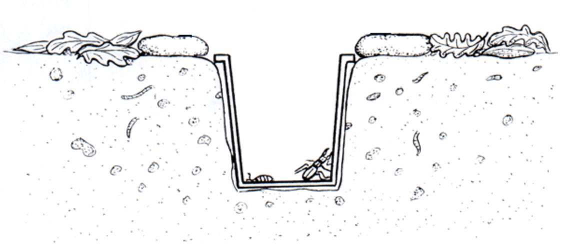


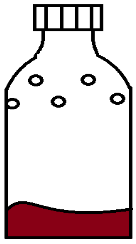
Figure 2 Scheme of a pitfall sunk into the soil.

Many life cycles of flying insects include stages where the insect is unable to fly and therefore cannot be monitored using flight traps. A common technique to catch cursorial insects is to place pitfalls, which are little cups sunk into the soil with their opening on surface level.
There were 6 cups randomly placed in each area, that will be emptied by hand and then analysed. (Jansen & Metz, 1979).

3. Yellow sticky traps

This is a flight trap combining interception and attraction using coloration.
Four strips were placed in an area where chicken are present, and four where they are absent. Density of the chicken population at the moment was 50% lower than during the other measurements. The density increased from 500 chickens per hectare, when the sticky straps where hung, to 1000 chickens per hectare.
The catch was collected four days later.
Then the batch was grouped based on body length, so effects on small flies like *Drosophila* could be distinguished from the effects on bigger ones. Insects with a body longer than 1.5cm are considered large, everything smaller than 0.5cm were listed as small.

4. Deli cup (bottle) bait trap



This method is the only one using a bait solution. The trap consists of a clear bottle, that was filled with a bait solution that in our case is a mixture of wine and vinegar to attract insects of the species *Drosophila.* At the top of the bottle there are small entry holes, that allowed the flies to enter but made it unable to get out. There were four cups placed in each area.

Figure 3 Sketch of a deli bottle bait trap as used in the experiments.

Vegetation

To visualize the impact of such a dynamic integrated system on the Vegetation ,the following research methods were performed:

1. Vegetation counting and observation
2. Harvest above ground parts and weigh biomass
3. Measuring chlorophyll content of the leaves for the three vegetation categories

It is important to gain insight on the composition of the vegetation, for instance which species are present in high numbers and how does this relate to fertilization? The N-content of the leaves is an important indicator of the amount of fertilization and can therefore contribute to the explanation of presence of clover.

1. Vegetation counting and observation

The counting was focused on three categories: herb like vegetation, grasses and clover. Herb like species contain plants like Sorrel (Rumex acetosa), narrow leaf plantain (Plantago lanceolata) and common comfrey (Symphytum officinale). Clover must be part of the observation because it is a proper indicator of the N content in the soil. It would not give a clear outcome to count clovers since they are stoloniferous, so this observation was based on whether grasses or clover were dominant.

2. Harvest Biomass

To check whether these observations are reliable the above ground parts are harvested and weighed. To research the clover-grass dominance separate biomass harvesting and weighing is a proper method. Six randomized samples that are 30×30 cm of size were harvested in each area. The samples were sorted in the categories: grass, clover and herb-like species. All sorted samples were put in the oven at 70 °C at Radix Agros for 12 hours and weighed afterwards.

3. Chlorophyll content

It is important to measure the chlorophyll content of the leaves on the regarding plot. This was done with a SPAD meter, a device that measures chlorophyll content directly on the unharvested plant (Chang & Robison, 2003). High levels of chlorophyll means higher N application pointing at high fertilization by chicken. In each area three measurements of grass, clover and herbs were taken on five strokes. This resulted in fifteen SPAD values of each specie per area.

Statistical methods

All data sets were analysed in SPSS Statistics 23 using ANOVA with a confidence interval of P < 0.05.

Results

Insects

Within the four different measurements that were used to assess insect populations clear trends could be seen. The presence of cursorial insects and flying insects captured on sticky straps and bait traps were decreased if chickens were present (Fig. 2-4). Another trend that could be seen by pairwise comparison of the area where chickens have barely been and the area where they were kept nine month ago and the area where they are now respectively. The differences between the area where the chickens were currently kept and where they have hardly been are clear, while the area where chickens were kept nine month ago lies somewhere in between those two areas, indicating that most of the effects are diverting and direct.
Unfortunately most of the differences turned out not to be significant, when evaluated with SPSS.

1. Sweeping nets

Assessing the insect populations using sweeping nets showed a pattern according to Fig.4. Least insects were caught in the area without chickens, while most insects were present in the area where chickens were present at the moment.

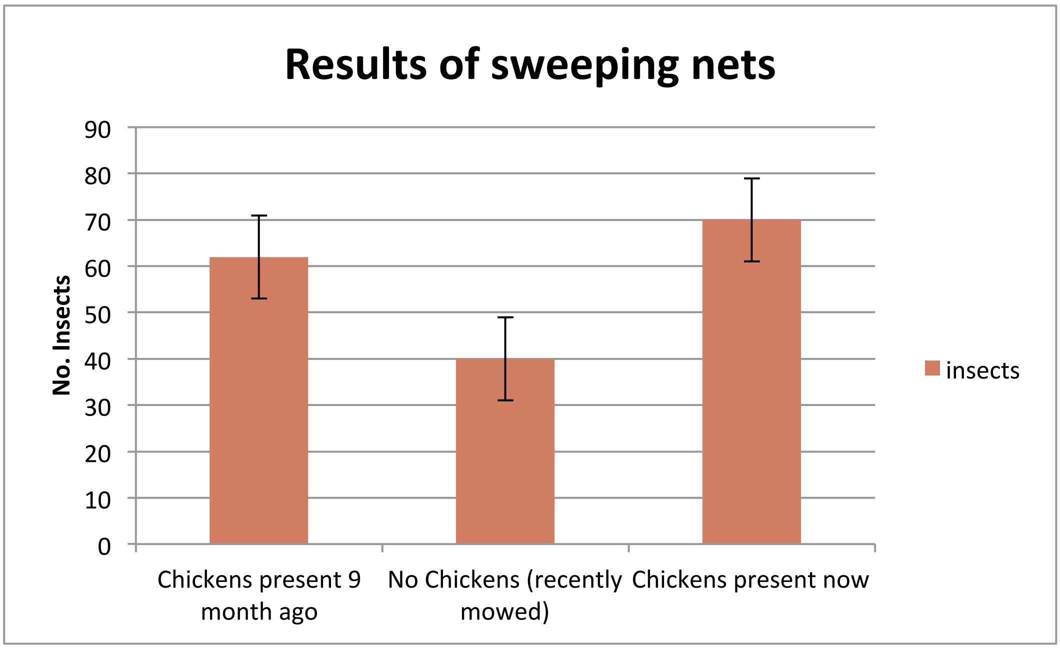


Figure 4 Insect populations in the different areas were assessed using sweeping nets. The area with no chickens was recently mowed and only 40 insects were caught. This is 35%/42% less than in the areas where chickens were present 9 month ago and are present now.

2. Pitfall

In each area 10 cups were placed. Some holes did not contain cups that got lost due to inexplicable reasons, and some cups were untraceable because the spots were not marked well enough. This led to reduction in our measurement sizes: In the area where chickens were present nine months ago and in the area where chickens were absent three and six out of ten cups could be scored respectively. The others where untraceable.

Because there was only one cup left in the area where chickens were present, the experiment in this area was repeated to get six cups.

Variation within those six cups was high. Those variation is not included in Fig. 5 as it displays the total batch. In the area where chickens were kept nine month ago the fullest cup contained 72 beetles, whereas the other two cups contained only 7 and 8 beetles. In the other areas variation was slightly lower but we still found different numbers of beetles between 2 and 19.

Most beetles where found in the area chickens were kept nine month ago.

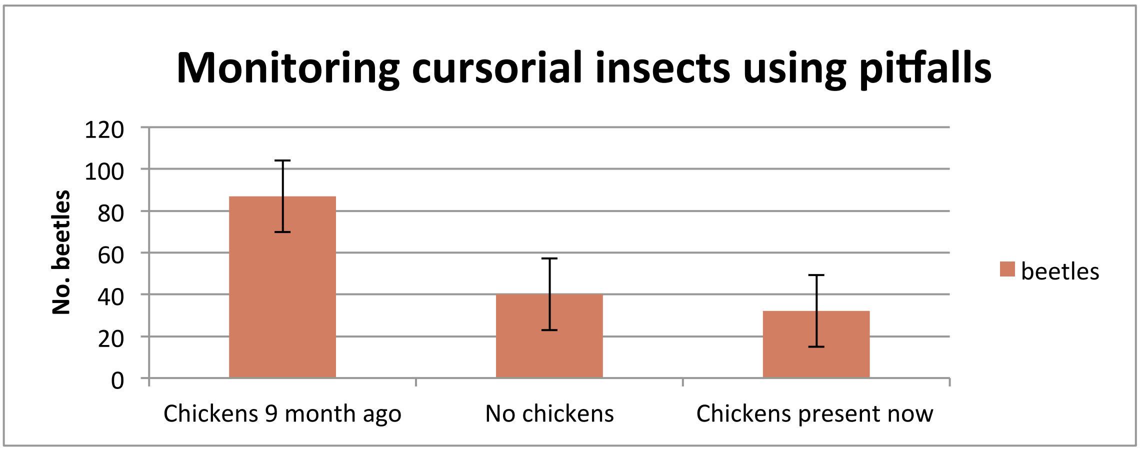


Figure 5 shows the beetles that were caught in the different areas using pitfalls. Most beetles (87) were found in the area where chickens were kept nine month ago. In the area where chickens are absent less than half of that (40) was caught and in the area where chickens are present the cups contained 32 beetles.

3. Yellow sticky traps

Scoring the yellow sticky strips showed that the overall insect population is decreased when chickens are present. This accounts for insects of all sizes. Small insects (bogy length <0.5cm) were dominant compared to large ones (length >1.5). Those large ones were rare, especially in the area chickens are present, and generally made up only 3% of the batch. Small insects with a body length of smaller than 0.5cm occurred quite often (Fig. 6).

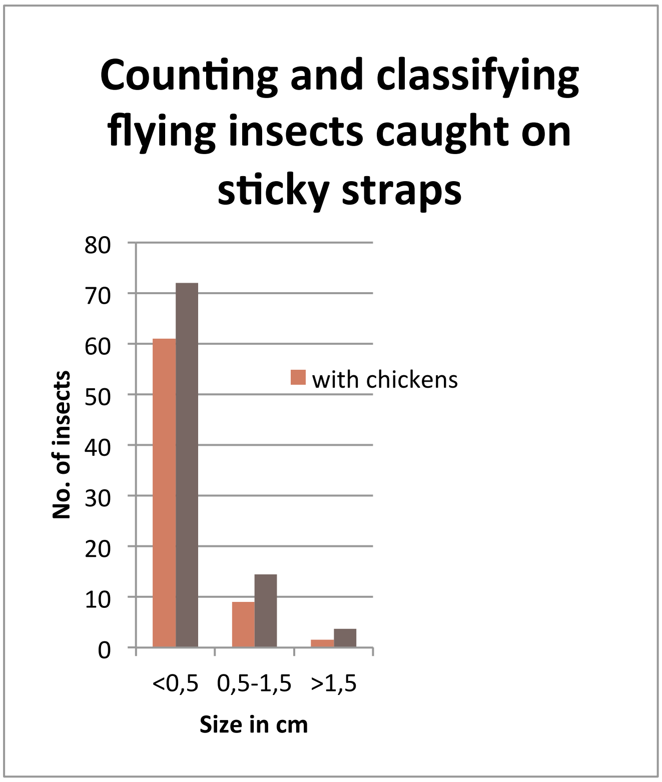


Figure 6 The insects found on the sticky straps were classified based on their body length. In the area with chickens present 85% small (<0.5cm), 13% medium (0.5-1.5cm) and only 2% large insects were found. In the area without chicken the population was increased by 26%. 80% of the insects found here were classified as small, 15% as medium and 4% as large.

4. Deli cup bait trap

The catch in the deli cup bait trap matched our expectations. Most insects were scored in the area where chickens are absent, while least insects were caught in the region chickens are around.
It was also noticeable that the insects caught in absence of chickens were more diverse. In those bottles not only small flies were scored, but also moths and large flies

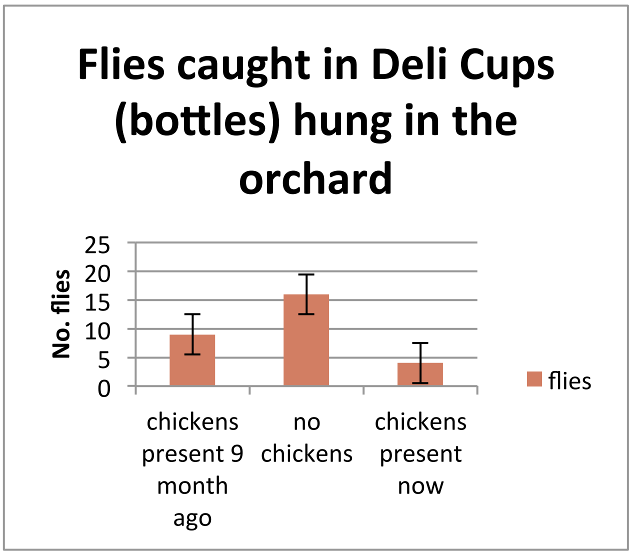


Figure 7 shows the flies caught in bait traps hung in the orchard. The amount of insects was highest in the area without chickens and lowest in the area were chickens are present now.

Vegetation
Thistle (carduae) was obviously present in the area without chicken, so thistle was counted as a separate category. Also a lot of thistle was found at the water side.
The least thistle was found where the chicken were present nine months ago,where the chicken are now is the number of thistle is inbetween and inthe area without chickens thistle is present in the highest number.
The herb-like species however were least present in the area with the chickens and most present if no chickens are present. The waterside gives an indication of a rough area, chickens foraged here, but not that much and mowig has taken place less frequently.

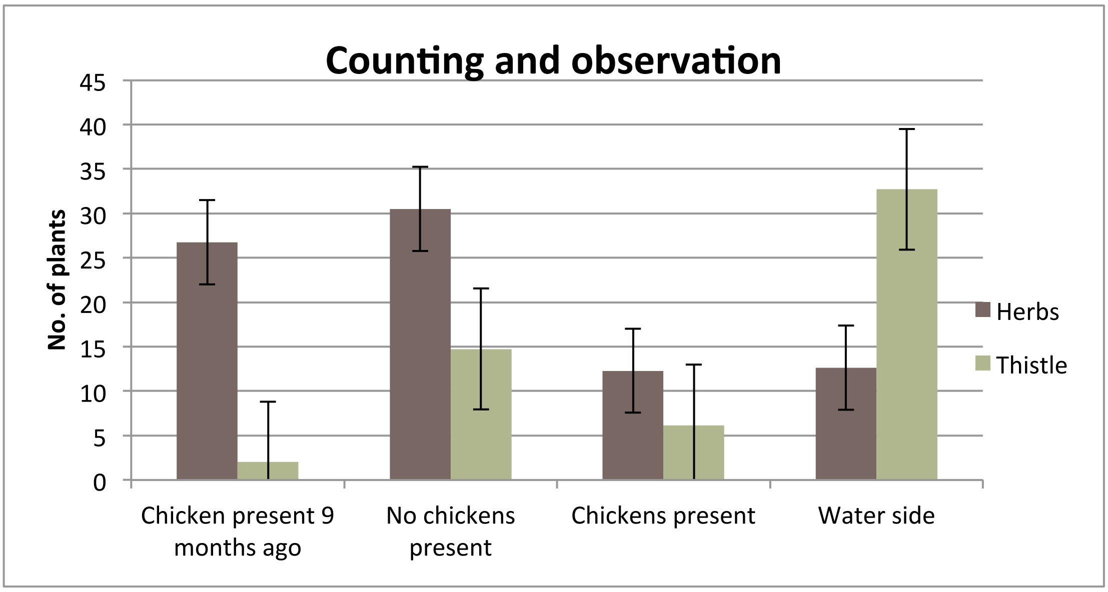


Figure 8 The number of plants count during the vegetation observation containing herb like species and thistle, each bar represents the average of three strokes, the counting is done for the three areas and the waterside, values are converted for equal stroke surfaces: 10×2 each stroke is counted twice.

Instead of an exact clover/grass counting the amount was approached by stating the dominace of the species for the different areas. We stated that clover was dominant in the area where the chickens have foraged nine months ago, grass was dominant in the area without chicken and an equal ratio was found in the area where chickens are foraging at the moment.

The clover dry weight was 44% of the total dry weight, which confirmed that clover is most present in the area where chickens have foraged nine months ago. The low percentage of the dry weight of herb-like species in the area with chicken is in agreement with the vegetation counting, where this area also contained the lowest number of herbs.

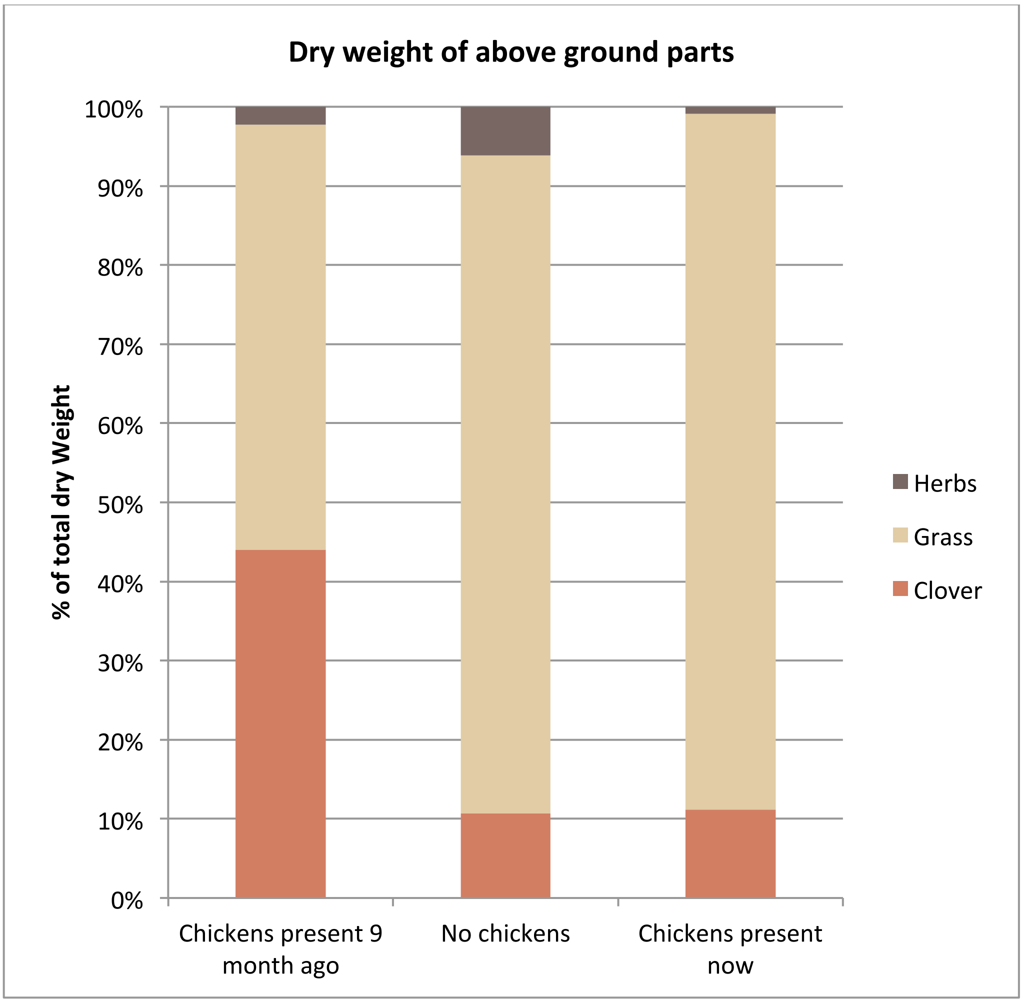


Figure 9 Dry weights in g of above ground parts of herb-like species, clover and grass as percentage of total DW on the three different areas.

When doing the observations hardly any Sorrel (Rumex acetosa) was observed in the area with chicken. A possible evidence for this low appearance of herb-like species in the area with presence of chicken is shown in figure 10 and 11 where a healthy leaf of Sorrel next to an eaten leaf of Sorrel is shown, indicating that chickens prefer foraging on sorrel.

Figure 10 Healthy leaf of Sorrel.

Figure 11 Eaten leaf of Sorrel.

The SPAD measurements showed that the lowest chlorophyll content for all species was found in the area where the chickens have foraged nine months ago. The highest chlorophyll content is measured in the area where the chickens are right now. Clover and herb-like species were significant indicators, but grass was not.

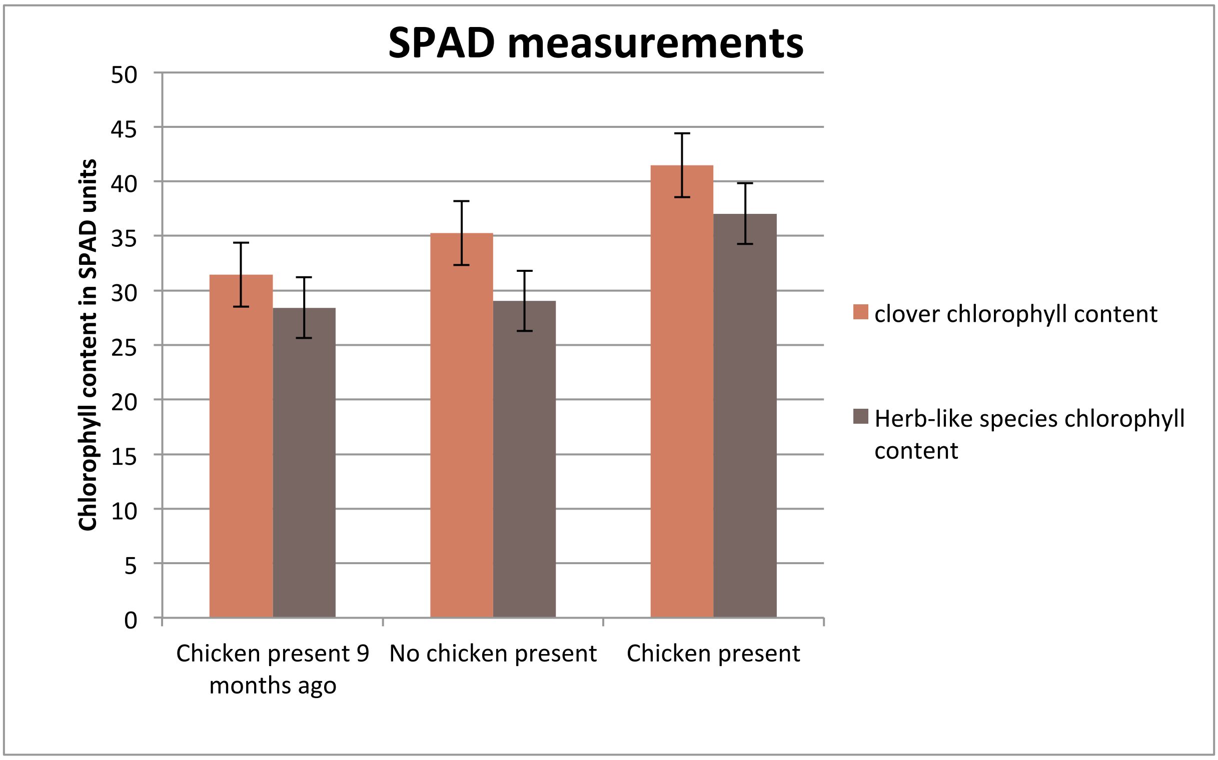


Figure 12 Chlorophyll content of clover and herb leaves measured with a SPAD meter.

Discussion

The results in relation to insects represent a lower number of insects compared to the area with the chickens. Except for the sweeping net method in which one catch in the area with chickens contained 15 insects whereas the other catches in that area differed between 0 and 7 insects. Probably this catch was done near the large chicken coop, so there was a bait-effect of the manure. Since other obtained data near the coop is used in the results, this one catch should not be excluded.
For the sticky strips, vinegar bottles and pitfalls the results are likely but one cannot fully rely on them since these catching methods would be more reliable if they would have been done over a longer time period with repetitions and when more samples would have been taken. The chickens also feed on below ground fauna, on which this research did not focus. What they forage below ground correlates to what they eat above ground and vice versa. To understand this relationship the research should be extended on the insect population as a whole.

Differences are found within the vegetation composition of the different areas, but in the orchard as a whole all vegetation was dense. The lack of vegetation however often plays a role in free range poultry systems, which can be seen in Fig. 13, where vegetation near the stable disappeared completely. Helen Hirt, 2000, also describes this uneven use of the hen-yard such that vegetation closest to the stable has disappeared. This high density of chickens on just a small piece of the hen-yard creates a manure load on this area with risks of N leaching and also risk for spread of disease among the chickens(Hermansen et al., 2004).

Figure 13 pictures taken of a hen-yard in De Kraats (GLD) where vegetation is damaged most near the stable.

Chickens in such systems are apparently not stimulated to forage the whole surface-area of the hen-yard, but stay close to the stable. In our orchard the chickens seems to be stimulated to do so since their stables are mobile; the chicken tunnels. To state how this influences the foraging behaviour of chicken more knowledge on animal behavioural science is required.

The high clover amount in the area where chickens have foraged nine months ago was astonishing at first, but the N applied during the time that the chickens were present must have leached since this is a big concern when applying chicken manure (Moore, Daniel, Sharpley, and Wood (1995).The time they were present was during September and October, which means that fall and winter makes the rinsing out of N go faster due to the high amount of precipitation. The same reasoning would be valid for the low chlorophyll content of leaves in the area where the chickens were nine months ago since this points out to a low N content in the soil.

The differences in vegetation composition might be due to chickens, since they fulfil their needs mainly by foraging. We cannot state that for sure since not all environmental factors are the same on the farm.

It is important to take enough measurements because research on the field is always dynamic. There are always environmental factors present when doing field research. Influences of cultivation and mowing for instance are also hard to determine, since mowing influences insect populations(Horton et al., 2003). Especially when doing research at the Fruittuin van West, which has a more robust design, sources of variation are thereby not kept away but are compensated due to high dynamics of the orchard. This robust system makes it harder to obtain reliable results. The design itself is still changing, the farmer is the first in the Netherlands who uses such an integrated system, which makes it impossible to compare it with others. To test what works best it is needed to innovate, doing so by creating new chicken husbandry, for instance to enlarge the coop using a new innovative stable, that was introduced after the chicken tunnels.

Conclusion

Integration of poultry with fruit production in orchards entails a change in dynamics of insect populations and a reduction of herb-like vegetation present in the system. Many of those effects are beneficial to the farmer. Insect populations are decreased and kept under control due to foraging by the chickens. Herb-like species are reduced by the presence of laying hens and vegetation on the strokes contains more nitrogen . Furthermore, manure is evenly distributed and vegetation patterns are uniform in areas where chickens are kept due to permanent outdoor access with mobile chicken coops resulting in natural feeding behaviour. This natural diet comprises both insects and vegetation. However, density in the evaluated system was relatively low. This causes dense vegetation in the rows even though chickens feed on the vegetation. Periodical mowing is therefore required. The optimal density of chickens is considered to be higher. This potential is to be explored, but holds great opportunities for further research regarding density of chickens and length of the periods between mowing.

But reduction of mowing is just one example of many beneficial effects of rearing chickens in orchards. Another advantage of integrated poultry with fruit production in orchards is, that it meets the demand by society for production that is sustainable as well as animal-friendly. Such commercial trends and a growing population call for systems where requirements are reduced to a minimum and production is optimized.

This research gives an indication of the opportunities an integrated orchard holds and provides a base for further research. Beneficial effects of poultry were evident even after short time periods and in an unsteady system, where chicken density fluctuated a lot.

If this research was elaborated the systems full potential could be realised, leading to higher efficiencies compared to conventional orchards.

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Appendix 2

Integrating free-range laying hens into orchards: The response of macrofauna to tree strip cultivation and the potential of reducing feed-conversion

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Abstract

Tree strip cultivation in integrated organic orchards with laying hens carries a great potential to reduce the feed conversion of chickens due to foraging on macrofauna. The response of earthworm populations to cultivation was conducted by taking soil samples on three differently managed areas; one field without chickens, one field where chickens were grazing 9 months prior to the time when the data were gathered, and one where hens were grazing during the data were gathered. Higher numbers of earthworms were found in the field where chickens were present. This may be explained by increased fragmentation, input of manure and disturbance, which may promote earthworm migration towards the upper soil layers and promote growth and reproduction. Cultivation had a positive impact on macrofauna abundance in the absence of chickens. In the presence of chickens, macrofauna levels decreased significantly upon cultivation but seemed to have regenerated within 16 days. Correlations between numbers and weight of earthworms suggested a shorter life expectancy in systems where chickens were present. Tree strip cultivation can reduce the feed conversion significantly, making this practice for farmers an advantageous strategy to reduce feed costs and overcome potential nutritional deficiencies due to new regulations imposed by the EU on the organic poultry sector.

Introduction

Since the 1930s food production has been moving towards more compartmentalized agricultural systems and large scale monoculture production (Pingali, 2012). Agriculture is currently the source of 24% of the greenhouse gas emissions into the atmosphere (IPCC, 2014) and thereby a remarkable contributor to climate change, causing harsher and less predictable weather (Fisher et al, 2002). Facing this, as well as decreasing availability of non-renewable agricultural inputs such as fossil fuels and inorganic phosphorus (Brecha, 2012; Rhodes, 2013), and raised public awareness around the issues of fair and localized trade, land use and animal welfare (Thompson et al, 2011), the systems within this paradigm are being challenged and criticized. There is a call for finding smart methods for ecological intensification, that utilize and offer ecosystem services, and are robust food production strategies within the changing landscape of the abovementioned environmental, political and social concerns (Bommarco et al., 2013). This study focuses on ecological intensification of orchard systems, whereby laying hens are introduced to serve multiple ecosystem services. More specifically, this paper will explore the potential of reducing the feed-conversion of the hens due to increased foraging on macrofauna, indicated by earthworm abundance, after soil cultivation. This is an urgent question for the organic laying hen sector as feed prices account for 70% of the variable costs (Walker & Gordon, 2003), and as it will no longer be allowed to include non-organic ingredients into the feed in the EU by December 2017 (Krimpen et al, 2015). This brings with it a great challenge of avoiding protein deficiencies, especially methionine (Krimpen et al, 2015; Wagenaar & Visser, 2006). Insects such as mealworms and earthworms, would provide a nutritional solution, but it is not economically feasible to buy them as a replacement for soybean cake or similar inorganic high protein feed sources (Wagenaar & Visser, 2006).

The measurements described in this paper are performed in a mixed fruit orchard and poultry production system, Fruittuin van West, located in Amsterdam. It is a 6.5 ha farm, which includes about 20 different species of fruit trees and berry bushes, and 500 laying hens living in mobile chicken coops. The current managers keep the chickens for egg production, which is an important source of income for their business. They are also aware of the potential of applying the chickens as a treatment to forage on pests, weeds and fertilize the food crops. Research on how to optimize and sustainably run such a system is lagging behind. The research that has been done on free-range laying hens in orchards mostly focusses on broilers, and looks at aspects such as animal welfare and pest and weed management benefits (Clark & Gage, 1996; Jones et al., 2007; Dal Bosco et al., 2014; Lavigne et al., 2011). Until now, the only study that linked free-range chicken management practices in orchards to soil quality found no significant reduction in earthworm populations three years after the integration of chickens (Clark & Gage, 1997). The integrated system studied was an orchard intercropped with potatoes. It also concluded that earthworm populations where positively correlated with soil organic matter, whilst soil organic matter was negatively correlated with cultivation (Clark & Gage, 1997).

The managers of Fruittuin van West apply a so-called Tournesol for soil cultivation on a strip of about 50 cm wide and 2 cm deep on each side of the trees and bushes every 2 months and 6 weeks respectively. Such a management practice, also called tree strip tillage or milling, is fairly new within the organic fruit sector (Granatstein & Sanchez, 2009). The organic fruit growers apply it in order to reduce weed competition and rodent habitat, and enable soil aeration (Granatstien & Sanchez, 2009). The manager in Fruittuin van West applies it because it releases nutrients to the trees and reduces competition by other vegetation and aerates soil (personal communication). The practice is both effective and cheap, but may cause damage to tree roots and/or deplete soil organic matter and soil fauna (Granatstein & Sanchez, 2009). To avoid these negative consequences, research needs to be performed on suitable depth and timing of cultivation, root pruning and regrowth, need for organic matter compensation, and effect on soil macrofauna.

Experimental research has shown that conventional tillage can significantly decrease the earthworm abundance and biomass, as well as alter earthworm species composition (Chan, 2001). In studies that measured earthworm abundance under conservation tillage, higher populations of earthworms tend to be found, though the effect found for species composition is similar to that of conventional tillage

(Chan, 2001). This paper will explore whether tree strip cultivation – a practice much less intensive than conventional tillage – will cause a decrease- or an increase in earthworm abundance (hypothesis I), and if earthworm populations regenerate in absence of tillage (hypothesis II). Answers to these questions may enable development of agricultural systems where earthworm populations can be viewed as a free and regenerative feed resource for poultry. This paper will explore this as an opportunity by measuring whether the decrease of macrofauna is stronger in the presence of chickens (hypothesis III), and whether the feed conversion of the hens drops after exposure of macrofauna due to soil cultivation (hypothesis IV).

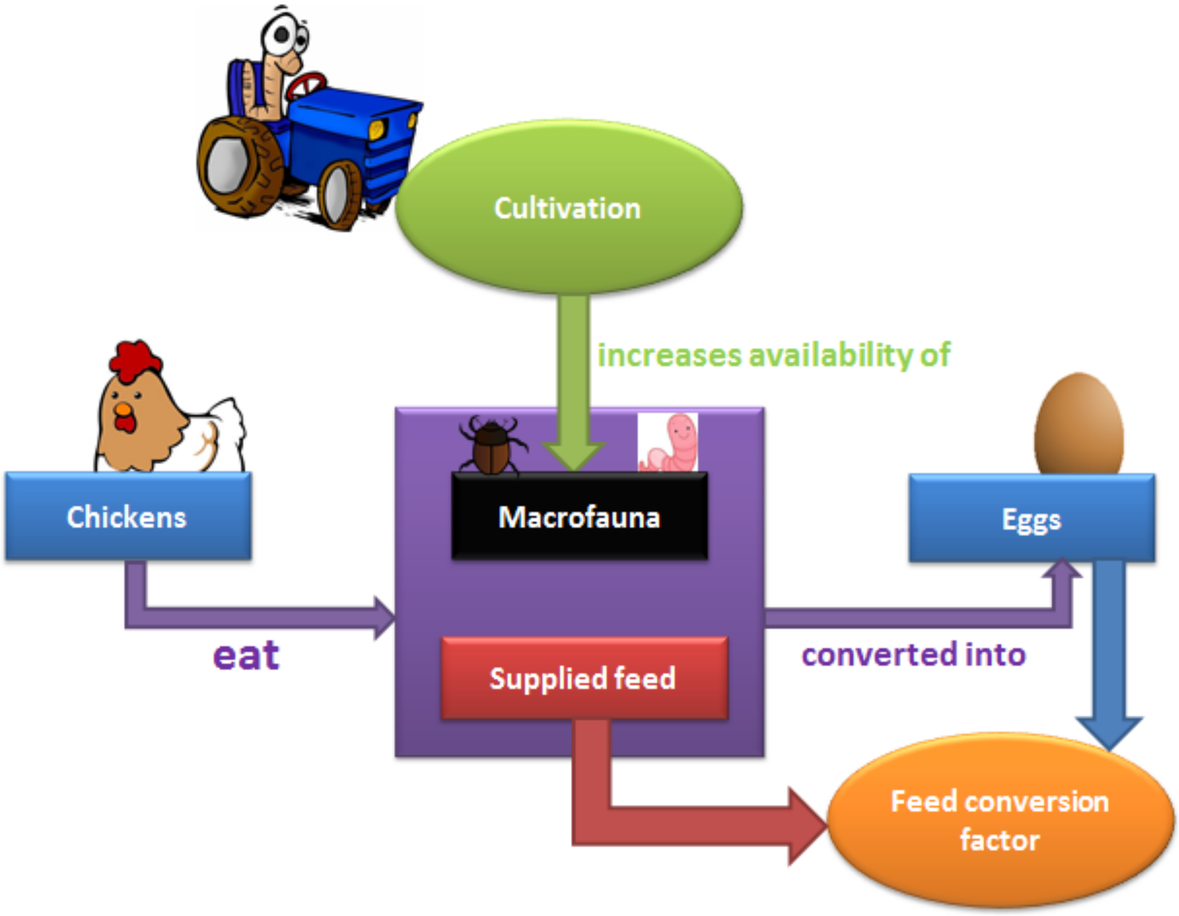

Figure 7: A conceptual map of the interaction between presence of chickens and cultivation and their combining effect on the feed conversion factor

The feed conversion factor is a measurement of the productivity of laying hens that equals the amount of consumed supplied feed (kg) per produced egg (kg). In the Netherlands feed conversion factors of different production systems range from 1.99 for battery cage hens up to 2.59 for organic hens (Dekker et al, 2011). In the system researched for this paper, the average feed conversion factor was 2.42 (Zandbergen 2016, preliminary). However, unlike other organic laying hens, the chickens in Fruittuin van West are getting feed that contains only 50% of laying pellets and 50% of grains. Considering this, the hens in Fruittuin van West could be regarded to be more productive, in terms of feed costs, than battery cage hens. The managers think the chickens are able to maintain such a high production level because they forage on the available macrofauna (personal communication). A decrease to an even lower feed-conversion after increased macrofauna exposure, due to soil cultivation (hypothesis IV), would strengthen this assumption.

Materials and Methods

Study area

The study area is located in the west of Amsterdam, the Netherlands, on the fruit orchard "Fruittuin van West" between Zwanenburg and Geuzenveld-Slotermeer. The orchard comprises of 6.5 hectares with 500 chickens of the Lohmann Brown breed.

Sample collection

Feed conversion

The amount of feed consumed by the laying hens was calculated by determining the weight of the supplied feed (kg) before and after cultivation was performed. Eggs were collected at the same day of cultivation. The weight of 10 eggs was measured six times (kg fresh biomass), averaged, and multiplied with the number of eggs collected. Feed conversion was calculated by dividing total amount of feed by total weight of eggs. Results were compared with data from Zandbergen (preliminary, 2016), collected in the same study area using the same methodology.

Number of chickens present within the area where the eggs were collected was determined by counting all the individuals present within the coops after sunset, during the night before cultivation was performed. The chickens were counted four times by four different individuals. The average number of chickens was used to calculate the laying percentage. Results were compared with data from Zandbergen (preliminary, 2016), collected in the same study area using a similar methodology.

Macrofauna

As earthworms are arguably the most important components of the soil biota in terms of soil formation and maintenance and soil structure and fertility, and their large size makes them one of the major contributors to invertebrate biomass in soils (Edwards, 2004), the abundance of earthworms was used as an indicator for soil macrofauna. At each sample site, approximately 20x20x20 centimetres of soil was removed by digging vertically into the ground with a spade. Earthworms from each cube of earth were sorted and counted by hand. Due to large variability in earthworm size, weight of the total number of worms was determined per sampling site at three points in time in rows that were cultivated as well as in rows that remained uncultivated. Average weight per worm was calculated by dividing weight per sample (g) with total number of worms per sample.

The method of measuring earthworms used may cause high soil disturbance, but is one of the most commonly applied soil sampling methods and works in all soil types (Carter & Gregorich, 2007) and facilitates a conducive basis to examine correlations between different management practices and earthworm population densities (Blair et al., 1996). As the distribution of earthworm populations are usually of patchy nature (Carter & Gregorich, 2007), the sampling was carried out systematically in a "zic-zac" pattern (figure 2). This sampling method is known to be more representative for patchy distribution patterns than random sampling (Coyne et al, 2007).

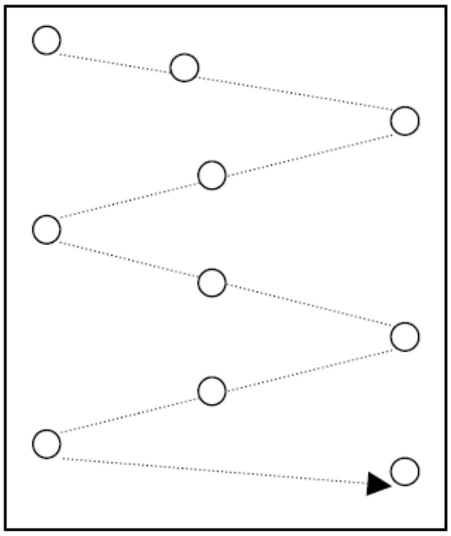

Figure 8: Systematic "Zic-Zac" sampling pattern

When possible, six samples were taken to obtain significant results for each area and point in time. The samples were taken the day before cultivation, during the day when cultivation was practiced, eight days after cultivation, eleven days after cultivation and sixteen days after cultivation in three different fields, referred to as 'No Chickens', 'Chickens 2015' and 'Chickens 2016' (figure 3). 'No Chickens' never had chickens present grazing and foraging prior to measurements were taken. In 'Chickens 2015', chickens were present at a density of 1000 chickens per hectare for 4-5 weeks (thus: 500 chickens per field), 9 months prior to the first measurements were taken. In field 'Chickens 2016' the chickens were present at a density of 1000 chickens per hectare one week prior to the first measurements were taken, and they remained present for all of the later measurements.

Statistical analyses were performed using SPSS version 22 on analysis of variance (ANOVA). The gathered data points were tested for normal distribution by ensuring that the error variance of the dependent variable was equal across the groups. With normal distribution confirmed, groups with similar dependent variables were compared pairwise for different fixed factors at a significance level of 0.05.

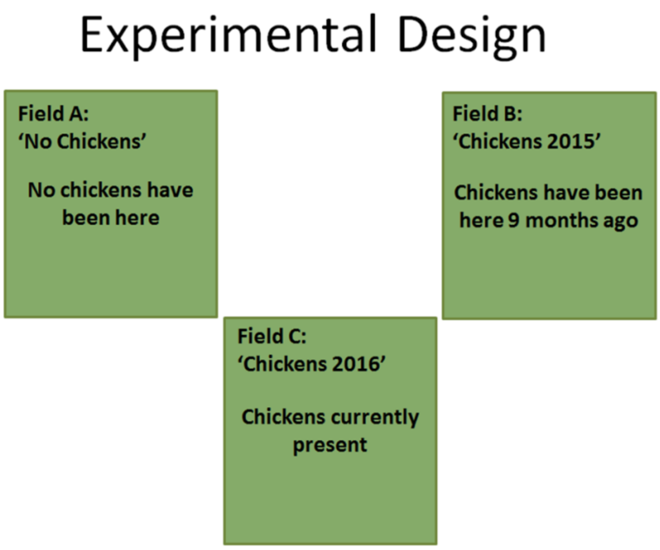

Figure 3: The experimental design used to obtain results; Three differently managed fields, field A where no chickens have been, field B where chickens were foraging in 2015 and field C where chickens are currently (2016) foraging

Results

Feed conversion

Data from Zandbergens study (2016, preliminary) showed that the feed conversion of the laying hens in the absence of cultivation was 2.44. After cultivation of 4.5 rows, a 20% drop in feed conversion to 2.03 was measured. This value is outside of the 95% confidence interval for feed conversion measured in the absence of cultivation. The laying percentage was also considerably lower at 73.3% compared to 84.4% measured by Zandbergen (2016, preliminary). The values found for laying percentage were outside of the 95% confidence interval of recent laying percentage measurements. For the statistical analysis of the laying percentage recent data was used, since former research indicates that the climatic environment is a primary factor affecting egg production (Garces et al., 2001).

Macrofauna

Before cultivation (figure 4) the areas ‘No Chickens’, ‘Chickens 2015’ and ‘Chickens 2016’ had an average of 14.2, 13.5 and 24.8 worms respectively. Statistical analysis showed that the average population of macrofauna was significantly higher ($P < 0.05$) in the presence of chickens (‘Chickens 2016’) than in their absence (‘No Chickens’ and ‘Chickens 2015’).

The day of cultivation (figure 4) significant ($P < 0.05$) changes in macrofauna populations of 36% increase and 43% decrease were found in ‘Chickens 2015’ and ‘Chickens 2016’ respectively as a result of cultivation. Field ‘No Chickens’ showed a similar trend as field ‘Chickens 2015’, with an increase in earthworm population of 36%.

Eight days after cultivation no significant changes in earthworm populations were found except for ‘Chickens 2015’, where macrofauna population had decreased ($P < 0.05$). Sixteen days after cultivation the levels of macrofauna were similar to those before cultivation ($P = 0.590$). Increase compared to measurements of day 0 and day 8 were confirmed with a significance of 0.069. Due to the management of the production system, it was not possible to measure the other fields as they had been cultivated again by the managers of the system.

To correct for possible initial deviations due to weather conditions, control measurements of macrofauna in absence of cultivation were taken during dry and sunny weather and were compared to the moist and rainy conditions present during the day before cultivation and the day of cultivation. The measurements during dry weather were taken on two different days and no significant difference was found between the two days or in comparison with the measurements taken during the rain.

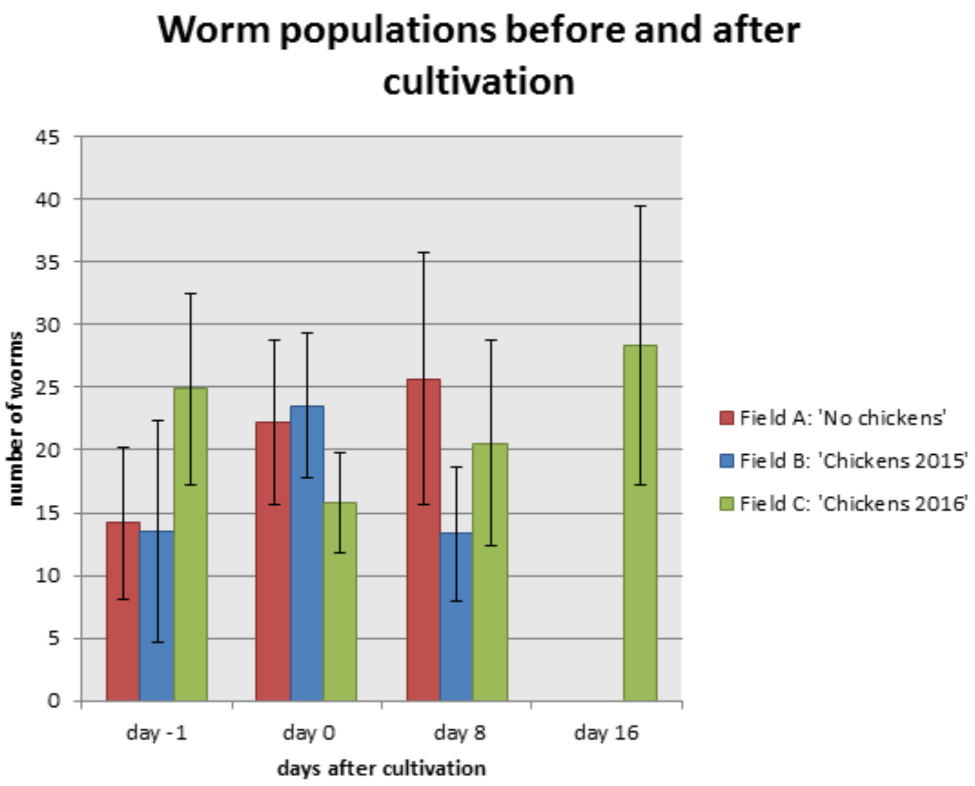

Figure 4: Number of worms measured before (day -1) and after (day 0, 8 and 16) cultivation in field A with no chickens, field B where chickens were present for 4-5 weeks 9 months previous to the first measurements and field C, where chicken were present one week prior to and during the measurements. Before sampling date 'day 16' the Fields A and B were cultivated again, and therefore no data about Field A and B on day 16 is available

The average total worm weight per sample site was found to not differ between the non-cultivated and cultivated rows (figure 5). However, statistical analyses were not performed on these data as the results did not show a normal distribution.

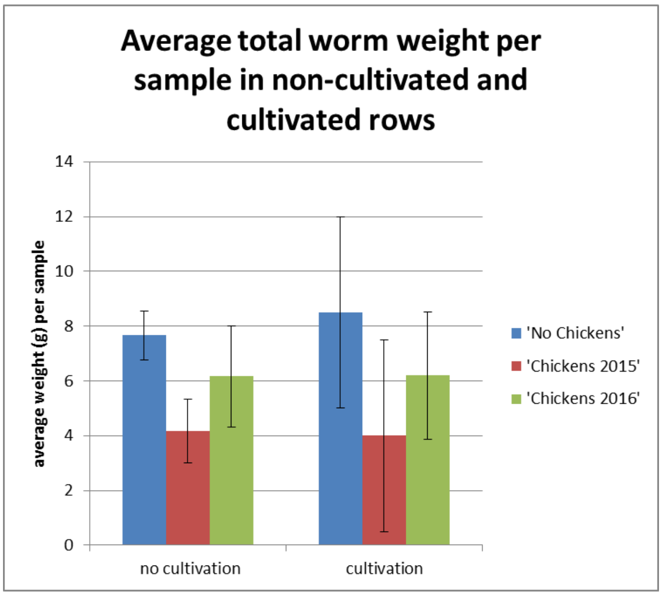

Figure 5: Average total worm weight per sample in non-cultivated and cultivated rows were found not to differ significantly

The pooled results from before and after cultivation did show a normal distribution with significantly higher numbers ($P < 0.05$) in the area 'No Chickens' compared to both 'Chickens 2015' and 'Chickens 2016' (figure 6).

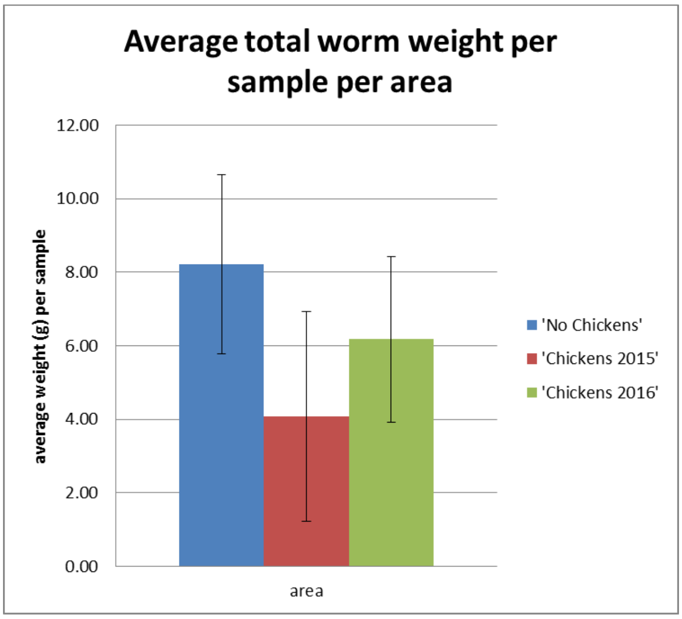

Figure 6: Average total worm weight per sample in the three different research areas 'No Chickens', 'Chickens 2015' and 'Chickens 2016'. 'No Chickens' has significantly higher worm weights than 'Chickens 2015' and 'Chickens 2016'

The data for average weight per worm is normally distributed, and found to not differ significantly due to cultivation. From the pooled results before and after cultivation, average weight was found to be significantly lower ($P < 0.05$) in the field where the chickens were present at the moment of sampling, 'Chickens 2016', compared to both of the fields where they were not, 'No Chickens' and 'Chickens 2015' (figure 7).

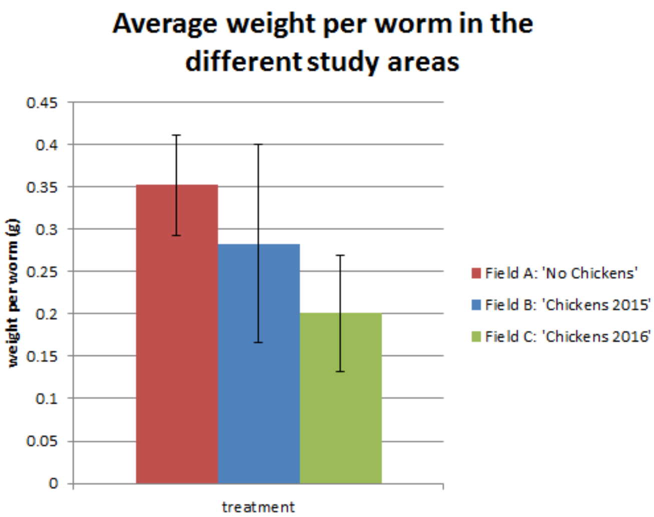

Figure 7: Average weight per worm measured in field A with no chickens, field B where chickens were present for 4-5 weeks 9 months previous to the first measurements and field C, where chicken were present one week prior to and during the measurements

Discussion

Feed conversion

The feed conversion after cultivation decreased by 30% from the average feed conversion in the absence of cultivation in previous measurements (Zandbergen 2016, preliminary). This differs clearly from our observed decrease in feed conversion of 20% after cultivation. Similar divergence was found for the laying percentages of 84.4% and 73.3%, respectively. This gives reason to believe that there may have been an error not accounted for, caused by not-found or predated eggs. Since the chickens got introduced to the area only one week prior to the first measurements, many hens were not familiar with the positioning of the nest boxes intended for egg laying, which meant eggs were found both within the foraging area as well as in the nest boxes (figure 8).

Figure 8: Some chickens were laying eggs in the grass instead of in the nest boxes. Because of the tall grass, these eggs were hard to find and some may have been overlooked

When assuming there is an error in laying percentage, and accounting for this error by recalculating the feed conversion, with the average amount of eggs usually produced by means of the average laying percentage, a new feed conversion of 1.77 is found (figure 10). This seems reasonable, as the laying percentage is, regarding the season (springtime), not expected to vary extremely. 27 eggs may be overseen easily due to the tall grass (figure 8) or possible predation of eggs by crows (Sullivan & Dinsmore,1990). Next to this, other reasons such as rain may have influenced the feed conversion as well, due to the fact that the main activities of free-ranging hens like grazing, ground pecking or ground scratching are weather-dependent (Hughes and Dun, 1983). According to the assistant performing the cultivation (personal communication), the chickens were less active foraging for worms during our measurements than during previous measurements (figure 9).

Figure 9: Pictures of chickens foraging in cultivated rows during rainy weather (left) and dry, sunny weather (right)

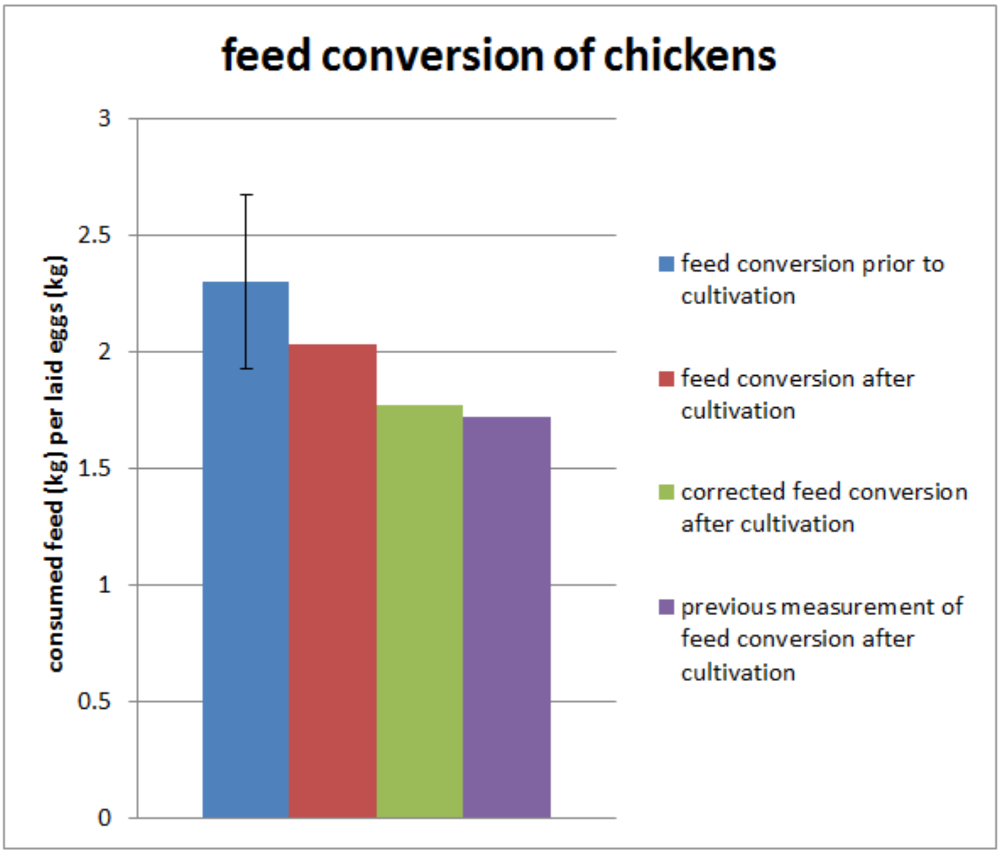

Figure 10: Measured feed conversion prior to cultivation and after cultivation; as well as recalculated feed conversion when low laying percentage was accounted for and feed conversion of a previous measurement

Macrofauna

Considering that chickens forage on macrofauna populations, it may seem surprising that the number of earthworms was significantly higher in the presence of chicken than in their absence, before cultivation. But even though foraging by the chickens takes place, there are several reasons for an increased earthworm abundance. As chickens produce organic matter in form of manure, it contributes to the food source of earthworms (Edwards & Bohlen, 1996). Furthermore, former research has showed that animal dung and nitrogen-rich diets increases the growth rate of earthworms (Edwards & Bohlen, 1996; Evans & Guild 1948; Barley 1959). Chicken's natural foraging behaviour commonly includes grazing, ground pecking and scratching of superficial soil layers, which contributes to the fragmentation and mixing of soil organic matter and litter. The growth rate of earthworms is strongly influenced by the particle size of provided food, explaining a stronger reproduction in the presence of chicken (Boström & Lofs-Holmin 1986; Edwards & Bohlen, 1996). Next to this, soil disturbance stimulates earthworms to migrate to the soil surface (Edwards & Bohlen, 1996). Predators use these behavioural patterns and apply different stimuli, such as picking on stones or stamping on the soil surface (Edwards & Bohlen, 1996), to initiate a greater abundance in the upper soil layers. This effect is also strengthened by the tree-strip cultivation and thus explains the higher numbers of worms after cultivation.

The divergence of earthworm abundance between the field without chickens and the field where the chickens have been 9 months prior to the measurements ('Chickens 2015') may be due to heterogeneous soil conditions. The soil in 'Chickens 2015' seemed to be consistently poor in organic matter and varied extremely in texture and structure. The samples were ranging from a heavily compacted clay to loose sandy soil conditions. These variations were confirmed by the manager (personal communication). Within the areas 'Chickens 2016' and 'No Chickens' the soil conditions were comparable in texture and structure, and seemed to have consistently more organic matter than 'Chickens 2015'. These soil factors were a source of variation not accounted for which influenced the results causing variation additional to the variation caused by earthworms natural patchy distributions due to microclimates and their inability to migrate long distances (Edwards, 2004), and may offer an explanation of the lower earthworm abundance in the field 'Chickens 2015' compared to 'No Chickens' 8 days after cultivation.

Rainfall can explain variation in earthworm numbers more than any other variable in a range of agricultural soils (Baker, 1998). During the period of sampling, different weather conditions were expected to have an influence on the number of earthworms found. However, control measurements taken during dry and sunny weather did not differ significantly as they were all found to be inside the same 85% confidence interval. The moisture content of the soil may also influence the fresh weight of earthworms (Edwards & Bohlen, 1996). Even though the weight of earthworms was only measured during dry and sunny weather, this is a factor that may cause extra variance that has not been accounted for.

Weight was measured to get a deeper understanding of the dynamics within the system. Due to time restrictions some samples had less than six repetitions. It may be because of that, and due to the low accuracy of the scale used and large variance within the data, the measurements of total worm weight per sample site were found to not be normally distributed. This inhibits further statistical analysis, however data may still be taken into account as indications. It seems odd that cultivation has a very strong effect on earthworm numbers, but no visible effect on earthworm weight. The higher numbers of earthworms may be explained by fragmentation and mixing of soil organic matter and litter, as well as by stimuli applied by chickens and possibly cultivation (Boström & Lofs-Holmin 1986; Edwards & Bohlen, 1996). Cultivation as well as chickens may have killed larger sized worms. Thus the increased number of worms may have been counterbalanced by the death of a low number of heavy worms. The data of weight per worm confirms this hypothesis: The weight per worm was significantly lower ($P < 0.05$) in the area where the chickens were present at the time of sampling. These data point out an additional effect of the system; chickens do on the one hand promote higher earthworm numbers and on the other hand lower earthworm weight, which may be linked to development. The (agro)ecological consequences of maintaining a less massive, less developed, but higher earthworm population should be researched further. Additionally, regeneration in weight as well as numbers should be measured. The components of the system and their effects on each other are visualised in the concept map below (figure 11).

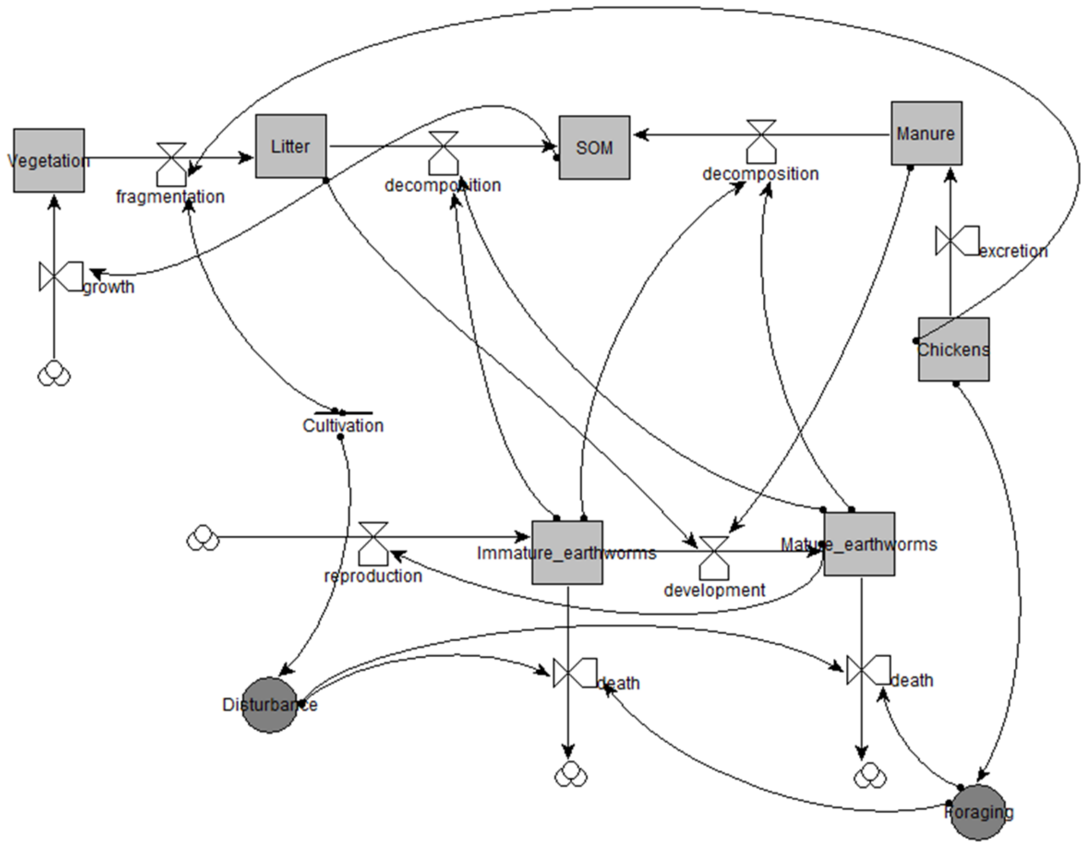

Figure 9: A relational diagram of the interactions between the presence of chickens and cultivation and their combining effect on earthworm numbers, reproduction and development

In general, the introduction of laying hens into an orchard provides several ecological services, such as the benefits of pest suppression (Allmenrödler & Koorn 2016, unpublished), fertilisation and as this research indicates, an increased earthworm abundance, which consequently contributes to a more favourable soil biota and increased soil fertility (Edwards, 2004). Next to these ecological advantages, the direct contribution to the productivity of the system makes it attractive for farmers to introduce chickens into their orchards. This may be seen as a so-called over-yielding effect, as including a wider range of system components into a production system commonly results in increased productivity (Tittonell, 2014). Furthermore, another implication for this specific system is to increase the intensity of the poultry production system, that more parts of the farm have chickens grazing on it. Logically, this is a trade-off between productivity and management costs as well as practicality, as some parts of the farm might get less accessible for customers and the farm "Fruittuin van West" is based on a self-harvesting principle.

To sum up, by tree-strip cultivation the feed conversion factor can be reduced significantly ($P < 0.05$) on a regular basis, depending on frequency and management. As feed prices account for 70% of the variable costs in the organic laying hen sector (Walker & Gordon, 2003), as well as the potential problems of essential amino acid deficiencies facing the organic egg production systems by future EU regulations (Krimpen et al, 2015; Wagenaar & Visser, 2006), this is a definite advantage in terms of feed costs and nutritional value of feed.

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Appendix

Table 1 Preliminary data used from the study of Zandbergen (2016), including the measurements made in this study (green). These data were used to determine changes in feed conversion due to cultivation and study the stability of laying percentage

dates	month	feed conversion	cultivation	laying %
14/15	February	2.56	no	83.9
21/22	February	2.48	no	NA
20/21	March	2.61	no	83.5
02/03	April	2.40	no	93.6
11/12	April	NA	no	87.4
17/18	April	2.74	no	87.5
24/25	April	NA	no	84.6
22/23	May	2.03	yes	73.3

Table 2 Summary of the data used to determine total number of chickens and total weight of eggs

	# chickens			
	coop 1	coop 2	coop 3	weight of 10 eggs (kg)
average	37.75	156.50	70.25	0.65
st. dev.	3.30	12.18	5.25	0.02
N	4	4	4	6

Table 3 Data used to determine the amount (kg) of consumed feed. The feeding buckets were measured the night before cultivation and the night after cultivation. Total number of eggs found were 194.

feeding buckets (kg)	
before cultivation	after cultivation
23.45	19.5
15	8.4
13.2	8
20.3	18.4
17.55	17.5
14.9	14.7
17.6	17.4
21.9	15.6
23.65	22.5
total number of eggs	194

Table 4 Summary of the measurements made to research macrofauna dynamics as response to the presence of chicken, cultivation and rain

No Chicken			number of worms			weight		
date	cultivation	rain	average	st. dev.	N	average	st. dev	N
22. may 2016	no	yes	14.17	6.05	6	NA	NA	NA
23. may 2016	yes	yes	22.17	6.52	6	NA	NA	NA
1. june 2016	yes	no	25.67	10.05	6	9	3.51	6
4. june 2016	no	no	19.33	4.16	3	8	1.15	3
9. june 2016	NA	NA	NA	NA	NA	NA	NA	NA
Chicken 2015			number of worms			weight		
date	cultivation	rain	average	st. dev.	N	average	st. dev	N
22. may 2016	no	yes	13.50	8.83	6	NA	NA	NA
23. may 2016	yes	yes	23.50	5.75	6	NA	NA	NA
1. june 2016	yes	no	13.33	5.32	6	4	0.89	6
4. june 2016	no	no	20.00	7.94	3	7	3.21	3
9. june 2016	no	no	11.67	3.21	3	1.65	1.14	3
Chicken 2016			number of worms			weight		
date	cultivation	rain	average	st. dev.	N	average	st. dev	N
22. may 2016	no	yes	24.83	7.68	6	NA	NA	NA
23. may 2016	yes	yes	15.80	3.96	5	NA	NA	NA
1. june 2016	yes	no	20.50	8.19	6	5	2.53	6
4. june 2016	no	no	31.67	11.02	3	7	3.21	3
9. June 2016	yes	no	28.33	11.06	3	8.59	1.73	3
9. june 2016	no	no	31.67	6.11	3	5.32	1.87	3