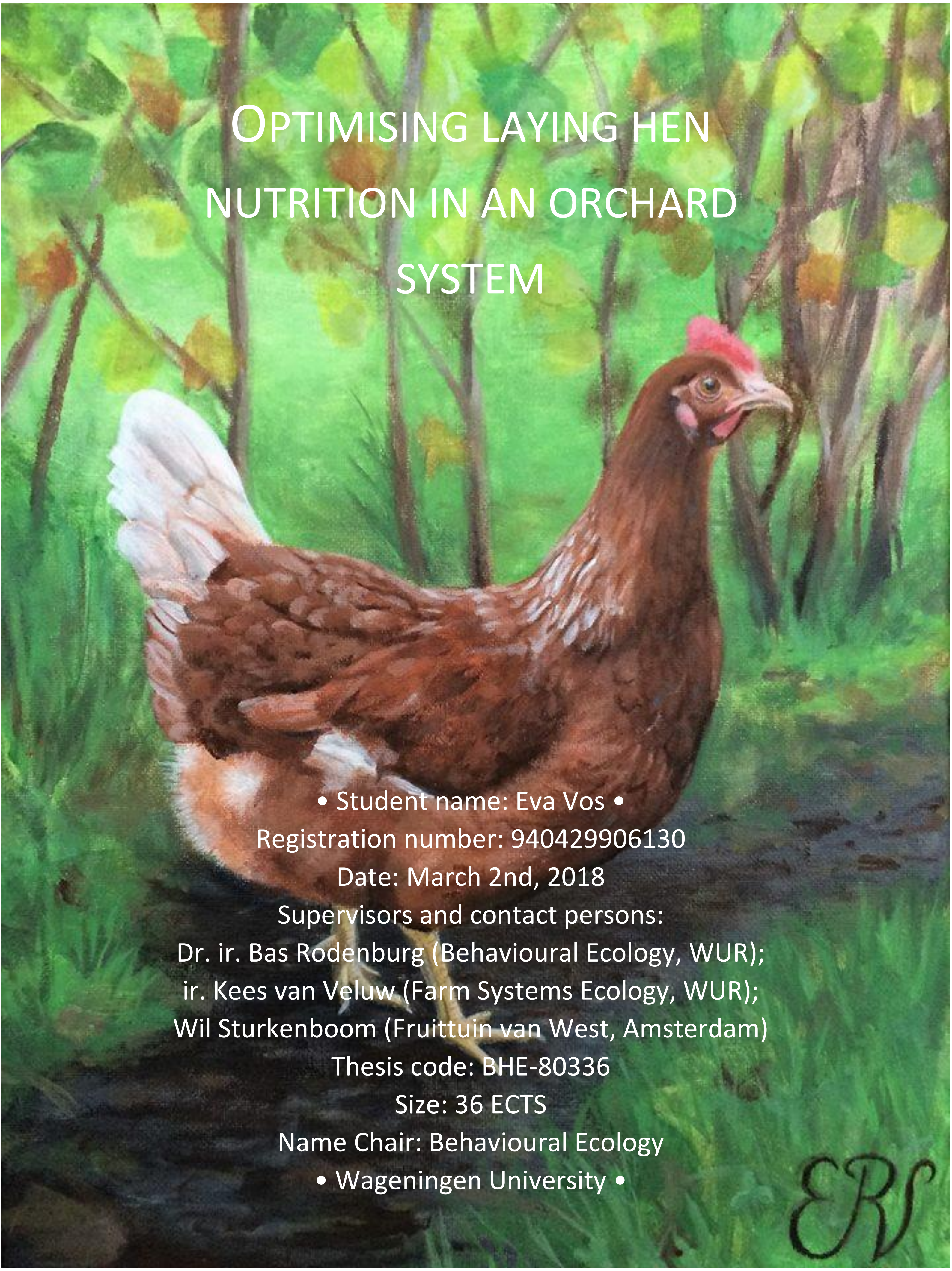

Optimising laying hen nutrition in an orchard system

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Abstract

Outdoor access can stimulate natural behaviour of laying hens. In this study the relation between foraging behaviour and compost application and rotary tilling is assessed. The aim is to investigate whether foraging behaviour can be stimulated by this treatment. A quantification of insect and worm abundance is set up in order to make more clear how many insects and worms are ingested by the foraging of chickens and how much of the layer feed could be replaced by insects and worms. This study is of a more exploratory type and has a holistic view on poultry keeping in an orchard system. Other factors that are investigated are the effect of compost and tilling and chickens on the vegetation and soil quality of the orchard. Weather data are collected as well. The 12 weeks experiment was carried out at Fruittuin van West, Amsterdam NL. Four fields of 90 m^2 were set up in the orchard between three rows of red current shrubs. In two fields, a group of 19 Lohmann Brown laying hens and one rooster were placed and the other two fields were empty. One of the chicken fields and one of the empty fields received the compost and rotary tilling treatment once every three weeks. The results suggest that foraging behaviour can be stimulated by compost application and rotary tilling ($p = 0.004$). Less crawling insects ($p < 0.001$) and a lower worm biomass ($p = 0.037$) were found in the chicken fields, which implied ingestion by chickens. Chickens that received the compost and tilling treatment ingested less of their layer feed, however, this effect was not significant. There was a significant higher crawling insect biomass in the compost & tilling treatment compared with the no compost & no tilling treatment. The results suggest that part of the layer feed can be replaced by attracting insects to the orchard by multiple compost applications and rotary tilling. Income from eggs, meat and savings on weeding, mowing and fertilising by the chickens outweigh the extra labour and feed costs involved in poultry keeping. This makes this system economically feasible, next to other positive but qualitative effects on fruit growing. This study also showed that it is impossible to meet the requirements of the law for a free range area in organic poultry farming, when poultry is kept outside year round. In this regulation a free range area covered with vegetation is obliged with a minimum of 4 m^2 per hen. However, in this study with 4.5 m^2 per hen, the vegetation cover was completely gone in the eighth week. Therefore, a lower chicken density or a system with rotational grazing is advised for keeping poultry in an orchard system.

Highlights

- Compost application with tilling stimulated total crawling insect biomass
- Lower crawling insect abundance and worm biomass were found in chicken fields
- Chickens showed more foraging behaviour in the compost and tilling treatment
- Part of layer feed can be replaced by insects and worms, attracted by compost and tilling
- Keeping laying hens in an orchard is economically feasible

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1. Introduction

1.1. Foraging behaviour

In the last decades, more attention is given to animal welfare. This caused a shift from very intensive chicken housing systems like battery cages to more extensive systems, like organic systems. This brought some big improvements for animal welfare, because chickens got access to an outdoor run, which provides them with a more natural and stimulating environment (Hegelund, Sørensen, & Hermansen, 2006). The possibility to perform natural behaviour is another factor that is associated with higher animal welfare (WelfareQuality, 2009). The ancestor of the domestic chicken, the red junglefowl (*Gallus gallus* L.), performs mainly foraging behaviour. Dawkins (1989) reported that 60% and 34% of the active part of the day red junglefowl hens were seen to be respectively ground pecking and ground scratching. Kruijt (1964) states that there are no big differences between the behaviour of red junglefowl and the domestic fowl. According to Fölsch et al. (1981) chickens spend 35.3 to 47.5% of their daily activity on foraging behaviour in natural habitats. From that it can be concluded that the domestic chicken has the same behavioural need to forage as well (Dawkins, 1989). However, in a study of Lindqvist et al. (2002), differences in contrafreeloading (CFL) were observed between red junglefowls and domestic chickens (White Leghorn). CFL describes the behaviour whereby an animal prefers feed which needs effort to obtain over easy accessible feed. In this study, the domestic chickens had a stronger preference for easy accessible feed compared with their wild relatives, that were more willing to work for their feed in order to gain more information about the feed source. In the last decades, the domestic chicken was amongst others selected for efficient feeding, which might explain the lower observed CFL. This is something to keep in mind in studying foraging behaviour of domestic chickens, because they might forage less than expected because of the offered feed. Domestic chickens still showed CFL in the study, so the behavioural need for CFL might still exist (Jensen et al., 2002).

1.2. Natural feed sources

In organic systems, chickens have outdoor access where they can perform foraging behaviour in the pasture. In this study the chickens permanently live in an orchard. Consequently, chickens feed on the vegetation and on insects and worms, which comprises part of their natural diet (Savory, Wood-Gush, & Duncan, 1978). Next to energy, vitamins and minerals, protein is very important for laying hens. They need sufficient and high quality protein for optimal health and egg production (Morris & Blackburn, 1982). In general in chicken husbandry these proteins are provided in the form of layer meal or pellets (CVB, 2012). This protein originates mostly from soy beans, which make up around 10% of layer pellets (Verwer, Peters, & Michels, 2015). Verwer et al. (2015) state that the composition of proteins from insect origin meets the dietary requirements of chickens, so insects might be an interesting alternative feed source for poultry. The same applies to the protein composition of earthworms (Taboga, 1980). The protein from the pellets might then be replaced by protein of insect and earthworm origin that the chickens find in the orchard. Therefore, it might be an interesting practice to stimulate local insect and worm populations and insect and worm intake of chickens.

Besides insects, vegetation in the orchard can be a healthy and sustainable part of the diet as well. In a study of Hughes and Dunn (1983) with hens that had pasture access between 8:00 and 17:00 h, a dry matter (DM) intake of herbage, worms and insects of 30-40 g per hen per day was estimated in addition to more than 100 g of concentrate feed. Another (thesis) study found a herbage consumption of 30 g DM herbage intake per hen per day, with an accompanied concentrate feed reduction of 15% and no negative effects on egg production (Bassler, 1997). Mugnai et al. (2014) found a maximum grass intake in spring, of 59.2 g fresh matter per hen per day. More green fodder in the diet can enhance egg quality and healthiness for humans. The yolk gets a more orange colour, caused by carotenoids, tocopherols and flavonoids (Cesare, Alessandro Dal, & Cecilia, 2010; Mugnai et al., 2014).

1.3. Research aims and hypotheses

These alternative feed sources might be a healthy and sustainable replacement for layer pellets. I studied different factors concerning this natural feeding, amongst others insect and earthworm count and biomass, feed intake, laying performance, vegetation cover and condition and body weight. The farmer aims for more self-sufficiency and thus lower feed costs for the laying hens as well. In chicken husbandry, feed costs can make up 70% of the total variable costs (Walker & Gordon, 2003). The highest feed costs are for the soy protein from the layer feed (FAO, n.d.; Van Gorp, 2018), so I will investigate how much of the layer pellet can be replaced by insect and earthworm protein, without changes in laying performance and body weight. In the study of Xu et al. (2014) with broilers, having 20 m^2 per chicken, 26% less feed was needed, compared with systems without outdoor access. Fanatico (1998) reported a reduction in feed intake of 30% (chicken density unknown).

In order to provide more protein in the orchard, I will investigate whether insects, molluscs and arthropods (from now on 'insects') and worms can be supplied and attracted by using compost in combination with rotary tilling (already incorporated in the farm management) multiple times per year. It is shown that young Lohmann Brown laying hens showed a preference for foraging in peat substrate, which has a high organic matter content, such as compost and that they showed a preference for foraging in substrate containing feed particles (Petherick & Duncan, 1989). Therefore I expect that when insects are more abundant, foraging behaviour could be stimulated, which in turn could have a positive effect on both hens and orchard.

One year before, it was measured that the chickens in Fruittuin van West spent 25% of their day active time budget on foraging behaviour (Zandbergen, 2016), so there is still a gap between the time budget of chickens in the orchard and their wild relatives. Therefore, stimulating foraging in the orchard is good from an animal welfare point of view (WelfareQuality, 2009), because the behavioural need for foraging is probably higher than what is fulfilled at the moment. I will study the behaviour of the laying hens in Fruittuin van West and whether foraging behaviour is stimulated when compost is applied together with rotary tilling. Areas with compost and tilling will be compared with areas without compost and tilling. Sossidou et al. (2008) showed that fewer nematode worms were found in compost based soils, which suggest a health benefit as well of compost application causing less parasitic infections.

Another beneficial effect could be a reduction of the amount of labour. Currently, at the farm, a grass/clover mixture is growing between the rows of current shrubs. Next to that also other species have found their place in the orchard, of which some are directly beneficial (dandelion, comfrey, vetch, etc) but others (thistle, nettle, rumex, etc) might function as weeds and compete with the shrubs for nutrients, water and sunlight, as the farmer explained (Sturkenboom, 2017). In order to manage the vegetation, the ground under the shrubs and bushes is tilled every now and then, weeds are pulled out manually and the grass/clover rows are mowed. This brings a lot of labour and fuel costs. However, the chickens can also function as mowers and weeders (Hermansen, Strudsholm, & Horsted, 2004), so labour could be reduced compared with a no chicken management. The quantification of these effects, amongst others dependent on chicken density, is still lacking. The effect of chickens and compost and tilling on the soil is expected to be insignificant in the short term of the current study.

Chickens may also function as insect pest control agents (Hermansen et al., 2004). Insect pest suppression could also take place by other insects (natural enemies). However, the chickens can also become a threat for natural enemies of pest insects. Therefore, it is important that these insects find a habitat in the orchard, so a stable insect population can be achieved as a renewable resource for pest suppression and chicken protein source, stimulated by compost application and rotary tilling time after time. This would make the orchard system more resilient. Chickens may also contribute in the suppression of fungal diseases in the orchard. The farmer has observed that in areas where chickens had foraged under fruit trees, the leaves were broken down faster, which gave less opportunities for the fungus to grow and spread (Sturkenboom, 2017).

The occurrence of worms and insects is influenced by the weather (Crozier, Tanaka, & Vernon, 2003; Petrovskii, Bearup, Ahmed, & Blackshaw, 2012), so it is important to link the insect and worm results to the weather data. The behaviour of chickens is influenced by weather factors as well. A study of Stadig et al. (2017) showed a lower free range use of broilers at higher wind velocity, more hours of sun and more rainfall, even though willows as shelter were provided in the free range, comparable with the current shrubs. However, the study of Stadig et al. is conducted in summer, so the effect of hours of sun might change with a lower temperature. Hegelund et al. (2005) showed relationships between range use by laying hens and temperature, wind speed, rainfall and season as well. In the current study there is no stable available, so I expect that chickens will seek shelter under the shrubs and in the mobile night shed during harsh weather circumstances (low temperature, high wind speed, and more rainfall) and therefore will show less active (foraging) behaviour.

The overall aim of the study is to investigate whether laying hen feeding in Fruittuin van West can become more sustainable, in terms of animal welfare (natural behaviour), ecology (natural system), and economics (feed and management costs). This is done by quantifying insect and worm populations and biomass, vegetation damage, measuring feed intake of the chickens and observing their behaviours. The effect of compost application and rotary tilling (management practise) on chicken behaviour and the effect of chicken behaviour on the ecology of system orchard will be assessed. If insects from the orchard could replace more of the dietary protein, less CO_2 will be emitted as well, because there is less deforestation and less transport of soy. Nonetheless, I will not elaborate on environmental sustainability.

I expect that the chickens will spent more of their active time on foraging when compost is applied together with rotary tilling, because the chickens may feed from the higher number of insects and worms that may be found when compost is applied. Domestic laying hens still show CFL next to freely available feed, so a positive correlation between insect and worm abundance and foraging behaviour is hypothesised. I expect that the time spent on foraging will go at the expense of standing, sitting and eating at the trough. The foraging behaviour may be shown mainly under the shrubs, where the compost was applied. I hypothesise a lower layer pellet intake in the compost and tilling treatment, because the chickens may ingest more of their protein during foraging on insects and worms instead. In the compost and tilling group, the vegetation cover and condition may be lower at the sides of the fields compared with the middle of the fields, due to the expected foraging at the compost sites. The difference between vegetation scores of the sides and the middle of the field of the no compost and no tilling group is expected to be negligible. Vegetation cover and condition in the fields after the presence of chickens may be substantially lower than before the chickens were there, because a substantial amount of certain weeds is eaten by the chickens and damaged by the scratching behaviour. Next to the differences between chicken groups, I expect no effect of compost on vegetation, because the growing season is at its end on the time of the experiment.

I expect that there are more insects and worms in the fields without chickens. The same number of insects and worms may be attracted by the compost in both treatments, but with the difference that they are not eaten. However, the absence of chicken manure could also result in less insects and worms compared with the chicken fields. I expect to find more differences in numbers between crawling insects and flying insects, as crawling insects are much less mobile compared with flying insects. For instance, an attracted fly in one field can more easily be caught in another field than a crawling insect.

2. Material and Methods

The observations and measurements for this study were carried out simultaneously in the orchard of Fruittuin van West in Amsterdam, the Netherlands, between September 18th and December 15th, 2017. This biodynamic farm and its facilities, built in 2013, are modern, innovative and sustainable in terms of operational management, design and material use, energy and effluent handling and ecology. The primary business is the cultivation of fruits. A flock of laying hens (Lohmann Brown) range freely in the orchard together with some roosters that are given shelter (other breeds). They are fed a diet of ad libitum layer pellets from feeders and around 60-90 g of spelt grains per chicken per day, spread by hand through the orchard to stimulate foraging behaviour under the fruit trees and shrubs. The area for the laying hens comprises three hectares. The chickens have much more space than the legal minimum for organic of 4 m^2 per hen (Skal, 2018). Costumers visit the farm six days a week, to pick their own fruits from the trees and shrubs and collect eggs from the laying boxes. In the orchard, the experimental setup as depicted in figure 2.0.1 was composed, where the observations and measurements have taken place. I studied different factors concerning this natural feeding, amongst others insect and earthworm count and biomass, feed intake, laying performance, vegetation cover and condition and body weight.

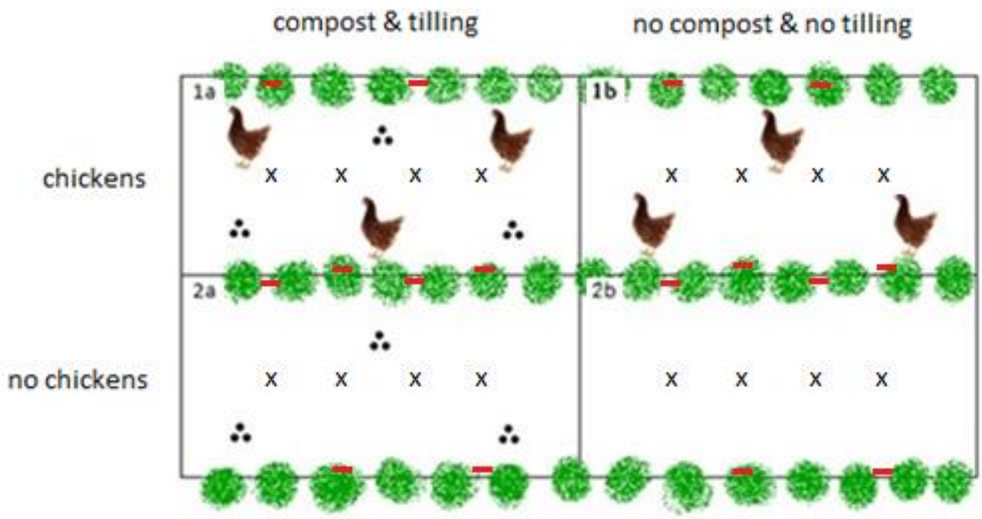

FIGURE 2.0.1 EXPERIMENTAL SETUP: ROW 1: CHICKENS; ROW 2: NO CHICKENS; SECTION A: COMPOST AND ROTARY TILLING; SECTION B: NO COMPOST NOR ROTARY TILLING. THE 'X' SIGNS STAND FOR THE LOCATION OF THE INSECT TRAPS (PITFALLS) AND THE RED STRIPES STAND FOR THE LOCATION OF THE STICKY SHEETS. NOTE: THE DIMENSIONS OF THE FIELDS AS SHOWN IN THE FIGURE DO NOT CORRESPOND WITH REALITY.

Within three rows of red berries of the variety 'Rolan', four fields were created of equal size: each one 90 m^2 (3 m x 30 m). In section A (half of both rows) compost was applied and the vegetation under the current shrubs was tilled, and not in section B. In row 1 chickens were placed. The total available area per chicken was at least 4.5 m^2. Chicken wire and nets were used for fencing. To equip the chicken fields (row 1), in each field, one laying box, a mobile night shed, two water dispensers (bucket with drinking nipples) and two feeders (one for spelt grains and one for layer pellets) were used. Each of the two chicken groups consisted of 19 healthy 'Lohmann Brown' laying hens and one rooster, that were caught from the flock. Roosters were included, because normally they are together with the hens in the main flock as well and this is obligatory in biodynamic poultry keeping (Demeter, 2018). The chickens were placed in fields 1A and 1B, so in total there were 38 hens and two roosters (19 hens plus one rooster per field).

Compost for the orchard was bought by the farmer. It consisted of poplar wood chips and soil (80-20) and rotten fruits were added as well. During storage insects were attracted. A volume of 6 L/m of the fresh compost (6-9 months of age at the start) was applied three times (once every 4 weeks) to the fields of section A, as described in the experimental setup (figure 2.0.1). Summed up, this is the amount of compost that the farmer normally applies once a year. So in this study, the total yearly quantity of 18 L/m was split up in three parts. Together with compost application, the row of soil and vegetation under the shrubs was tilled to a depth of 3cm at the start of the experiment and then once every 4 weeks. No tilling was applied in the treatment without compost.

2.1. Chicken behaviour

The behaviour was observed by scan sampling (see ethogram in table 2.1.1) with a 10 minutes interval. During 9 weeks, every Monday morning (when the farm was closed for costumers), the number of chickens performing a specific behaviour was counted for 2.5 hours in total. The observations were split up in four parts. One week, field A was observed from t = 0 to t = 30 minutes, then field B from t = 40 to t = 70, then field A again from t = 80 to t = 110 and then field B again from t = 120 to t = 150. The next week observations started at field B and then field A, etcetera. Next to the behaviours from the ethogram (see table 2.1.1), the location of the chickens was observed as well, namely the number of chickens on the grass and in the shrub area. The location of the chickens was also linked with foraging, so the number of chickens that were foraging on a certain moment was divided between chickens that forage on the grass and in the shrub area. The eating behaviour was split up in eating layer pellet and eating spelt grains.

TABLE 2.1.1 ETHOGRAM, SLIGHTLY ADAPTED FROM (MOLLENHORST, RODENBURG, BOKKERS, KOENE, & DE BOER, 2005)

Behaviour	Code	Description
foraging	F	Scraping over ground with foot, pecking on ground
eating	E	Eating from feeding trough
drinking	D	Drinking water from trough
dust bathing	DB	Laying down in substrate and making fluttering movements
grooming	G	Cleaning itself with beak or feet, feather ruffling, preening
sitting	Si	Sitting idle, body on ground
walking	W	Walking from place A to B
standing	St	Standing idle, no contact body to ground

At the start of each observation session the observer approached the field and let the chickens adapt to the observers presence for 5 minutes before observing. The position of the observer was behind the fence, with the possibility to overlook the whole field. To determine the minimum distance from the chickens a small approach test was carried out a few days before the observations started. The distance between the observer and the chicken at the moment that the chicken moved away from the observer was measured. During observations, every detail of the surroundings that could have influenced the results was written down, for instance a tractor driving by. From the sampling data the average time budget of the behaviours of the chickens could be obtained. This time budget from the chickens in the compost field (1a) was compared with that of the chickens in the no compost field (1b).

2.2. Feed intake

Drinking water and feed were provided ad libitum. Layer pellets were provided in feed-o-matic feeders with 20 kg maximum fill (see figure 2.2.1), but spelt grain was provided in smaller and less weather resistant feeders (see figure 2.2.2), so they were filled with 2 to 3 kg daily. The remainders of spelt were noted down daily as well. Every week the remainders of laying pellets were weighed and the layer pellet feeders were filled up. The layer pellets that were fed to the chickens were Van Gorp 475 ECO legkorrel 95% organic, with a protein content of 17.5% RE of which 15.5% is organic soy (Van Gorp, 2018).

At the end of the experiment, the hens body weight was measured and compared amongst both groups and with a random group from the orchard. An economic quantification was made in order to calculate savings on feed costs when dietary protein was replaced by insects and worms and the supplementation of vegetation as fodder. The aim is to get an indication of the amount of layer pellets that can be replaced by insects and worms from the orchard (attracted by compost) and greens from the weeds and the sward and the accompanying savings on money.

FIGURE 2.2.1 FEEDER LAYING PELLETS

FIGURE 2.2.2 FEEDER SPELT GRAINS

2.3. Laying performance

The eggs were counted per group every day. Normally, the hens lay the eggs in the laying boxes and the eggs roll to the sides of the boxes where the customers can collect them. During the study, the costumers were hindered to collect the eggs during the day, so planks were fixed in the laying box behind the collecting sides. The eggs were counted at the end of the day and placed at the collecting sides on the other side of the planks, so customers could collect them. On one moment, a batch of eggs from both groups was weighed in order to compare egg weight between groups.

2.4. Insects

A combination of 4 insect traps (pitfalls) (see figure 2.4.1) and 4 sticky sheets of the brand Trapper® LTD, Bell Laboratories, Inc. (see figure 2.4.2) were used in each field to catch insects on a weekly basis over a period of 12 weeks (every Monday). These two methods were chosen, because they have different target insects. Pitfalls catch mainly crawling insects, and the sheets the flying insects. Together, the traps give a more precise view on the insects living in the orchard. In every field, the traps were placed in a line in the middle of the row with a constant distance in between, and the sheets were hung up at 1.5 m height in the shrubs or on poles, on the same place as the pitfalls, but varying in orientation, as shown in figure 2.0.1. After collecting the insects each week, the insect biomass, types and number of species groups were determined. Only the big animals were determined, like worms, spiders, flies, maggots, slugs, snails and beetles.

FIGURE 2.4.1 INSECT TRAP (PITFALL)

FIGURE 2.4.2 STICKY SHEET

The 16 insect traps consisted each of one big cup (Ø = 7.5 cm; depth = 10.8 cm), which was installed by digging a hole with an auger in a way that the edge of the cup was at ground level. Then, 5 cm of water and a drop of dishwasher detergent was added. A lid with pins covered the cup in a way that there was around 1.5 cm between the lid and the cup, to prevent rain, leaves or chicken droppings to fall in. When the traps needed to be emptied, the water with the insects was collected in percolators, labelled and put in a plastic bag. After that, the pitfalls were filled again for the next measurements (Groot & Bianchi, 2017).

The 16 sticky sheets were placed in the shrubs or on the poles by the shrubs at 1.5 m height. When the insect sheets were collected, new sheets were installed when there were a lot of insects on it. When the sheets were still (nearly) empty, they were reused in the next week. The insects were counted and determined and insect weight was estimated.

2.5. Worms

For measurements on worms, a cube of 20 x 20 x 20 cm was dug out with a spade on a weekly basis (on Mondays) in every field, between the middle of the row and the shrub area, in order to prevent damage to the roots of the shrubs. The worms were taken out and counted and weighed afterwards. After measuring, the worms were put back on the top soil.

2.6. Vegetation

In each field eight vegetation samples were made: four in the middle and four at the sides of the row. A frame of 1 m^2 was used to select the sample sites that were chosen randomly. The visually assessed samples were scored for both vegetation cover and vegetation condition. On the one hand the percentage of vegetation covering the ground was assessed and on the other hand the amount of damage to the grasses and plants. The samples of vegetation cover and condition were put in a scale of 1 to 10, with the scores for vegetation cover: 1 = 0-10%; 2 = 10-20%; 3 = 20-30%; 4 = 30-40%; 5 = 40-50%; 6 = 50-60%; 7 = 60-70%; 8 = 70-80%; 9 = 80-90% and 10 = 90-100% and for vegetation condition: 1 = extremely damaged vegetation (figure 2.6.1); to 10 = undamaged vegetation (figure 2.6.2). Before the experiment started, the orchard and the vegetation underneath and between the shrubs were accessible to chickens, but with a much lower density. This could have had an influence on the start situation of the experiment. This was accounted for in the statistical model by using the changes in the scores vegetation cover and condition, instead of the absolute values. The changes in vegetation cover and condition score of the fields from week 0 to week 6, 8 and 12, at the end of the experiment, were assessed. So measurements were taken before, during and after the chickens were there. The effect of the chickens, but also of the compost and tilling practise on vegetation could be assessed this way.

FIGURE 2.6.1 VEGETATION CONDITION SCORE 1

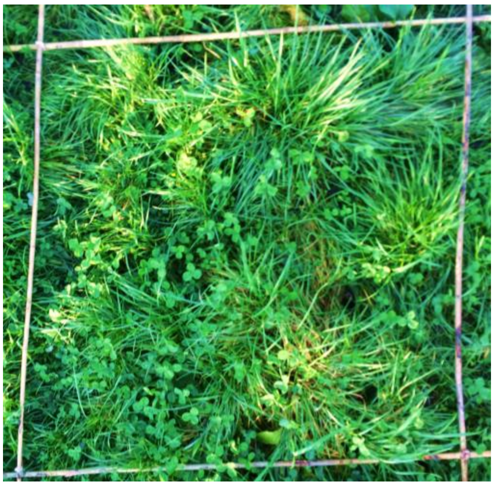

FIGURE 2.6.2 VEGETATION CONDITION SCORE 10

2.7. Visual Soil Assessment

In order to assess the effect of the treatments on the soil, a visual soil assessment (VSA) was carried out at the end of the experiment (week 12). The factors soil structure, soil porosity and earthworm count were scored. For soil structure and porosity, the possible scores were: 0 = poor condition; 1 = moderate condition; 2 = good condition, and for the earthworm count: 0 = poor (< 15); 1 = moderate (16 - 44); 2 = good (> 45). The scores were given to each sample by comparing them visually with the pictures on the student handout: VSA scorecard from Science Learning Hub, derived from Shepherd (2009).

2.8. Weather

There is a weather station on the farm, linked to the software of RimPRO (Trapman, 2018) that measured the maximum temperature (Tmax; °C), minimum temperature (Tmin; °C), average temperature (Tavg; °C), rainfall (mm), rainfall (h/d) and average relative humidity (RH; %). Weather data from December 6th onwards are derived from a weather station on another fruit growing farm in Lisserbroek (10 km away) using the same software. This was done because the farmer turned his weather station off. For the factors sunshine (h/d), cloudiness (scale 0-8) and wind speed (m/s) data from a weather station at Schiphol was used, 5 km from the farm.

2.9. Statistical analysis

After data collection, data was analysed statistically with IBM SPSS Statistics (version 25.0) and compared with literature. I compared group means for all measured variables between the compost and no compost group and the chicken and no chicken group and studied whether differences were significant. In the General Linear Model on feed intake, I did not include interaction in the model (compost*chickens), because there were not enough degrees of freedom in the model, due to the fact that there were no repetitions of each treatment group. One-way ANOVA was used for data that met the normality and homogeneity of variances requirements, assessed with QQ-plots and Levene's test ($\alpha > 0.05$) respectively. The F-value with df_1 and df_2, the p-value, and df_{total} are given. For data that did not meet these requirements, Kruskal-Wallis (p-value and sample size (N) are given) or Mann-Whitney tests were carried out (Mann-Whitney U, the p-value and sample size (N) are given). Spearman rank correlations between all measured factors were studied as well. Spearman's rho (ρ), the p-value and the sample size (N) are given. The significance affirmations are based on a probability of $\alpha < 0.05$.

3. Results

3.1. Chicken behaviour

In the approach test, the measurements did not differ significantly between groups, as assessed with a One-way ANOVA, with 'estimated distance (m)' as dependent variable and 'group' as fixed factor. Data is shown in figure 3.1.1. The largest observed value was chosen in order to minimise disturbance of behaviour. A minimum observer distance of two metres was determined by the approach test.

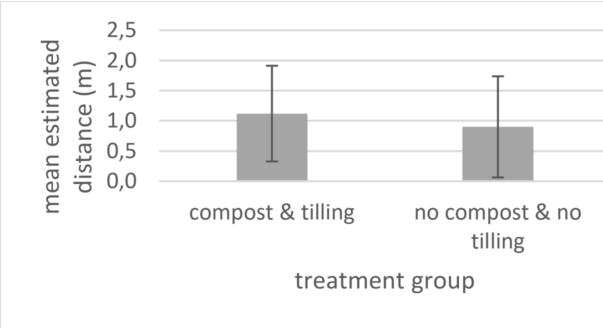

FIGURE 3.1.1 RESULTS APPROACH TEST. MEAN ESTIMATED DISTANCES (M) PER TREATMENT GROUP. ERROR BARS: 95% CI

A Kruskal-Wallis test was performed to compare the means of all observed behaviours. Significant differences between the two treatment groups were shown in the behaviours foraging ($p = 0.005$, $N = 143$), eating layer pellets ($p = 0.001$, $N = 143$) and dust bathing ($p = 0.008$, $N = 143$). Foraging and dust bathing were performed more often in the compost & tilling treatment group, and eating layer pellets was performed less in this group compared with the no compost & no tilling treatment group. The results of these and the other observed behaviours are shown in figure 3.1.2.

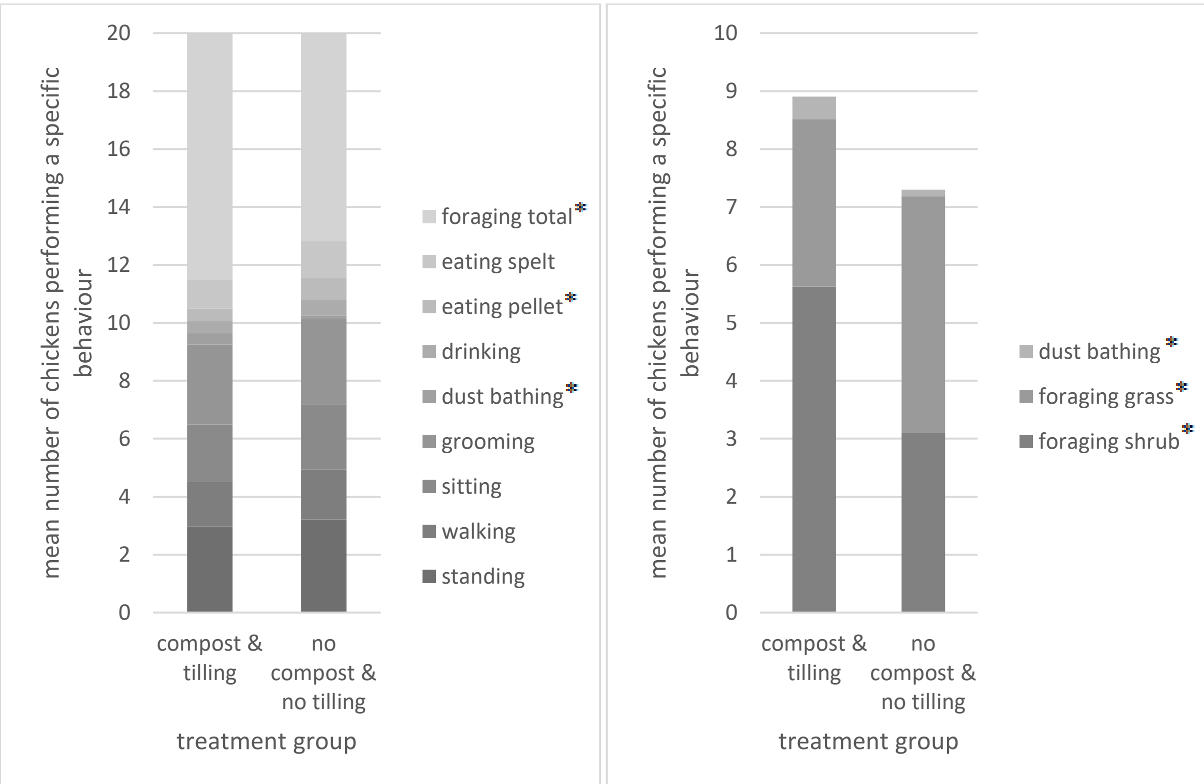

FIGURE 3.1.2 MEAN OF CHICKENS THAT PERFORMED A SPECIFIC BEHAVIOUR PER TREATMENT GROUP. LEFT: ALL OBSERVED BEHAVIOURS; RIGHT: DUST BATHING AND FORAGING DIVIDED BY LOCATION. $N_{TOTAL} = 20$. SIGNIFICANT: [*]

A Mann-Whitney test was performed to compare the total foraging, foraging under shrubs, foraging on grass and dust bathing behaviour between the two treatment groups. Total foraging, foraging under shrubs and dust bathing were observed more often in the compost & tilling group ($U = 1860.00$, $p = 0.004$, $N = 143$; $U = 1089.00$, $p < 0.001$, $N = 143$; $U = 2131.00$, $p = 0.009$, $N = 143$, respectively). Foraging on grass was observed more in the no compost & no tilling treatment group ($U = 1738.50$, $p = 0.001$, $N = 143$). There were significant negative Spearman rank correlations between total foraging and eating spelt at the trough ($\rho = -0.478$, $p = 0.045$, $N = 18$) and between foraging and walking ($\rho = -0.723$, $p = 0.001$, $N = 18$).

Independent of the type of behaviour, the data on chicken location were analysed with a Mann-Whitney test, with 'foraging under shrubs' and 'foraging on grass' in the test variable list, and treatment group as grouping variable. It is shown that chickens in the compost & tilling treatment group spent more time under the shrubs ($U = 1121.00$, $p < 0.001$, $N = 143$, 13.49 ± 2.68) compared with the no compost & no tilling treatment group (10.08 ± 3.52) and less on the grass ($U = 1121.00$, $p < 0.001$, $N = 143$, 6.51 ± 2.68 and 9.92 ± 3.52), as visualised in figure 3.1.3.

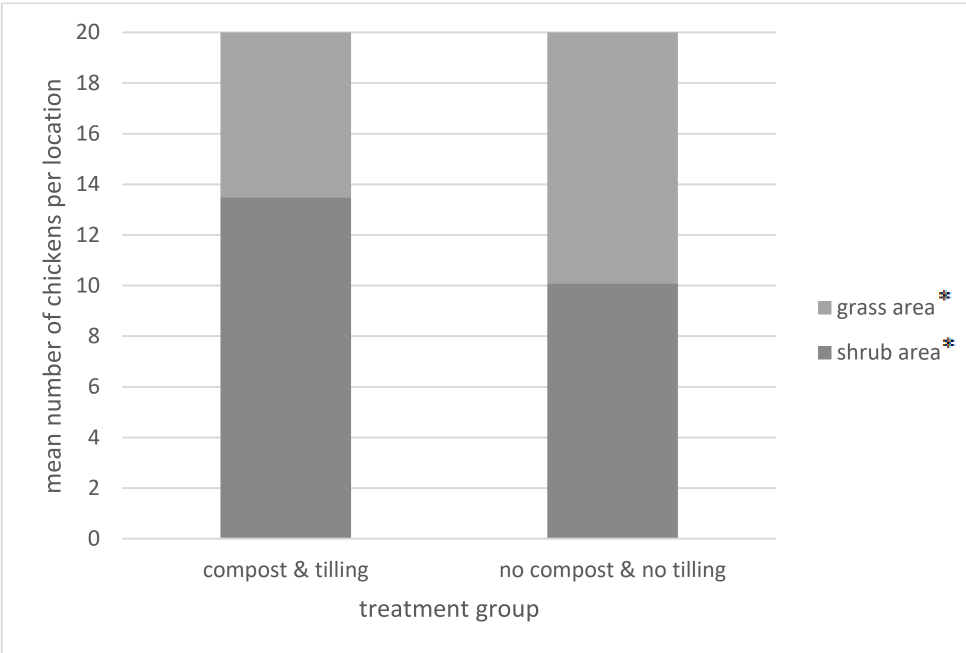

FIGURE 3.1.3 MEAN NUMBER OF CHICKENS PER LOCATION PER TREATMENT GROUP. $N_{TOTAL} = 20$. SIGNIFICANT: [*]

Some correlations between behaviour and weather variables were found as well, as outlined in chapter 3.8.

3.2. Feed intake

An ANOVA showed that the average spelt intake, the average pellet intake, and the average total feed intake do not differ significantly between the two groups. However, total feed intake, pellet intake and spelt intake in the compost & tilling treatment group were respectively 9.5 %, 26.0 % and 4.0 % lower than in the no compost & no tilling treatment group. The results are showed in figure 3.2.1.

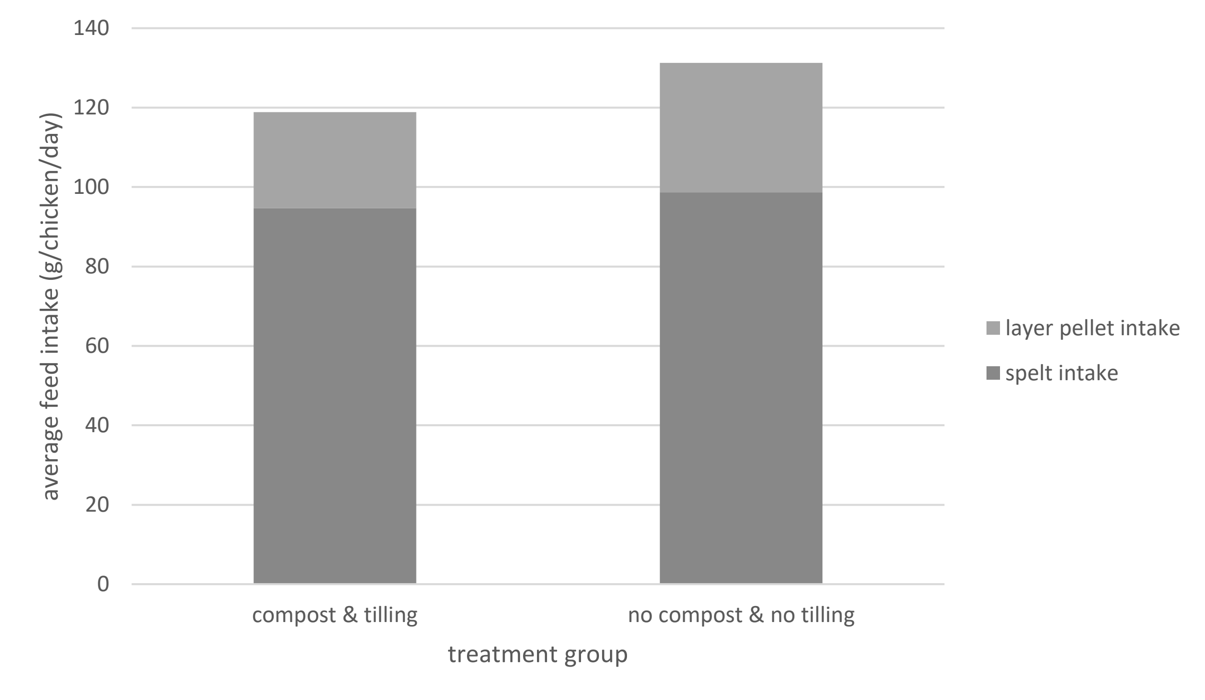

FIGURE 3.2.1 AVERAGE FEED INTAKE (G/CHICKEN/DAY) PER TREATMENT GROUP.

A General Linear Model with total feed intake as dependent variable and treatment group as fixed factor was run. Looking at the main effect, the treatment (compost & tilling or no compost & no tilling) did not contribute in predicting total feed intake in the model. Another General Linear Model with total feed intake as dependent variable and week number as fixed factor was run. It was shown that week number was important in predicting the total feed intake in the model ($F(7,8) = 6.150$, $p = 0.010$, $df = 16$, $R^2_{adj} = 0.706$).

The same models are run, but here with spelt intake as dependent variable and then pellet intake as dependent variable. For both spelt and pellet intake, looking at the main effect, the treatment (compost & tilling or no compost & no tilling) did not contribute in predicting spelt nor pellet intake in the model. However, week number was important in predicting spelt and pellet intake in the model (spelt: $F(7,8) = 59.702$, $p < 0.001$, $df = 16$, $R^2_{adj} = 0.965$; pellet: $F(7,8) = 4.662$, $p = 0.023$, $df = 16$, $R^2_{adj} = 0.631$). So in general, there was no significant effect of the treatment on the spelt, pellet and total feed intake of the chickens. However, the spelt, pellet and total feed intake differed between the weeks. Data on weekly feed intake is shown in figure 3.2.2.

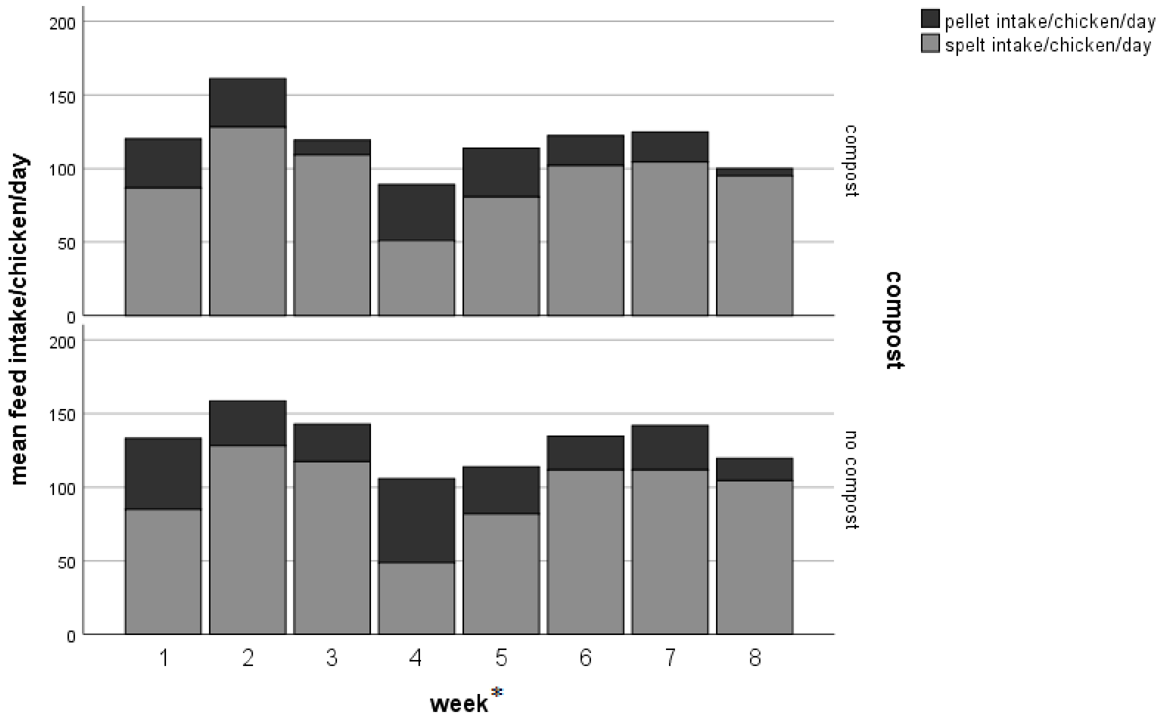

FIGURE 3.2.2 AVERAGE FEED INTAKE (GRAM/CHICKEN/DAY) PER TREATMENT GROUP PER WEEK. SIGNIFICANT: [*]

Negative Spearman rank correlations were found between the observed behaviour eating pellet at the trough and the average number of worms found in pitfalls (ρ = -0.527, p = 0.025, N = 18) and the average total number of insects found in pitfalls (ρ = -0.506, p = 0.032, N = 18). So the less insects were found, the more chickens were observed to eat pellet at the trough. Also, a negative correlation was found between the total feed intake and the number of worms found in pitfalls (ρ = -0.613, p = 0.012, N = 16), so the more worms were found in pitfalls, the less feed was eaten by the chickens. Feed intake correlated with some weather variables as well. This is shown in chapter 3.8.

A statistically significant difference (F(2,51) = 3.892, p = 0.027, df = 53) in body weight between the groups was shown as determined by a One-way ANOVA. A Tukey Post Hoc test showed that body weight is significantly lower (1.73 ± 0.13 kg, p = 0.024) in the compost and tilling group compared with the orchard (reference) group (1.80 ± 0.17 kg). There were no significant differences between the compost and tilling and no compost and tilling group and between the no compost and tilling group and the orchard (reference) group. The data on body weight are shown in figure 3.2.3.

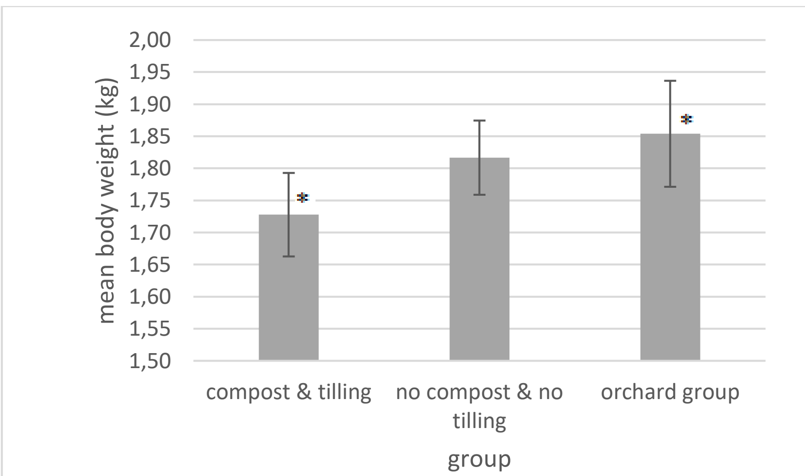

FIGURE 3.2.3 MEANS OF BODY WEIGHT (KG) PER GROUP. ERROR BARS: 95% CI. SIGNIFICANT: [*]

3.3. Laying performance

A One-way ANOVA was carried out with ‘number of eggs per day’ as dependent variable and ‘group’ as fixed factor. The number of eggs per day differed significantly ($F(1,99) = 11.131$, $p = 0.001$, $df = 101$) between treatment groups as shown in figure 3.3.1. The hens from the group with the no compost & no tilling treatment had laid more eggs compared with the compost & tilling treatment group.

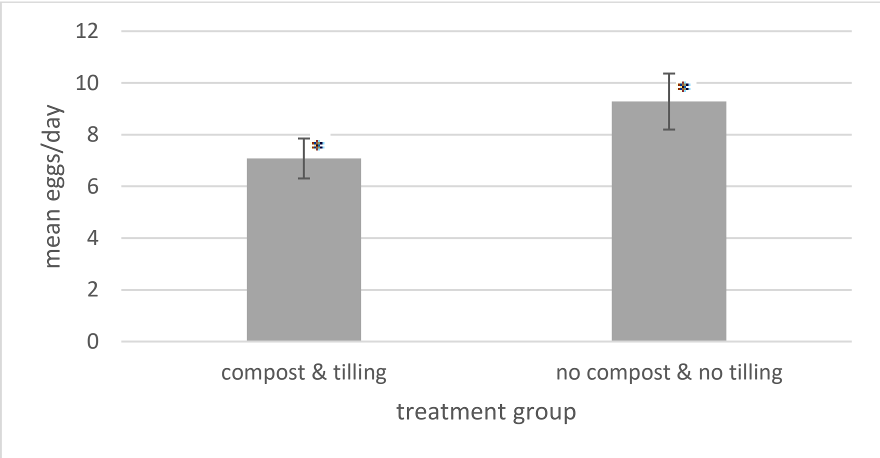

FIGURE 3.3.1 MEANS OF NUMBER OF EGGS PER DAY PER GROUP. ERROR BARS: 95% CI. SIGNIFICANT: [*]

A General Linear Model with number of eggs per day as dependent variable and group and week as fixed factors was run. Both group (compost or no compost) ($F(1,83) = 26.214$, $p < 0.001$, $df = 101$) and week ($F(8,83) = 29.911$, $p < 0.001$, $df = 101$) as main effects and the interaction between group and week ($F(8,83) = 5.365$, $p < 0.001$, $df = 101$) are important in predicting the number of eggs in the General Linear Model ($R^2_{adj} = 0.754$). The means of the number of eggs per day per group and per week are shown in figure 3.3.2. It shows an overall increase of the average number of eggs laid per week throughout the experiment.

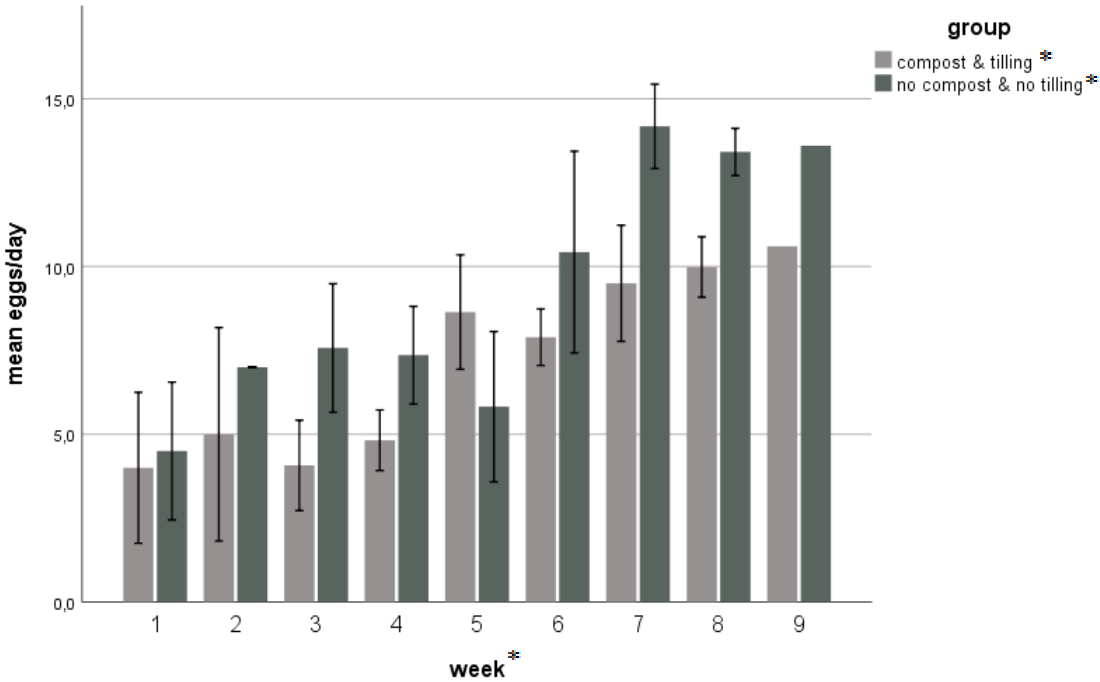

FIGURE 3.3.2 MEANS OF NUMBER OF EGGS PER DAY PER TREATMENT GROUP AND WEEK. ERROR BARS: 95% CI (THERE ARE NO ERROR BARS ON DATA FROM WEEK 9, BECAUSE N = 1). SIGNIFICANT: [*]

A One-way ANOVA was carried out with 'egg weight (g)' as dependent variable and 'groups' as fixed factor. Average egg weight of the compost & tilling group (56.1 ± 2.8) differed significantly ($F(1,26) = 7.878$, $p = 0.009$, df= 27) from the no compost & no tilling group (60.1 ± 2.4). So egg weight was lower in the compost & tilling treatment group (see figure 3.3.3).

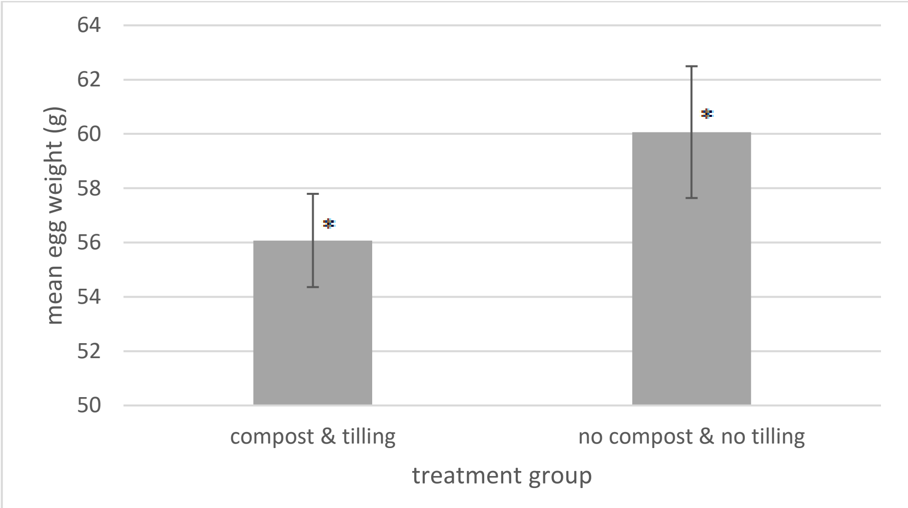

FIGURE 3.3.3 MEANS OF EGG WEIGHT (G) PER TREATMENT GROUP. ERROR BARS: 95% CI. SIGNIFICANT: [*]

3.4. Insects

A Kruskal-Wallis and Mann-Whitney U test were carried out with average number of spiders, beetles, larvae, flying insects, worms and other insects in pitfalls, total number of insects and total insect biomass in pitfalls, average number of spiders, beetles, flies, wasps and other insects on sticky sheets, total number of insects and total insect biomass on sticky sheets as test field and compost treatment group as groups variable. There was a significant effect of the compost treatment on the average number of other insects in pitfalls ($U = 3565.500$, $p = 0.010$, $N = 188$), total insect biomass in pitfalls ($U = 3652.000$, $p = 0.037$, $N = 188$), number of spiders on sticky sheets ($U = 2955.500$, $p = 0.038$, $N = 166$) and number of beetles ($U = 2781.000$, $p = 0.009$, $N = 166$) on sticky sheets. In the compost & tilling treatment, the number of other insects in pitfalls, number of spiders on sticky sheets and number of beetles on sticky sheets were lower and total insect biomass in pitfalls was higher compared with the no compost & no tilling treatment. The results are shown in figure 3.4.1.

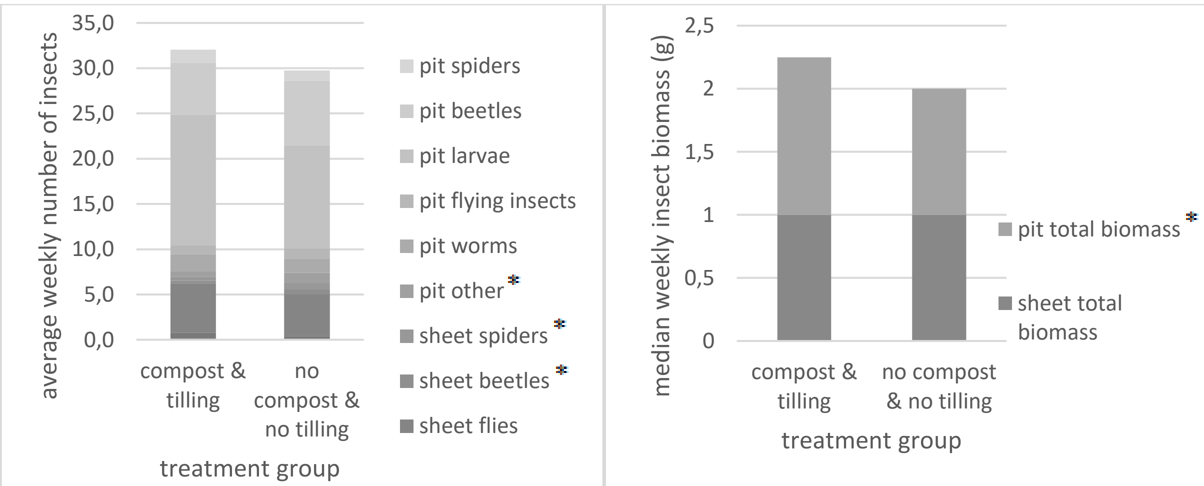

FIGURE 3.4.1 MEANS OF NUMBER OF INSECTS (LEFT) AND MEDIAN TOTAL BIOMASS OF INSECTS (G) (RIGHT) IN PITFALLS (PIT) AND ON STICKY SHEETS (SHEET) PER COMPOST TREATMENT GROUP. SIGNIFICANT: [*]

Another Kruskal-Wallis and Mann-Whitney U test were carried out with the same variables in the test field, but with chickens treatment group as groups variable. Significant effects of the presence of chickens in the field were shown for several variables on insect data, as shown in table 3.4.2.

TABLE 3.4.2: SIGNIFICANT RESULTS FROM KRUSKAL-WALLIS AND MANN-WHITNEY TESTS OF INSECT DATA. MANN-WHITNEY U, THE P-VALUE AND THE SAMPLE SIZE (N) ARE GIVEN.

Results Kruskal-Wallis and Mann-Whitney test	*Mann-Whitney U*	*p-value*	*N*
# spiders pit	U = 2495.000	p < 0.001	N = 188
# beetles pit	U = 2206.500	p < 0.001	N = 188
# larvae pit	U = 2330.000	p < 0.001	N = 188
# flying insects pit	U = 3036.500	p < 0.001	N = 188
# worms pit	U = 3669.500	p = 0.038	N = 188
# other insects pit	U = 3301.000	p = 0.001	N = 188
# total insects pit	U = 1045.000	p < 0.001	N = 188
Total biomass pit	U = 2677.500	p < 0.001	N = 188
# flies sheet	U = 2592.500	p = 0.006	N = 166
# other insects sheet	U = 3116.500	p = 0.047	N = 166
# total insects sheet	U = 2687.000	p = 0.014	N = 166
Total biomass sheet	U = 64.000	p = 0.030	N = 30

In the chicken treatment, the average number of spiders, beetles, larvae, flying insects, worms and other insects in pitfalls, total number of insects and total insect biomass in pitfalls was lower. The average number of flies and other insects on sticky sheets, total number of insects and total insect biomass on sticky sheets was higher, compared with the no chicken treatment. To summarise: the chickens had a significant effect on all measured insect variables, except for the number of spiders, beetles and wasps found on sticky sheets. The results are shown in figure 3.4.3.

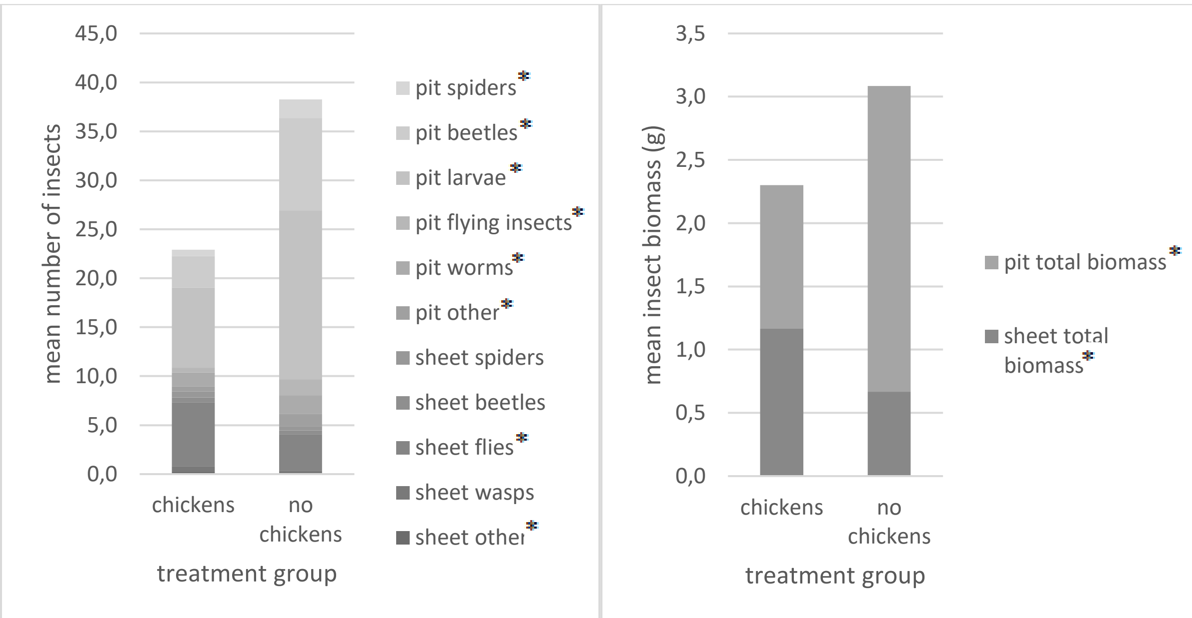

FIGURE 3.4.3 MEANS OF NUMBER OF INSECTS (LEFT) AND TOTAL BIOMASS OF INSECTS (G) (RIGHT) IN PITFALLS (PIT) AND ON STICKY SHEETS (SHEET) PER CHICKEN TREATMENT GROUP. SIGNIFICANT: [*]

Spearman rank correlations were found between the number of different insect groups found in pitfalls and the vegetation scores. Significant positive correlations were found between insect abundance and vegetation quality, as shown in table 3.4.4. There were also a lot of correlations between insect numbers and biomass and weather factors, which can be found in chapter 3.8.

TABLE 3.4.4 SIGNIFICANT SPEARMAN RANK CORRELATIONS BETWEEN (CRAWLING) INSECTS FOUND IN PITFALLS (PIT) AND VEGETATION COVER AND CONDITION IN THE MIDDLE AND AT THE SIDE OF THE FIELDS. SPEARMAN'S RHO (ρ) , THE P-VALUE AND THE SAMPLE SIZE (N) ARE GIVEN.

Spearman rank correlations	*Vegetation cover middle*	*Vegetation cover side*	*Vegetation condition middle*	*Vegetation condition side*
# beetles pit	ρ = 0.710, p = 0.010, N = 12	ρ = 0.711, p = 0.009, N = 12	ρ = 0.714, p = 0.009, N = 12	ρ = 0.746, p = 0.005, N = 12
# larvae pit	-	ρ = 0.585, p = 0.046, N = 12	-	-
# flying insects pit	ρ = 0.721, p = 0.008, N = 12	ρ = 0.829, p = 0.001, N = 12	ρ = 0.747, p = 0.005, N = 12	ρ = 0.817, p = 0.001, N = 12
# other insects pit	-	ρ = 0.621, p = 0.031, N = 12	ρ = 0.634, p = 0.027, N = 12	ρ = 0.683, p = 0.014, N = 12
# total insects pit	-	ρ = 0.678, p = 0.015, N = 12	-	ρ = 0.611, p = 0.035, N = 12
Total biomass pit	-	ρ = 0.803, p = 0.002, N = 12	ρ = 0.640, p = 0.025, N = 12	ρ = 0.742, p = 0.006, N = 12

3.5. Worms

A One-way ANOVA was carried out with average worm biomass (g/worm), worms (worm/m^3) and biomass (g/m^3) as dependent variables and compost as factor. There was no significant effect of compost on all of the three variables ($p > 0.05$). The results are shown in figure 3.5.1 on the left.

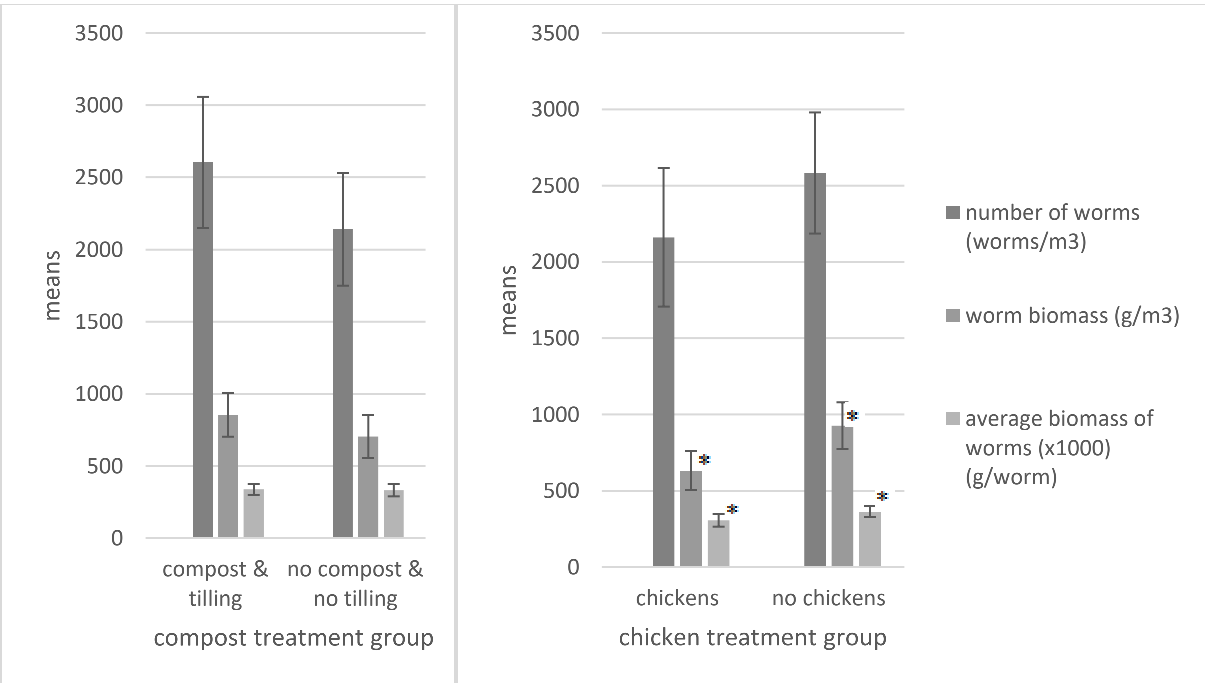

FIGURE 3.5.1 MEANS OF NUMBER OF WORMS (WORMS/M^3), WORM BIOMASS (G/M^3) AND AVERAGE BIOMASS OF WORMS (X1000) (G/WORM) PER TREATMENT GROUP (LEFT: COMPOST & TILLING AND NO COMPOST & NO TILLING; RIGHT: CHICKENS AND NO CHICKENS). ERROR BARS: 95% CI. SIGNIFICANT: [*]

Another ANOVA was run with the same dependent variables, but with chickens as factor. The average biomass of worms was significantly higher (0.36 ± 0.84 g) in the no chicken fields ($F(1,46) = 4.605$, $p = 0.037$, $df = 47$) as well as the worm biomass (927.08 ± 362.41 g/m^3; $F(1,46) = 9.351$, $p = 0.004$, $df = 47$) compared with the chicken fields. The number of worms/m^3 in the no chicken fields was higher as well, but the effect was not significant. The results are shown in figure 3.5.1 on the right. In a GLM it was shown that there were no significant interaction effects of compost and chicken treatment groups.

There was a correlation between foraging and number of worms ($\rho = 0.523$, $p = 0.026$, $N = 18$) and biomass per m^3 ($\rho = 0.722$, $p = 0.001$, $N = 18$), so an increase in number and biomass of worms per m^3 was related to increased foraging behaviour.

3.6. Vegetation

Independent samples Kruskal-Wallis tests were carried out. The first Kruskal-Wallis test (group: compost & tilling, no compost & no tilling) showed no effect of the compost & tilling treatment on all vegetation scores. The results are shown in figure 3.6.1. There were also no differences between the sides and the middles of the fields.

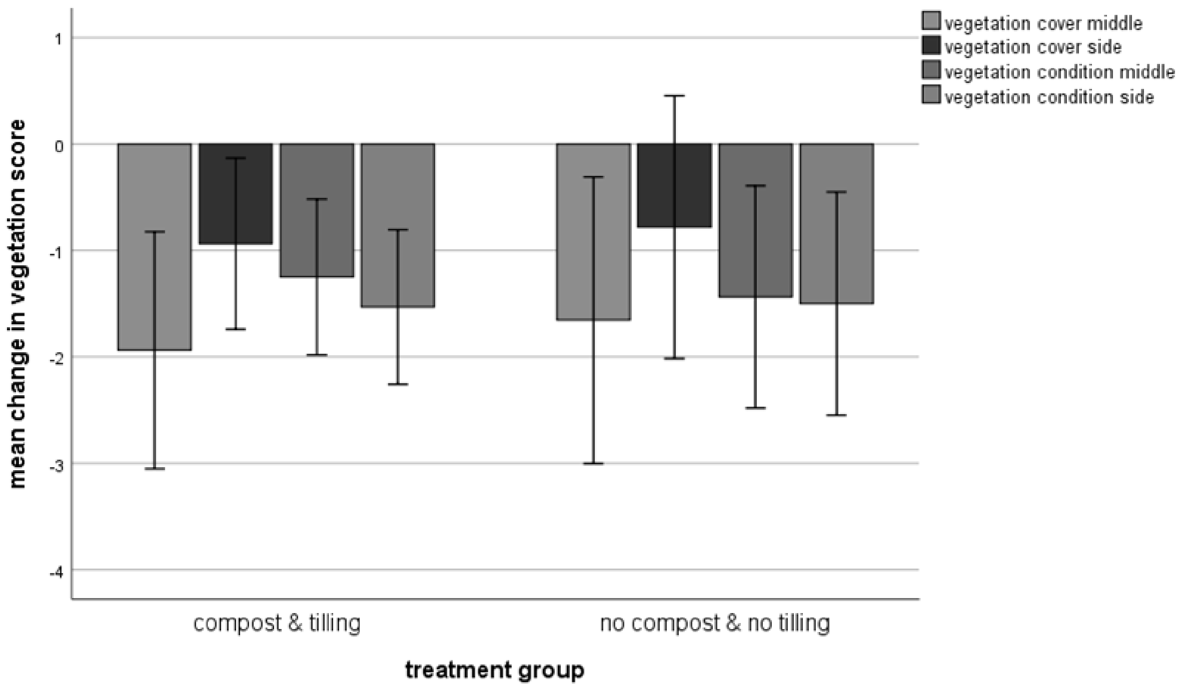

FIGURE 3.6.1 MEANS OF CHANGE IN VEGETATION SCORES PER TREATMENT GROUP (COMPOST & TILLING AND NO COMPOST & NO TILLING). ERROR BARS: 95% CI.

The second Kruskal-Wallis test (independent: vegetation cover middle, vegetation cover side, vegetation condition middle, vegetation condition side; group: chickens, no chickens) showed significant differences ($p < 0.001$, $N = 64$) between the chicken and no chicken group for all average changes in vegetation scores. The average changes in all vegetation scores were negative in the chicken group, and positive in the no chicken group, as showed in figure 3.6.2. This means that on average, chickens caused a decrease in vegetation cover and condition.

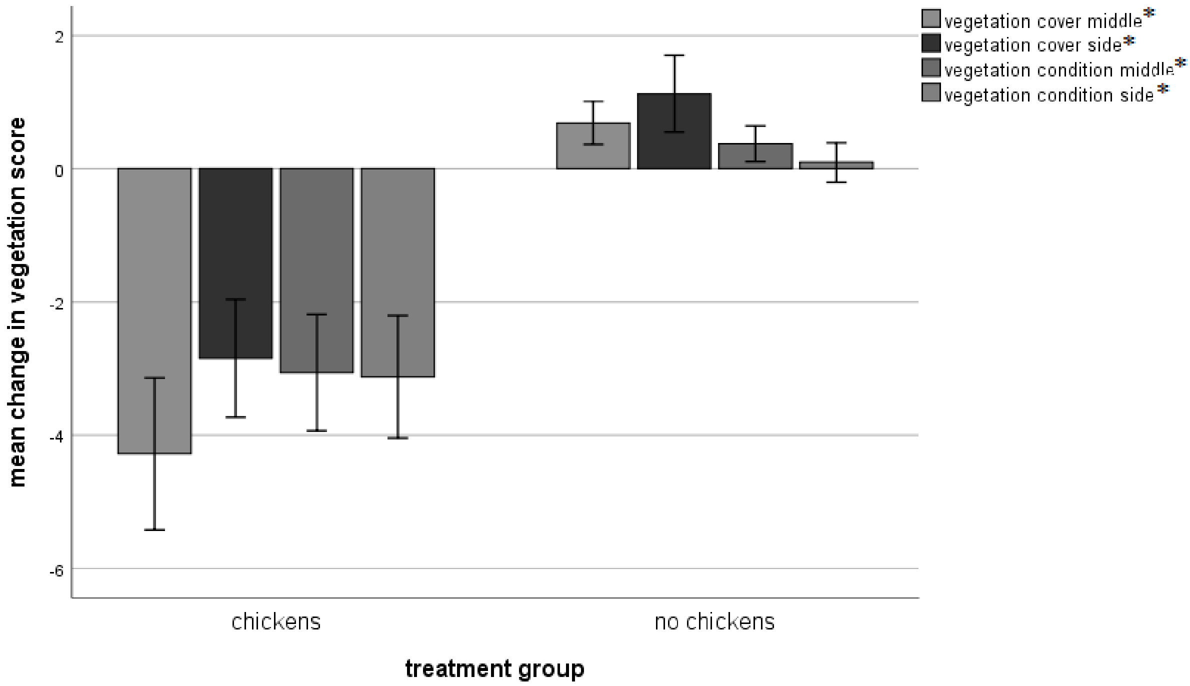

FIGURE 3.6.2 MEANS OF CHANGE IN VEGETATION SCORES PER TREATMENT GROUP (CHICKENS AND NO CHICKENS). ERROR BARS: 95% CI. SIGNIFICANT: [*]

The last Kruskal-Wallis test (group: week) showed that the change in vegetation condition score on the sides in all fields differed significantly between weeks (p = 0.013, N = 64). The other scores differed non-significantly between weeks, as shown in figure 3.6.3.

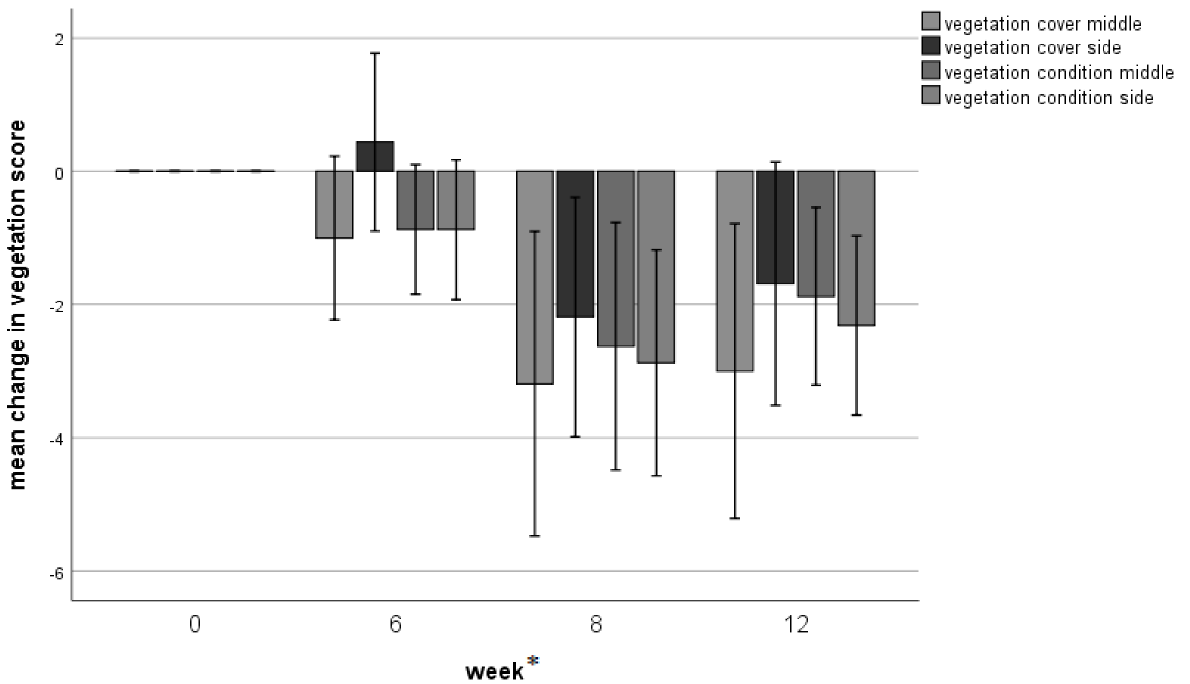

FIGURE 3.6.3 MEANS OF CHANGE IN VEGETATION SCORES PER WEEK. ERROR BARS: 95% CI. SIGNIFICANT: [*]

Next to scoring I asked farmer Wil Sturkenboom to visually assess the vegetation as well. He was very content with the low vegetation cover and condition under the shrubs of the chicken fields after the experiment, because there were almost no weeds left. However, the grass area of the chicken fields was too far gone. He wanted to see a good looking grass field with clover for nitrogen fixing. The ideal situation was between week 5 and 6 according to the farmer. The influence of chickens and compost on the shrubs performance (expected fruit yield) is not yet visible before May according to the farmer (Sturkenboom, 2017).

3.7. Visual Soil Assessment

An independent samples Kruskal-Wallis test was carried out on the data on Visual Soil Assessment (VSA). As hypothesised, there were no significant differences between the four fields concerning the VSA scores for soil structure, soil porosity, earthworm count and the total score. The scores for the different fields are shown in figure 3.7.1.

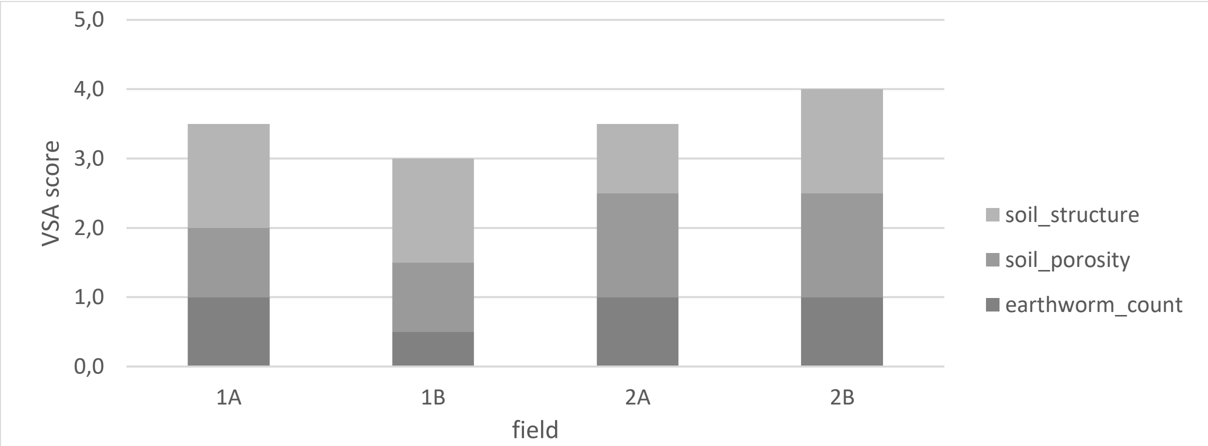

FIGURE 3.7.1 VISUAL SOIL ASSESSMENT SCORES PER FIELD (1A = CHICKENS, COMPOST & TILLING; 1B = CHICKENS, NO COMPOST & NO TILLING; 2A = NO CHICKENS, COMPOST & TILLING; 2B = NO CHICKENS, NO COMPOST & NO TILLING).

3.8. Weather

In annex 8.1., figures of the weekly averaged data of four of the most important weather variables are displayed. These variables (together with some linked variables, like Tmax and Tmin are related to Tavg and rainfall (mm/d) and rainfall (h/d) are related) showed the most correlations with other variables from the experiment. The weather played a big role in the vegetation quality over the weeks. The high levels of rainfall reinforced the damaging effect of the scratching of the chickens on the vegetation. In 7 to 8 weeks, the fields with chickens became very muddy. As a consequence, we decided to stop the study on chickens from week 9. All other measurements continued to week 12.

Spearman rank correlations were studied between the weather factors maximum temperature (Tmax; °C), minimum temperature (Tmin; °C), average temperature (Tavg; °C), rainfall (mm/d), rainfall (h/d), average relative humidity (RH; %), sunshine (h/d), cloudiness (scale 0-8) and wind speed (m/s) and the other variables on behaviour, feed intake and insect data. The weather had an influence on the expression of the behaviours foraging, walking and standing, as shown in table 3.8.1. on the next page. Only the significant correlations are displayed.

TABLE 3.8.1 SIGNIFICANT SPEARMAN RANK CORRELATIONS BETWEEN BEHAVIOUR AND WEATHER VARIABLES TEMPERATURE, RELATIVE HUMIDITY AND CLOUDINESS. SPEARMAN'S RHO (ρ), P-VALUES AND SAMPLE SIZES (N) ARE GIVEN.

Spearman rank correlations	*Maximum temperature (Tmax; °C)*	*Average temperature (Tavg; °C)*	*Minimum temperature (Tmin; °C)*	*Relative humidity (RH; %)*	*Cloudiness (scale 0-8)*
Foraging	ρ = 0.512, p = 0,030, N = 18	ρ = 0.639, p = 0,004 N = 18	ρ = 0.607, p = 0.008, N = 18	-	-
Walking	-	ρ = -0.719, p = 0.001, N = 18	ρ = -0.775, p < 0.001, N = 18	-	-
Standing	ρ = -0.739, p < 0.001, N = 18	ρ = -0.577, p = 0.012, N = 18	-	ρ = -0.585, p = 0.011, N = 18	ρ = 0.513, p = 0.030, N = 18

Effects of the weather on feed intake of the chickens are shown in table 3.8.2.

TABLE 3.8.2 SIGNIFICANT SPEARMAN RANK CORRELATIONS BETWEEN FEED INTAKE AND WEATHER VARIABLES TEMPERATURE, RELATIVE HUMIDITY, CLOUDINESS AND SUNSHINE. SPEARMAN'S RHO (ρ) , THE P-VALUE AND THE SAMPLE SIZE (N) ARE GIVEN.

Spearman rank correlations	*Maximum temperature (Tmax; °C)*	*Average temperature (Tavg; °C)*	*Relative humidity (RH; %)*	*Cloudiness (scale 0-8)*	*Sunshine (h/d)*
Total feed intake	-	-	-	-	ρ = -0.563, p = 0.023, N = 16
Pellet intake	ρ = 0.685, p = 0.003, N = 16	ρ = 0.522, p = 0.038, N = 16	ρ = 0.513, p = 0.042, N = 16	ρ = -0.591, p = 0.016, N = 16	ρ = 0.510, p = 0.044, N = 16
Spelt intake	-	-	-	ρ = 0.638, p = 0.008, N = 16	ρ = -0.744, p = 0.001, N = 16

Correlations between insect data and weather variables are shown in table 3.8.3 on the next page. The only correlation that is not shown in the table, is the correlation between the number of worms found in pitfalls and the relative humidity (RH, %) (ρ = -0.392, p = 0.006, N = 48).

TABLE 3.8.3 SIGNIFICANT SPEARMAN RANK CORRELATIONS BETWEEN INSECT NUMBERS AND BIOMASS FOUND IN PITFALLS AND ON STICKY SHEETS AND WEATHER VARIABLES TEMPERATURE, RAINFALL, RELATIVE HUMIDITY, CLOUDINESS, SUNSHINE AND WIND SPEED. SPEARMAN'S RHO (ρ) , THE P-VALUE AND THE SAMPLE SIZE (N) ARE GIVEN.

Spearman rank correlations	*Maximum temperature (Tmax; °C)*	*Average temperature (Tavg; °C)*	*Minimum temperature (Tmin; °C)*	*Rainfall (mm/d)*	*Rainfall (h/d)*	*Cloudiness (scale 0-8)*	*Sunshine (h/d)*	*Wind speed (m/s)*
# beetles pit	$\rho = 0.643$, $p < 0.001$, N = 48	$\rho = 0.645$, $p < 0.001$, N = 48	$\rho = 0.630$, $p < 0.001$, N = 48	$\rho = -0.532$, $p < 0.001$, N = 48	$\rho = -0.589$, $p < 0.001$, N = 48	$\rho = -0.488$, $p < 0.001$, N = 48	$\rho = 0.640$, $p < 0.001$, N = 48	-
# flying insects pit	$\rho = 0.497$, $p < 0.001$, N = 48	$\rho = 0.493$, $p < 0.001$, N = 48	$\rho = 0.548$, $p < 0.001$, N = 48	$\rho = -0.476$, $p = 0.001$, N = 48	$\rho = -0.541$, $p < 0.001$, N = 48	-	$\rho = 0.450$, $p = 0.001$, N = 48	-
# larvae pit	$\rho = -0.430$, $p = 0.002$, N = 48	$\rho = -0.384$, $p = 0.007$, N = 48	$\rho = -0.374$, $p = 0.009$, N = 48	$\rho = 0.408$, $p = 0.004$, N = 48	$\rho = 0.419$, $p = 0.003$, N = 48	-	-	-
# other pit	$\rho = 0.393$, $p = 0.006$, N = 48	$\rho = 0.315$, $p = 0.029$, N = 48	-	$\rho = -0.295$, $p = 0.042$, N = 48	$\rho = -0.356$, $p = 0.013$, N = 48	-	$\rho = 0.389$, $p = 0.006$, N = 48	-
# spiders sheet	$\rho = 0.530$, $p < 0.001$, N = 47	$\rho = 0.431$, $p = 0.002$, N = 47	$\rho = 0.322$, $p = 0.027$, N = 47	$\rho = -0.372$, $p = 0.01$, N = 47	$\rho = -0.410$, $p = 0.004$, N = 47	$\rho = -0.374$, $p = 0.010$, N = 47	$\rho = 0.389$, $p = 0.007$, N = 47	$\rho = -0.447$, $p = 0.002$, N = 47
# beetles sheet	$\rho = 0.695$, $p < 0.001$, N = 47	$\rho = 0.705$, $p < 0.001$, N = 47	$\rho = 0.702$, $p < 0.001$, N = 47	$\rho = -0.622$, $p < 0.001$, N = 47	$\rho = -0.682$, $p < 0.001$, N = 47	$\rho = -0.317$, $p = 0.030$, N = 47	$\rho = 0.583$, $p < 0.001$, N = 47	-
# flies sheet	$\rho = 0.757$, $p < 0.001$, N = 47	$\rho = 0.690$, $p < 0.001$, N = 47	$\rho = 0.654$, $p < 0.001$, N = 47	$\rho = -0.619$, $p < 0.001$, N = 47	$\rho = -0.710$, $p < 0.001$, N = 47	$\rho = -0.434$, $p = 0.002$, N = 47	$\rho = 0.652$, $p < 0.001$, N = 47	$\rho = -0.326$, $p = 0.025$, N = 47
# wasps sheet	$\rho = 0.500$, $p < 0.001$, N = 47	-	-	$\rho = -0.400$, $p = 0.005$, N = 47	$\rho = -0.400$, $p = 0.005$, N = 47	$\rho = -0.489$, $p < 0.001$, N = 47	$\rho = 0.443$, $p = 0.002$, N = 47	$\rho = -0.541$, $p < 0.001$, N = 47
# other sheet	$\rho = 0.316$, $p = 0.030$, N = 47	-	-	$\rho = -0.368$, $p = 0.011$, N = 47	$\rho = -0.352$, $p = 0.015$, N = 47	$\rho = -0.327$, $p = 0.025$, N = 47	$\rho = 0.383$, $p = 0.008$, N = 47	$\rho = -0.336$, $p = 0.021$, N = 47
# total insects sheet	$\rho = 0.785$, $p < 0.001$, N = 47	$\rho = 0.715$, $p < 0.001$, N = 47	$\rho = 0.671$, $p < 0.001$, N = 47	$\rho = -0.642$, $p < 0.001$, N = 47	$\rho = -0.734$, $p < 0.001$, N = 47	$\rho = -0.453$, $p = 0.001$, N = 47	$\rho = 0.652$, $p < 0.001$, N = 47	$\rho = -0.342$, $p = 0.019$, N = 47
Total biomass sheet	$\rho = 0.698$, $p < 0.001$, N = 47	$\rho = 0.588$, $p < 0.001$, N = 47	$\rho = 0.495$, $p < 0.001$, N = 47	$\rho = -0.521$, $p < 0.001$, N = 47	$\rho = -0.571$, $p < 0.001$, N = 47	$\rho = -0.517$, $p < 0.001$, N = 47	$\rho = 0.582$, $p < 0.001$, N = 47	$\rho = -0.446$, $p = 0.002$, N = 47

No significant correlations were found between weather variables and data from the worm samples.

4. Economic quantification & system analysis

The obtained results show some interesting effects. However, the feasibility of the treatments in practice is in general dependent on financial feasibility. In terms of economic sustainability it is important to quantify the cashflows of the different treatments. Each treatment has to fulfil the management norm, that means that the shrubs need fertilizer and weed control in order to yield high quality fruits. Treatment 2b (no chickens and no compost & no tilling) does not fulfil this norm anyhow, so this treatment is not feasible and thus excluded from the quantification, otherwise, it would give the same results as treatment 2a (no chickens and compost & tilling). By means of the economic quantification, shown in table 4.1, farmers and decisionmakers are able to choose which management practice would fit best on the farm. The amounts mentioned in table 4.1 are per linear metre shrubs on a yearly basis and assuming that the chickens are kept this way year round. The profit from fruit is kept out, because the effect of the measurements on fruit yield is not yet verifiable. Also, the investment costs of the start of introducing chickens in the orchard is excluded from the calculations.

TABLE 4.1 ECONOMIC QUANTIFICATION WITH YEARLY COSTS AND PROFITS OF THREE OF THE TREATMENTS PER LINEAR METRE SHRUBS UNDER THE APPLIED MANAGEMENT STRATEGIES. PROFIT FROM FRUIT IS EXCLUDED.

Amounts (€)	**Compost & tilling**				**No compost & no tilling**			
	Costs		Profit		Costs		profit	
Chickens	Pellets	1.62	Eggs	22.97	Pellets	2.18	Eggs	22.97
	Spelt	3.46	Meat	1.20	Spelt	3.60	Meat	1.20
	Compost	0.11	Reduced labour	0.21	Labour chickens	2.45	Reduced labour	0.27
	Labour chickens	2.45	extra manure	1.83	Labour orchard	0.12	extra manure	1.83
	Labour orchard	0.51	Rooster care	0.50	Compost	0.11	Rooster care	0.50
	Hen purchase	0.73			Hen purchase	0.73		
	Total costs	8.88	Total profit	26.72	Total costs	9.19	Total profit	26.78
	Total			17.84	Total			17.59
No chickens	Compost	0.11						
	Mowing & tilling	0.12						
	Weeding	0.15						
	Compost labour	0.45						
	Total costs	0.83	Total profit	-				
	Total			- 0.83				

Since the data on egg production from this study were not very reliable, this calculation is done assuming a laying percentage of 75%. For the feed costs and meat profit, the results from the current study are used. Information on manure profit is obtained from van Horne et al. (1995) and labour costs are obtained from the website of the CBS (2017). The remaining data are obtained from the farmer (Sturkenboom, 2017). In the annex a table is included which contains all factors that were taken into account in the calculations (see annex 8.2).

Next to the economically quantifiable factors as shown in table 4.1, there are many other unquantifiable and more qualitative factors involved as well, also ones that were not included in this study. These factors together are visualised in figure 4.2, which contains the following elements:

1. Red current shrubs
2. Flying insects
3. Weed plants
4. Grass
5. Crawling insects
6. Worms
7. Clover
8. Chickens
9. Compost

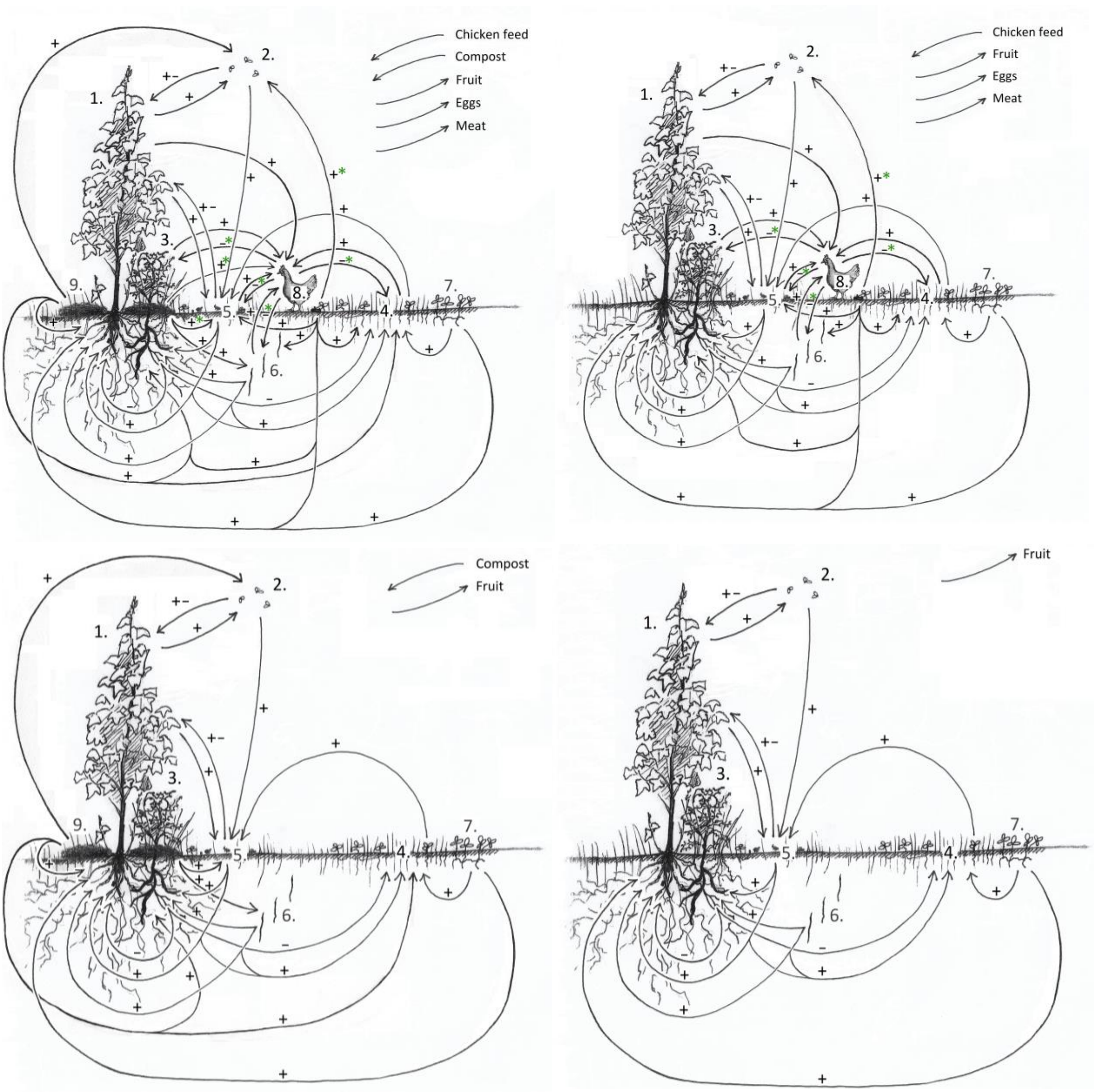

FIGURE 4.2 VISUAL REPRESENTATION OF THE ORCHARD SYSTEM WITH ALL FACTORS FOR ALL TREATMENT FIELDS (UPPER ROW: CHICKENS; DOWN ROW: NO CHICKENS; LEFT: COMPOST & TILLING; RIGHT: NO COMPOST & NO TILLING). SIGN: [*]

Without any treatments, there are already a lot of relations between different elements in the orchard as shown in figure 4.2 (down, right). The interactions found significant in the current study are denoted by a dark green asterisk (*). Every element fulfils many functions and each important function is supported by many elements, as described as the second and third permaculture design principle (Mollison & Holmgren, 1991). The main element here is the current shrub, of which its performance is dependent on the competition with weeds, pollination by flying insects, infestation of pest insects (flying and crawling) and fertilisation from nitrogen fixing of clover. Crawling insects and worms have an indirect effect on the shrub in terms of soil improvement. When compost is applied (see figure 4.2 (down, left)) worm and crawling insect populations are slightly stimulated. However, in the current study these effects were not significant, except for insect biomass found in pitfalls and some crawling insect types in pitfalls and on sticky sheets. In the long term, with warmer seasons included, this effect is expected to be significant. The increase in worm and crawling insect populations can enhance soil quality even more which thereafter stimulates growth of the grass/clover mixture and the current shrubs, but also of the weeds. By the breakdown of compost by worms and insects nutrients are made available for the grass/clover mixture, the current shrubs and the weeds.

Chickens can balance out the increase of weed populations by the mentioned insect and compost effects as shown in figure 4.2 (upper, left). Their manure fertilises the shrubs, sward and weeds even more. However, the sward and the weeds are damaged by the foraging and scratching of chickens, so in the end the nutrients are only benefitting the shrubs and the chickens themselves. In the chicken density and duration of the current study, nitrogen from the manure was quite abundant. With a manure production between 115 (Smith & Frost, 2000) and 150 g/chicken/day (Horne et al., 1995) and a fraction of 16 g N/kg manure (Smith & Frost, 2000), the nitrogen that was added to the soil is estimated to be between 229 and 299 kg N/ha, so in order to prevent N-leaching, a lower density is advised, or the time that the chickens are on the same area should be shorter. Next to vegetation, the manure can stimulate worm and insect populations as well. On the other hand, chickens ingest worms and crawling insects, so there is a negative effect on those populations caused by the chickens. Consequently, the indirectly increased effect on soil quality is then limited as well. However, the flying insect populations are stimulated by the presence of chicken manure, and those populations can have a positive effect on the populations of crawling insects as well, because they can produce more larvae, which are counted in as crawling insects. In this treatment, the chickens benefit from the shrub as it provides shelter, from the compost as it provides foraging substrate, which stimulated foraging behaviour in this study, from worms and insects for feed, and from the sward which also functions as a feed source.

The last treatment, shown in figure 4.2 (upper, right), is the same as the latter mentioned before, but with the compost effect excluded. However, in the current study, there was no general significant difference between compost and tilling treatments on vegetation cover and condition, so the effect of chickens on weeds remain more or less the same as in the treatment with compost and tilling as studied in fall. In the no compost & no tilling treatment, more external inputs are needed in the form of layer feed, as this system provides less worm biomass and crawling insects compared to the chicken field with compost & tilling treatment. However, the amounts of provided feed did not differ significantly. In the current study, the effects of the relationship between elements on fruit yield could not be assessed. However, it is expected that fruit yield will be higher in the areas with chickens, caused by the extra nitrogen from the chicken manure. This effect would be interesting to study further. The effect of chickens on the soil would also be interesting to assess in a long term study. With the density of the current study, organic matter content of the soil is expected to be lower with chickens, as they ingest a lot of vegetation. In the ideal chicken density, the soil organic matter is expected to increase, as the vegetation would be able to recover and grow more because of the manure as well. Overall, in the treatment with the elements compost and chickens included (figure 4.2, upper, left), the most interactions take place, so a more stable system is expected, when the elements are in balance. A high biodiversity is desirable, as it makes the orchard system more resilient. Therefore, it is advised to create habitats for all sorts of insects, where they can reproduce without being eradicated completely by chicken ingestion.

Another qualitative factor that results from keeping chickens in the orchard is an improvement of the image of the sector, which in the case of Fruittuin van West can lead directly to a higher farm income, because the farm is freely accessible for people. Results from a study of Pettersson et al. (2016) in the United Kingdom showed that people find outdoor access the most important factor determining animal welfare. People think that free range hens are happier, healthier and that they lay eggs that taste better. De Jonge and Van Trijp (2013) showed as well that outdoor access is most important for the perceived animal friendliness in chickens. In general, people say to be willing to pay more for products from animals with high welfare standards (Bennett, 1996, 2016). So the sight of chickens foraging in the orchard can stimulate people to buy their eggs.

5. Discussion

This research was carried out in order to investigate whether chicken nutrition could become more sustainable in terms of animal welfare, ecology and economics. It was hypothesised that chicken foraging behaviour could be stimulated by the application of compost and rotary tilling, amongst others because insects and worms were expected to be attracted by compost combined with tilling. As a result it was hypothesised that part of the feed could be replaced by insects and worms, by realising a local and natural feed source for the chickens, which would give savings on feed costs. Savings on weeding and mowing costs were expected as well. The foraging behaviour of the chickens would contribute to vegetation control.

This study had some general limitations: it was carried out on quite a small scale, due to all kinds of practical limitations like available materials, time, and weather circumstances, which resulted in no repetitions of the experimental setup, one shift of behavioural observations per week, and 9 weeks of chicken data collection instead of 12 respectively. Also, observer bias might have taken place, because the treatments of each field were inevitably known to the observer. Consequently, this study is more of an exploratory type and can lead to more in depth future research on each of the single variables. At the same time, this study had a holistic view on the orchard system, whereby many factors were taken into account, which can give valuable information in context. In the next paragraphs, each variable that was studied and its results are discussed.

5.1. Chicken behaviour

As hypothesised, from the results of this study it can be concluded that the application of compost combined with tilling leads to a higher number of chickens performing foraging behaviour. This foraging was also linked to the location of the compost, namely under the shrubs. This is in line with the study of Petherick and Duncan (1989), who showed that young laying hens had a preference for peat as a foraging substrate, which has a high organic content similar to compost. They showed more pecking and scratching behaviour in the peat compared with sand, sawdust and wood shavings. In the current study, independent from the type of behaviour, chickens from the compost & tilling treatment group were found to be more often under the shrubs. It is not proven that foraging goes at the expense of sitting and standing. On contrary, foraging was related to less eating spelt at the trough as hypothesised, and less walking. In the compost & tilling treatment group, also more dustbathing was performed.

When more insects (and worms) were present (for instance in the compost & tilling treatment) chickens needed less effort to find the insects, which might have resulted in showing less foraging behaviour compared with a situation with lower insect (and worm) abundance. However, the positive effect of the compost & tilling treatment is still higher, because more foraging is observed in the compost & tilling treatment. All behavioural observations were carried out in the morning between 10:00 and 12:30 h. However, the activity of chickens is not consistent throughout the day. Hansen (1994) showed that the activity of laying hens increased during the day. Therefore in the current study, a larger difference in foraging behaviour could have been observed between treatment groups when the chickens would have been observed in the afternoon as well.

The method of observation that was used was scan sampling. In this method, the short behavioural displays are missed, like aggressive interactions or mating behaviour. However, the major behaviour of interest in this study was foraging. The short behaviours were not that important in this study. The experimental fields were fenced by different pieces of wire and nets, which had to be tied together. Despite best efforts, it took several weeks to more or less close the fields properly. So in the first weeks, quite some chickens escaped, which were replaced by randomly caught chickens from the orchard. A couple of times the fences were opened by customers in order to take away eggs from the laying boxes and not closed again properly, which also resulted in chickens escaping. On a certain moment, in one field, hens started to peck at the feet of the rooster. The feet started to bleed, so the rooster was replaced with another, after which there were no pecking problems anymore. In total three hens were killed by predatory birds throughout the experiment. They were replaced as well. So the groups of chickens did not consist of the same individuals throughout the whole experiment, which might have resulted in more inaccurate data. Next to that, after a few weeks of observations, the hens turned out to have differing ages as well. However, it is not presumably that this had a significant effect on the observed foraging behaviour. For instance, Scholz et al. (2010) showed that there was no age effect on the level of foraging behaviour in Lohmann Brown laying hens, so the changing differences in age between the experimental chickens through the replacement of animals were not likely to affect foraging observations.

5.2. Feed intake

A lower feed intake was expected in the compost & tilling treatment group. Although the differences in spelt, pellet and total feed intake did not differ significantly, the average pellet intake and the total intake did differ more between groups compared with average spelt intake. When more replications would have been carried out (higher degrees of freedom in the model), the difference might have been significant. There was a negative correlation between the observed behaviour eating pellet at the trough and the number of insects found in pitfalls. So the more insects were found, the less chickens were observed to eat pellet at the trough and the other way around. It is plausible that this relationship is causal, because it could explain that when a shortage of insects arises chickens go back to the provided layer pellet. This might then be an indication of preference of chickens for insects over pellet feed, or that they showed contrafreeloading. Also a negative correlation between worms in pitfalls and total feed intake was observed, so the more worms there were, the less feed was eaten by the chickens, this is an indication of preference for worms over the feed or an expression of contrafreeloading as well. Spelt, pellet and total feed intake differed between weeks, which might have been caused by differing weather circumstances, as discussed in the weather section 5.8.

Insect intake could have been higher and consequently the feed intake lower, when insects were not killed and removed from the fields by the experiment. In that case, the effect could have been significant. In week four of the experiment, there was a miscommunication about the amount of spelt, in which the chickens received a lot less spelt, which was thus limited on that days. As a consequence, chickens started to eat more of the layer pellets to compensate the smaller amount of spelt. However, the total amount of ingested feed was lower than in the other weeks, which might suggest that the spelt grain was normally too easily accessible. In this week, the absence of spelt and the fact that the layer pellets were a little less easily accessible (the spelt feeder was more easily accessible than the pellet feeder, which was only accessible from one side) stimulated the chickens to show more contrafreeloading and forage more. Pellets and spelt could sometimes be preferred over insects, because they are easier to get as they are offered in troughs and because domestic chickens show not much contrafreeloading. When rationed, maybe chickens are stimulated even more to forage, because they have no ad libitum choice for pellet or grains. This possible effect has to be studied further in future research. On days when I was not at the experimental site, staff or trainees fed the chickens, and sometimes they were not informed that well. Sometimes they put the spelt grains on the ground instead of in the feeder, so the remainder could not be measured exactly. Next to that, the spelt grain feeder allowed for more feed to be spoiled, which might have influenced the measured remainders and might have given bias to the data. In general, the results suggest that part of the layer feed and/or the spelt grain can be replaced by insects and worms. However, this concept needs more in depth research.

Body weight in the compost & tilling treatment group was lower compared with the reference group, contrary to the expectation that body weight would be the same amongst groups. However, body weight measurements were only carried out at the end of the experiment and not in the beginning. So it is not possible to say that the lower body weight is caused by the treatment. It could also be that the selected chickens for that field weighted less in advance or that the chickens selected for the reference group were heavier than the actual average, which might be caused by heavier chickens being easier to catch as they might be a bit slower in trying to escape from the catcher.

5.3. Laying performance

A similar laying performance amongst groups was expected, with a decrease in egg production over time. However, the egg production increased throughout the weeks of the experiment in both chicken groups. Daylength decreased as the experiment was carried out in fall. Daylength is linked with laying (Cesare et al., 2010), so a decrease in egg production was expected. During the experiment, the chickens turned out to be of different age groups. This could be the reason for the illogical increase in egg production by replacing escaped older hens by younger ones in the first weeks of the experiment. The egg weight differed significantly between groups as well, against expectations, which also suggest that the average age differed between groups, as literature shows that egg weight increases with the age of the hen (Cowen, Bohren, & McKean, 1964; Gilbert, Peddie, Teague, & Mitchell, 1978; Weatherup & Foster, 1980). Next to that, sometimes eggs were taken out of the laying boxes by costumers, despite multiple signs, explanations and fixed wooden planks. I rejected all data on egg counts on days where I noticed eggs had been taken. However, on some days I could have not noticed it, so combined with inconsistent age of the chickens, in general, the data on laying performance is not very accurate and reliable. Therefore, it is not appropriate to draw conclusions from the data.

5.4. Insects

It was hypothesised that insects would be attracted by the compost & tilling treatment. However, it is not proven that there was an effect of the compost & tilling treatments on insect number found in pitfalls. Only the insect biomass was higher in the compost & tilling treatment, which suggests that bigger insects were attracted. It is also not proven that there was a difference between the treatments in number and biomass of insects trapped on sticky sheets.

It was expected that the presence of chickens would result in lower insect abundance. In line with the hypothesis, a lower insect number and biomass were found in pitfalls in the chicken groups. This suggests that the chickens had foraged on crawling insects. A higher number of insects and higher insect biomass were found on sticky sheets in the chicken groups, compared with the no chicken fields. This can be explained by the manure attracting flying insects. Also, positive correlations were found between insect abundance and vegetation quality, which could be explained by the vegetation being a feed source for the insects, so when the vegetation quality decreased, insect abundance became lower. Or it could have been an indirect effect, with decreasing vegetation and declining insect abundance both caused by the foraging behaviour of the chickens.

Sometimes during the experiment, there were chickens from the orchard that managed to get in the no chicken fields and foraged there. This could have had an influence on the insect data. For the results this means that the effect of chickens on insect number and biomass might have only been bigger than that is measured now. The sticky sheets became less sticky after rain, which could have influenced the results. Also, the type of insects that are caught might be dependent on this catching method. For instance, insect species have their own specific flight height (Byers, 2011). Therefore, selection might have taken place that gives results of insect population divisions that deviate from reality. The same applies to the pitfalls, as there might be a bias due to insect body mass and activity, with more active insects having a higher chance to be trapped. Also the cup diameter has an influence on the number of big insects caught (Hancock & Legg, 2012). The results from this study are highly depending on season. In spring and summer, the outcomes are likely to differ a lot in composition and numbers.

There is no standardized method on insect counting, so it is hard to estimate the actual insect populations in the orchard and to compare the findings of this experiment with others. Anyhow, the results from the treatments within this study could still be compared with each other. Insect intake by chickens might have been higher in a situation without traps compared to these results, because insects were killed and removed by the experiment. These insects could not be ingested by the chickens anymore. In this study, data on insect species was very limited, because the trapped insects were only classified in general groups. Further research on species level is needed in order to determine beneficial and pest insect populations and to investigate insect biodiversity, which all could have an - in organic agriculture - important effect on each of the elements of the orchard system.

5.5. Worms

Such as insects, worms were also expected to be attracted by the compost & tilling treatment. Indeed, more worms and higher worm biomass (g/m^3) were found in the compost & tilling treatment fields. However, the effect was not significant, which might have been different when more replications were done (higher degrees of freedom in the model), because the application of organic matter to the soil surface and disturbance of the top soil is known to attract worms (Edwards & Bohlen, 1996). The effect of chickens on average biomass per worm (g/worm) and total worm biomass (g/m^3) was significant, so worms with lower weight and lower worm biomass were found in fields with chickens compared with fields without chickens. A positive correlation was found between foraging behaviour and worm number and biomass per m^3, which seems to contradict the first mentioned effect. However, the ground disturbance caused by scratching of chickens might attract more worms (Edwards & Bohlen, 1996). The effect that was found of chickens on average biomass per worm (g/worm) is consistent with results of the study of Zandbergen (2016) at Fruittuin van West. This might either mean that chickens had a preference for foraging on larger worms or that the presence of chicken manure stimulated worm reproduction, and therefore on average smaller worms were found. An explanation for the present findings can be that the positive effect of manure on worm population is outweighed by the ingestion by chickens and that therefore the effect was not significant in the model. The influence of fresh chicken manure on average biomass per worm and worm population could therefore be studied in future research, from which the chickens are excluded.

In the current experiment, the distance between the location of the taken worm samples and the night shed was not consistent in the first five weeks, after that, a fixed distance from the shed was used. This was done to standardise a potential influence of fresh chicken droppings on worms, that was not reconsidered at the start of the experiment. This potential influence is thus not accounted for in the first five weeks of the study. Sometimes during the experiment, there were chickens from the orchard that managed to get in the no chicken fields and foraged there. This could have had an influence on the worm data. For the results this means that the effect of chickens on worm number and biomass might have only been bigger than that is measured now, because there might have been more worms when the chickens would have been kept out more properly.

5.6. Vegetation

As expected, there was no significant effect of the compost & tilling treatment on all vegetation scores, which can be explained by the fact that the growing season had come to an end by the time the experiment started. It is proven that the chickens had an effect on the vegetation scores, which is in line with the hypothesis. All scores were lower in the fields with chickens. This can be explained by ingestion of vegetation by chickens and by damage caused by the scratching behaviour of the chickens during foraging. There were no differences in scores between the sides and the middles of the fields.

This study also showed that the free range regulation for organic poultry farming is not possible to meet when poultry is kept outside year round. In this regulation a free range area covered with vegetation is obliged with a minimum of 4 m^2 per hen. After the keeping of one poultry flock, the area should be empty for 60 days (Skal, 2018). However, in this study with at least 4.5 m^2 per hen, the vegetation cover was already almost completely gone in the eighth week. According to the farmer, the vegetation cover and condition were on its best in the fifth and sixth week. The findings of the current study align with results from literature. A study of Heckendorn et al. (2009) showed that vegetation in fields with 10 m^2 per hen was improved compared with fields with 5 m^2 per hen. The latter led to a significant decrease in vegetation cover and height. The low chicken density (10 m^2) did not lead to decreasing vegetation cover. A study of Cesare et al. (2010) also showed that hens kept on 10 m^2 per hen had a year round vegetation cover compared with the standard 4 m^2 per hen. Therefore, in order to maintain a good quality sward, a lower chicken density than the requisite minimum or a system with rotational grazing is advised for keeping poultry in an orchard system, with just a night shelter instead of a real chicken house.

Sometimes during the experiment, there were chickens from the orchard that managed to get in the no chicken fields and foraged there. This could have had an influence on vegetation cover and condition. For the results this means that the effect of chickens on vegetation might have only been bigger than that is measured now, because the damage on vegetation would be less if chickens were kept out more properly. The same applies to the fact that I had to go in the fields for data collection on insects and vegetation and for applying compost and tilling. However, during vegetation sampling, the sample was not taken from an area where the slightly formed path was.

A disadvantage of this study is that vegetation intake by chickens cannot be derived from the vegetation scores, because it is qualitative instead of quantitative and damage to vegetation is not only caused by ingestion, but also by ground scratching. Therefore, this parameter only addresses the effect of chickens on the vegetation and not the other way around.

5.7. Visual Soil Assessment

There were no differences in soil porosity, soil structure and earthworm count and the total score for the Visual Soil Assessment (VSA) between the fields as hypothesised. A downside of these VSA measurements is that they were only carried out at the end of the experiment. It was therefore not possible to look at the changes in VSA scores for the different treatments. However, it was already known to the farmer that his soil was of a good quality, and it is not something that can change in a matter of weeks. So it was anyhow to expect that there were no differences between the treatments. However, in further research the long term effect of poultry keeping in an orchard system on the soil quality and for instance on the build-up of organic matter and the balance of minerals in the soil might be interesting to study.

5.8. Weather

It was expected that weather variables were related to behaviour and insect abundance. Many correlations were found between the weather variables temperature, rainfall, relative humidity, sunshine, cloudiness and wind speed and data on behaviour, feed intake and insects. Foraging behaviour increased with higher temperatures, as hypothesised. There was no correlation between foraging and hours of sun per day, in contrast with the study of Stadig et al. (2017), who found more free range use when the sun was shining less. The difference between this and the current study can be explained by the season. Walking and standing behaviour decreased with higher temperatures. The results of less foraging with lower temperatures can also be explained by the findings that at lower temperatures, there are less insects (see next paragraph). So the temperature effect might be indirect and there might be a causal relationship between insect abundance and foraging behaviour.

As expected, crawling insect abundance (or activity) was highly dependent on temperature and sunshine. Except for larvae, more insects were more abundant or active when temperature was higher and when there were more hours of sunshine. This suggests that higher insect abundance can be expected in summer, which is consistent with literature (Crozier et al., 2003; Petrovskii et al., 2012). Therefore, feed could be more easily replaced by insects in summer time. On the other hand, larvae were more abundant when temperature was lower and when there was more rainfall. So in a certain degree, larvae abundance can stand in for the decreasing abundance of the other insects when temperature drops and when more rain is expected instead of sunny weather.

Total feed intake and spelt intake decreased with more sunshine, which might also be linked to insect abundance, with more insects available during sunny weather, so less feed might be needed. This also suggests preference of chickens for insects over their (spelt) feed. However, pellet intake increased with more hours of sun and higher temperatures, together with insect abundance. The reason for this is not clear, so more in depth research is needed on this topic.

5.9. Economic quantification and system analysis

It was hypothesised that attracting insects by compost and tilling in the presence of chickens would give savings on feed costs, and on also weeding and mowing. It was shown that keeping poultry in an orchard system is economically feasible. When excluding Investment costs and profit from fruit, profits of € 17.84 (in compost & tilling treatment) and € 17.59 (in no compost & no tilling treatment) per linear metre could be obtained, contrary to a no chicken management, with an income of - € 0.83 per linear metre. The difference in profit between treatments is mainly caused by lower feed costs in the compost & tilling treatment, as expected. There would also be savings on weeding and mowing in the chicken fields. However, keeping poultry in the orchard might bring next to higher income some financial risks as well in the case of poultry diseases or problems with predation. Initial investment in materials and knowledge brings costs as well, not included into this economic quantification.

In the system with chickens and compost included, the most interactions take place, so a more stable system is expected. Many relationships between elements of the orchard system were described, but only a few were quantified. Therefore, more research is needed to assess amongst others the effects of chickens on beneficial and pest insect populations and on fruit yields in order to design the optimal sustainable balance in the orchard system. A high biodiversity is desirable, as it makes the orchard system more resilient. Therefore, it is advised to create habitats for all sorts of insects, where they can reproduce without being eradicated completely by chicken ingestion.

5.10. Key conclusions

Application of compost combined with rotary tilling stimulated foraging and dust bathing behaviour in Lohmann Brown laying hens in an orchard system. The chickens caused a reduction in crawling insects and earthworm biomass, which can be explained by ingestion by chickens. Chickens that received the compost and tilling treatment ingested less of their layer feed, however, this effect was not significant. In all compost & tilling treatment fields, higher crawling insect biomass was found. The results suggest that part of the layer feed could be replaced by attracting insects to the orchard by multiple compost applications and rotary tilling. More research is needed on the effect of rationing layer feed and additional grains on stimulating foraging behaviour and intake of herbage, insects and worms.

This study showed that the free range regulation for organic poultry farming is not possible to meet when poultry is kept outside year round. In this regulation a free range area covered with vegetation is obliged with a minimum of 4 m^2 per hen. However, in this study with 4.5 m^2 per hen, the vegetation cover was completely gone in the eighth week. Therefore, a lower chicken density or a system with rotational grazing is advised for keeping poultry in an orchard system. This advice also applies to the estimated nitrogen deposition through the excreta of the chickens, which might be too high to prevent N leaching with this chicken density.

For fruit growers the use of laying hens as weeders and fertilizers can be very interesting, because the required land is already there. Income from eggs, meat and savings on weeding, mowing and fertilising by the chickens outweigh the extra labour and feed costs involved in poultry keeping. This makes this system economically feasible, next to other positive but qualitative effects on fruit growing. However, keeping poultry in the orchard might bring next to higher income some financial risks as well in the case of poultry diseases or problems with predation. More research is needed to assess the effects of chickens on different types of pest insects and on fruit yields.

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7. References

Bassler, A. (1997). *Prospects of keeping laying hens on grass/clover pasture : an introductory study an a mixed farming system*: [S.l.], NL: Bassler.

Bennett, R. M. (1996). Willingness-to-pay measures of public support for farm animal welfare legislation. *Veterinary Record, 139*(13), 320-321.

Bennett, R. M. (2016). Consumer attitudes to injurious pecking in free- range egg production. *Animal Welfare, 25*(1), 91-100. doi:10.7120/09627286.25.1.091

Byers, J. A. (2011). Analysis of Vertical Distributions and Effective Flight Layers of Insects: Three-Dimensional Simulation of Flying Insects and Catch at Trap Heights. *Environmental entomology, 40*(5), 1210-1222. doi:10.1603/en11043

Cesare, C., Alessandro Dal, B., & Cecilia, M. (2010). Effect of rearing system and season on the performance and egg characteristics of Ancona laying hens. *Italian Journal of Animal Science, 8*(2), 175-188. doi:10.4081/ijas.2009.175

Cowen, N. S., Bohren, B. B., & McKean, H. E. (1964). Increase in Pullet Egg Size with Age. *Poultry Science, 43*(2), 482-486. doi:10.3382/ps.0430482

Crozier, S., Tanaka, A., & Vernon, R. S. (2003). Flight activity of Agriotes lineatus L. and A. obscurus L. (Coleoptera: Elateridae) in the field. In. Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada: J. Entomol. Soc. Brit. Columbia 100.

CVB. (2012). Tabellenboek veevoeding: voedernormen landbouwhuisdieren en voederwaarde veevoeders\CVB-reeks. *Tabellenboek veevoeding 2012*.

Dawkins, M. S. (1989). Time budgets in Red Junglefowl as a baseline for the assessment of welfare in domestic fowl. *Applied Animal Behaviour Science, 24*(1), 77-80. doi:10.1016/0168-1591(89)90126-3

de Jonge, J., & van Trijp, H. C. M. (2013). The impact of broiler production system practices on consumer perceptions of animal welfare. *Poultry Science, 92*(12), 3080-3095. doi:10.3382/ps.2013-03334

Demeter, S. (2018). Demeter kippen. Retrieved from http://stichtingdemeter.nl/demeter-kippen-en-de-afschermplicht/

Edwards, C. A., & Bohlen, P. J. (1996). *Biology and ecology of earthworms*: London [etc.], GB: Chapman & Hall.

Fanatico, A. (1998). Sustainable chicken production: Livestock Production Guide. In. Arkansas: ATTRA (Appropriate Technoloty Transfer for Rural Areas)

FAO. (n.d.). Protein sources for the animal feed industry. *Agriculture and Consumer Protection.* Retrieved from http://www.fao.org/docrep/007/y5019e/y5019e03.htm

Fölsch, D. W., & Vestergaard, K. (1981). *Das Verhalten von Tieren.* Retrieved from Basel:

Gilbert, A. B., Peddie, J., Teague, P. W., & Mitchell, G. G. (1978). The effect of delaying the onset of laying in pullets with a low- calcium diet on subsequent egg production. *British Poultry Science, 19*(1), 21-34. doi:10.1080/00071667808416438

Groot, J., & Bianchi, F. (2017). Analysis and (re-)design in action: hand-out field practical Chevrerie de la Croix de la Grise, Havinnes, Belgium. In.

Hancock, M. H., & Legg, C. J. (2012). Pitfall trapping bias and arthropod body mass. *Insect Conservation and Diversity, 5*(4), 312-318. doi:10.1111/j.1752-4598.2011.00162.x

Hansen, I. (1994). Behavioural expression of laying hens in aviaries and cages: Frequencies, time budgets and facility utilisation. *British Poultry Science, 35*(4), 491-508. doi:10.1080/00071669408417715

Heckendorn, F., Häring, D. A., Amsler, Z., & Maurer, V. (2009). Do stocking rate and a simple run management practice influence the infection of laying hens with gastrointestinal helminths? *Veterinary Parasitology, 159*(1), 60-68. doi:10.1016/j.vetpar.2008.10.013

Hegelund, L., Sørensen, J. T., & Hermansen, J. E. (2006). Welfare and productivity of laying hens in commercial organic egg production systems in Denmark. *NJAS - Wageningen Journal of Life Sciences, 54*(2), 147-155. doi:10.1016/s1573-5214(06)80018-7

Hegelund, L., Sørensen, J. T., Kjær, J. B., & Kristensen, I. S. (2005). Use of the range area in organic egg production systems: effect of climatic factors, flock size, age and artificial cover. *British Poultry Science, 46*(1), 1-8. doi:10.1080/00071660400023813

Hermansen, J. E., Strudsholm, K., & Horsted, K. (2004). Integration of organic animal production into land use with special reference to swine and poultry. *Livestock Production Science, 90*(1), 11-26. doi:10.1016/j.livprodsci.2004.07.009

Horne, P. L. M. v., Have, P. J. W. t., & Hoste, R. (1995). *Energieverbruik en kosten van afzet en verwerking van mest*: Den Haag [etc.], NL: LEI-DLO [etc.].

Hughes, B. O., & Dun, P. (1983). Production and behaviour of laying domestic fowls in outside pens. In *Applied Animal Ethology* (Vol. 11, pp. 201-201).

Jensen, P., Schütz, K., & Lindqvist, C. (2002). Red jungle fowl have more contrafreeloading than White Leghorn layers: effect of food deprivation and consequences for information gain. *Behaviour, 139*(9), 1195-1209. doi:10.1163/15685390260437335

Kruijt, J. P. (1964). Ontogeny of Social Behaviour in Burmese Red Junglefowl (Gallus Gallus Spadiceus) Bonnaterre. *Behaviour. Supplement*(12), I-201.

Mollenhorst, H., Rodenburg, T. B., Bokkers, E. A. M., Koene, P., & de Boer, I. J. M. (2005). On- farm assessment of laying hen welfare: a comparison of one environment- based and two animal-based methods. *Applied Animal Behaviour Science, 90*(3), 277-291. doi:10.1016/j.applanim.2004.08.011

Mollison, B., & Holmgren, D. (1991). *Introduction to permaculture*: Tasmania, AU: Tagari.

Morris, T. R., & Blackburn, Q. A. (1982). The shape of the response curve relating protein intake to egg output for flocks of laying hens. *British Poultry Science, 23*(5), 405-424. doi:10.1080/00071688208447974

Mugnai, C., Sossidou, E. N., Dal Bosco, A., Ruggeri, S., Mattioli, S., & Castellini, C. (2014). The effects of husbandry system on the grass intake and egg nutritive characteristics of laying hens. *Journal of the Science of Food and Agriculture, 94*(3), 459-467. doi:10.1002/jsfa.6269

Petherick, J. C., & Duncan, I. J. H. (1989). Behaviour of young domestic fowl directed towards different substrates. *British Poultry Science, 30*(2), 229-238. doi:10.1080/00071668908417143

Petrovskii, S., Bearup, D., Ahmed, D. A., & Blackshaw, R. (2012). Estimating insect population density from trap counts. *Ecological complexity, 10*, 69-82.

Pettersson, I. C., Weeks, C. A., Wilson, L. R. M., & Nicol, C. J. (2016). Consumer perceptions of free-range laying hen welfare. *British Food Journal, 118*(8), 1999-2013. doi:10.1108/bfj-02-2016-0065

Savory, C. J., Wood-Gush, D. G. M., & Duncan, I. J. H. (1978). Feeding behaviour in a population of domestic fowls in the wild. *Applied Animal Ethology, 4*(1), 13-27. doi:http://dx.doi.org/10.1016/0304-3762(78)90090-1

Scholz, B., Urselmans, S., Kjaer, J. B., & Schrader, L. (2010). Food, wood, or plastic as substrates for dustbathing and foraging in laying hens: A preference test. *Poultry Science, 89*(8), 1584-1589. doi:10.3382/ps.2009-00598

Shepherd, T. G. (2009). Visual Soil Assessment. Volume 1. Field guide for pastoral grazing and cropping on flat to rolling country. In (2nd ed., pp. 119): Horizons Regional Council, Palmerston North.

Skal. (2018). Huisvesting en uitloop. Retrieved from http://www.skal.nl/veehouderij/pluimvee/huisvesting/

Smith, K. A., & Frost, J. P. (2000). Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters. Part 1: cattle and sheep. *Bioresource Technology, 71*(2), 173-181. doi:10.1016/s0960-8524(99)00061-9

Sossidou, E. N., Rose, S. P., Silva, S. S. P., Hall, N. W., Tserveni-Goussi, A., & Christodoulou, V. (2008). Different soil media for free-range laying hens. *British Poultry Science, 49*(4), 390-395. doi:10.1080/00071660802159041

Stadig, L. M., Rodenburg, T. B., Ampe, B., Reubens, B., & Tuyttens, F. A. M. (2017). Effect of free-range access, shelter type and weather conditions on free-range use and welfare of slow-growing broiler chickens. *Applied Animal Behaviour Science, 192*, 15-23. doi:10.1016/j.applanim.2016.11.008

Statistiek, C. B. v. d. (2017). Uurlonen van werknemers naar beroepsgroep, 2016. from CBS

Sturkenboom, W. (2017). [Practical knowledge about the orchard].

Taboga, L. (1980). The nutritional value of earthworms for chickens. *British Poultry Science, 21*(5), 405-410. doi:10.1080/00071668008416688

Trapman, M. (2018). *RIMpro*. Retrieved from http://rimpro.eu/

Van Gorp, A. (2018). [Voedingswaarde 475 legkorrel ECO 95% bio.].

Verwer, C., Peters, M., & Michels, E. (2015). *Samenvatting: Project Kip en Ei: een verkenning naar de toepassing van insecteneiwit in pluimveevoer*: Driebergen, NL: Louis Bolk Instituut.

Walker, A., & Gordon, S. (2003). Intake of nutrients from pasture by poultry. *Proceedings of the Nutrition Society, 62*(2), 253-256. doi:10.1079/pns2002198

Weatherup, S. T. C., & Foster, W. H. (1980). A description of the curve relating egg weight and age of hen. *British Poultry Science, 21*(6), 511-519. doi:10.1080/00071668008416704

WelfareQuality. (2009). *Welfare Quality Assessment protocol for poultry*: Lelystad, NL: Welfare Quality Consortium.

Xu, H., Su, H., Su, B., Han, X., Biswas, D. K., & Li, Y. (2014). Restoring the degraded grassland and improving sustainability of grassland ecosystem through chicken farming: A case study in northern China. *Agriculture, Ecosystems and Environment, 186*, 115-123. doi:10.1016/j.agee.2014.02.001

Zandbergen, J. (2016). *Introducing poultry in orchards to restore ecological relationships in agricultural production systems.* (MSc), Wageningen University, Wageningen.

8. Annex

8.1. Weather data during the experiment

In figure 8.1.1. and 8.1.2. the four most important weather variables are showed, varying over time.

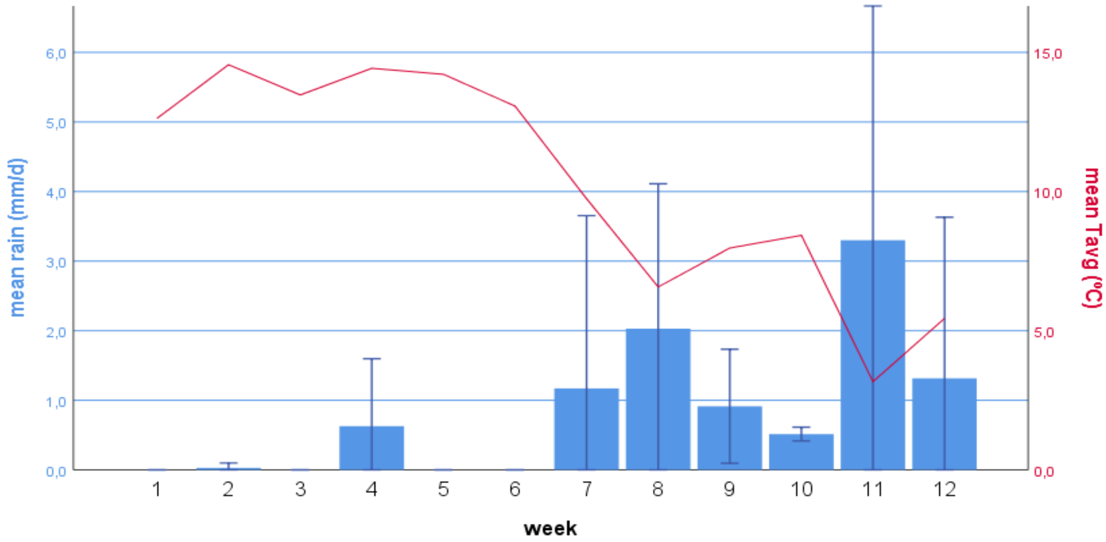

FIGURE 8.1.1. MEAN RAINFALL (MM/D) AND AVERAGE TEMPERATURE (TAVG; °C) PER WEEK. ERROR BARS: 95% CI.

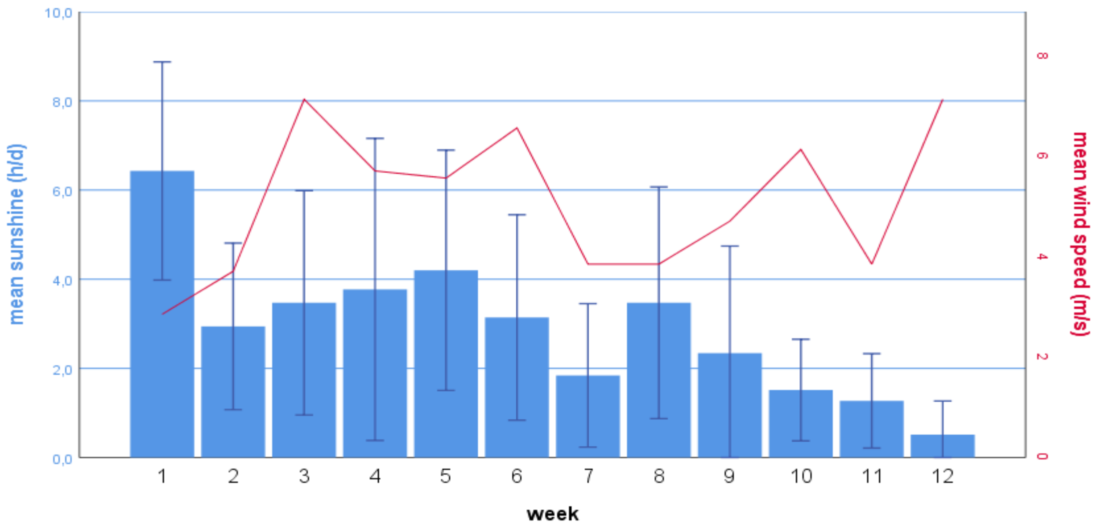

FIGURE 8.1.2. MEAN SUNSHINE (H/D) AND MEAN WIND SPEED (M/S) PER WEEK. ERROR BARS: 95% CI.

8.2. Economic quantification calculation factors

All factors that were taken into account for the economic quantification (section 4.) are listed in table 8.2.1.

TABLE 8.2.1. CALCULATION FACTORS FOR THE ECONOMIC QUANTIFICATION AS NOTED IN SECTION 4.

Pellets (euro/kg)	€ 0.55	chickens	20
Spelt (euro/kg)	€ 0.30	roosters (#)	1
Compost (euro/m3)	€ 3.00	Hens (#)	19
Young hen purchase (euro/#)	€ 7.00	Area per field (m^2)	90
mowing and tilling labour (euro/m/y)	€ 0.12	2 times 30 (m)	60
Weeding labour (euro/m/y)	€ 0.15	chickens per linear metre	0.3333
Compost labour (euro/m/y)	€ 0.15	hens per linear metre	0.3167
caring for chickens labour (euro/y/chicken)	€ 7.34	roosters per linear metre	0.0167
Eggs (euro/#)	€ 0.35	Life laying percentage	0.7567
meat 'soup' (euro/#)	€ 7.00	laying period y	1.135
meat 'soup' (euro/kg)	€ 6.30	Ratio chicken slaughtered per year	0.67
rooster care (euro/#)	€ 30.0	manure production chicken (kg/hen/y)	55[2)]
avg pellet intake 1B (kg/chicken/d)	0.0326	price dried chicken manure (euro/kg)	€ 0.40[1)]
avg spelt intake 1B (kg/chicken/d)	0.0986	price fresh chicken manure (euro/kg)	€ 0.10[2)]
avg pellet intake 1A (kg/chicken/d)	0.0242	compost use (L/m/y)	18
avg spelt intake 1A (kg/chicken/d)	0.0947	Compost use (m^3/m/y)	0.018
laying percentage	0.750		
days per year	365.25		
average BW 1A (kg)	1.73		
average BW 1B (kg)	1.82		
slaughter age (y)	1.5		
Meat weight (av) per chicken (kg)	0.9		

1) https://www.123natuurproducten.nl/product/kippenmestkorrels-pallet-20-zakken-25-kg/?gclid=EAIaIQobChMIypj7hbjr2AIVU5kbCh299gR8EAkYASABEgJUGvD_BwE
2) (Horne et al., 1995)

8.3. Poster on research location

This poster was made in order to inform the customers of Fruittuin van West about the research, therefore it was written in Dutch.

FIGURE 8.2.1. POSTER AT RESEARCH SITE AT FRUITTUIN VAN WEST

8.4. Painting Lohmann Brown laying hen

This painting was made as a gift for the staff of Fruittuin van West.

FIGURE 8.4.1. PAINTING OF A LOHMANN BROWN LAYING HEN UNDER RED CURRENT SHRUBS AT FRUITTUIN VAN WEST