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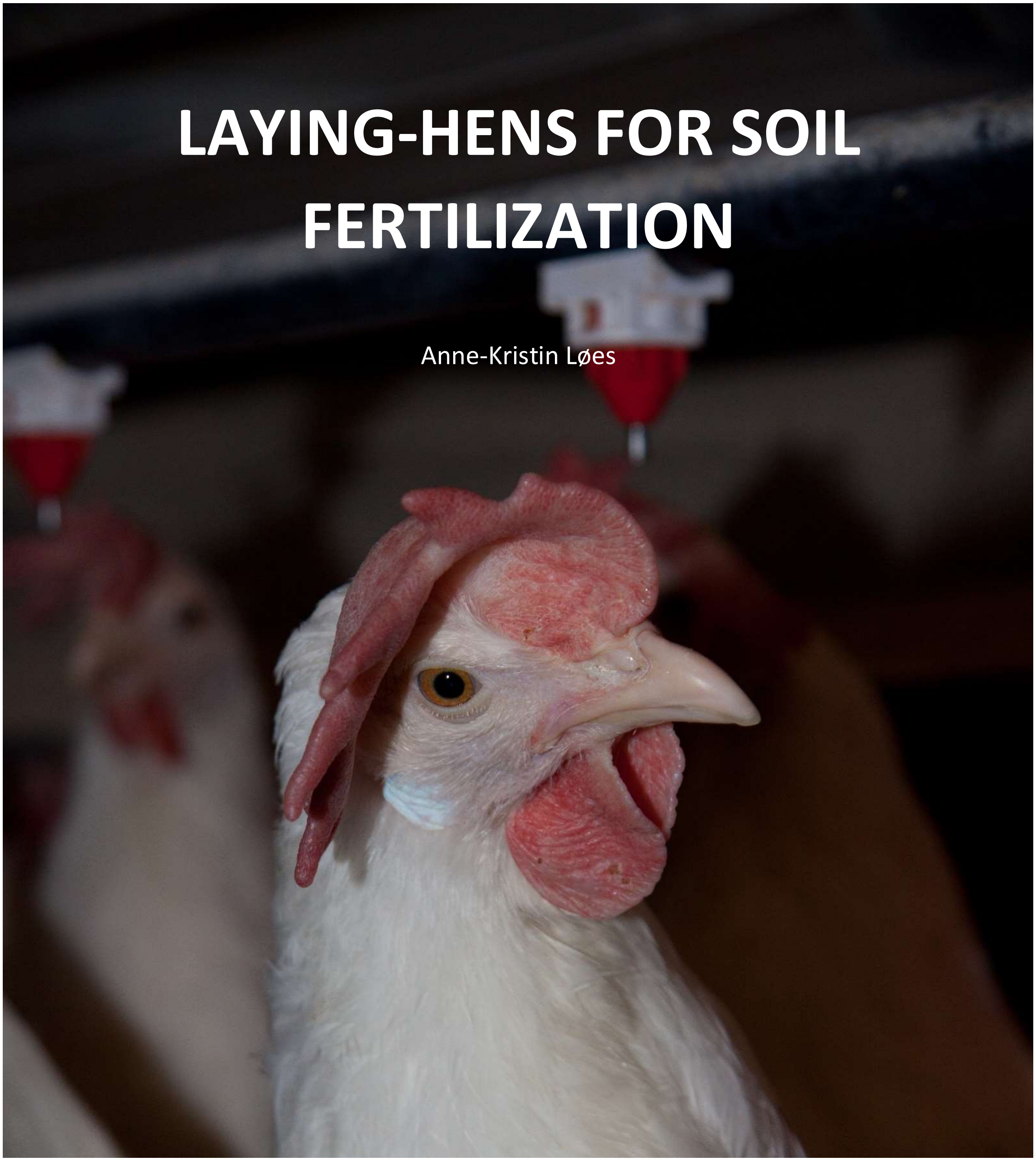

LAYING-HENS FOR SOIL FERTILIZATION

Anne-Kristin Løes

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LAYING-HENS FOR SOIL FERTILIZATION

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SAMMENDRAG

Vi har ca. 3,5 millioner verpehøns i Norge, hvorav ca. 240.000 er økologiske. Dagens verpehøner er slanke og små. Levendevekta for ei voksen høne er ca. 1,8 kg. Mens høna har avtatt i størrelse over tid, har slaktekyllingene blitt stadig større. Dermed er det vanskelig å utnytte samme slaktelinje for disse dyregruppene. Mobile slakterier har møtt stor interesse blant økobønder. Transporten til slakteriet er en påkjenning, så hvorfor ikke frakte døde dyr i stedet for levende? Mobile slakterier kan være godt egnet for fjørfe. Der kan hønene avlives, flås, renskes for innvoller og kjøles ned, for senere å bli til mat. Per i dag blir verpehøner i de fleste tilfeller uansett avlivet på gården, enten ved at de gasses i hjel i huset, eller i en gasskontainer som kommer til gården. Vi mangler en fabrikk i Norge som kan gjøre døde høner om til kjøtt- og beinmel. Derfor kjøres døde høner i dag til et nasjonalt forbrenningsanlegg på Hamar. Dette er dårlig utnyttelse av en verdifull ressurs.

En måte å utnytte slaktede høner på, er en forsiktig oppvarming (hydrolyse) med tilsetning av enzymer. Da kan finmalt slaktet fjørfe bli til olje og proteiner med god kvalitet. Slik prosessering kan øke interessen for slakting av verpehøns. Sedimentene som er igjen når olje og vannløselig protein er fjernet, er rike på viktige plantenæringsstoff som nitrogen, fosfor og kalsium. Når slakting ikke er ønskelig eller mulig, f.eks. ved lang transportavstand, ville det vært fordelaktig om hønene kunne brukes som jordforbedringsmiddel lokalt. Det ville spare bonden for betydelige kostnader, og vi ville få utnyttet næringsstoff og organisk materiale som i dag går tapt. Som del av prosjektet «Helhetlig bioøkonomisk utnyttelse av verpehøns» (2015-17), finansiert av Regionalt forskingsfond Midt-Norge, ble det gjennomført flere undersøkelser av utrangerte verpehøns på Tingvoll i 2017. Gjødselvirkningen av sedimenter etter hydrolyse ble undersøkt i et potteforsøk med raigras, som ble høstet tre ganger. Nedbrytning av kvernede hele høner i jord ble undersøkt med forskjellige blandingsforhold og blandingsmåter. Tanken var at bonden kan gjennomføre en kontrollert nedbrytning av hønene på gården, f.eks. ved å la dem omdannes til jord i en gammel gjødselkjeller.

I pottene med raigras var det klart bedre vekst med tilførsel av sedimenter enn med kalksalpeter ved de to første høstingene. Det gjaldt særlig når sedimentet var finmalt. Da hadde det også større effekt på fosforkonsentrasjonen i jorda.

Opphakkede hele høner, blandet med jord i ulike mengdeforhold, ble lagret i 4 måneder ved 10-15 °C. Når mengdeforholdet var 1 del oppkverna høne til 3 deler jord, var materialet ganske godt nedbrutt og hadde ikke særlig ubehagelig lukt. Mekanisk bearbeiding under lagring ville sannsynligvis ha økt omdanningshastigheten. Rundt høne-partiklene dannet det seg runde, harde aggregater av jord, hvor det stakk ut sopphyfer. Faste partikler som bein, nebb og fjær ble ikke fullstendig nedbrutt i løpet av 4 måneder, men for myke partikler var det en stor andel som ble nedbrutt.

SUMMARY

The Norwegian population of laying-hens comprises about 3.5 million, out of which about 240 000 are certified organic. Breeding for high egg production and low body weight, combined with larger body weight in chicken hampering the utilization of the same slaughter lines, has reduced the interest for utilizing laying-hens for food purpose. Most hens are currently disposed of by gassing with CO_2; either in the house or in a container being brought to the farm. Dead hens are then transported to Hamar in South-East Norway, to become incinerated in the only Norwegian plant for category 1-organic materials. Mobile slaughtering systems are relevant for poultry. After slaughtering, the animals could be used for food, or processed by milling and enzymatic hydrolysis into valuable oil and soluble proteins. Residual sediments contain valuable nutrients such as nitrogen, phosphorus and calcium. When utilization for feed is not an option, it would be beneficial to utilize the spent laying hens as a fertilizer on farm. This may decrease the costs of the farmer, and be a much better utilization of organic matter and plant nutrients.

The project “Complete and Bio-economical Exploitation of Laying-Hens” (2015-27), funded by the Regional Research Council of Mid-Norway, studied the effect of sediments as fertilizers for ryegrass, and observed the decomposition of chopped, dead laying hens mixed with soil. The idea was to reveal about how much soil would be needed to decompose a hen, to assess whether e.g. a former storage room for solid manure could be utilized for decomposing spent laying hens.

Sediments were an efficient fertilizer for ryegrass, especially when finely milled. The growth was then larger with sediments than with calcium nitrate for the initial two cuts. Finely milled sediment also had a more significant effect to increase the phosphorus concentration in the soil.

Pots of chopped hens mixed with soil were stored for 4 months at 10-15 °C. With 1 part of hen to 3 parts of soil (by weight), the chopped hens were quite well decomposed and the odor was not too unpleasant. Mechanical treatment of the mixture during storage would contribute to increase the decomposition. Around the particles of chopped hen, solid aggregates were formed, where fungal hyphae were observed. Solid particles such as feathers and bones were not completely decomposed over 4 months, but for the softer particles, a large proportion was decomposed.

LAND/COUNTRY:	NORWAY
FYLKE/COUNTY:	MØRE AND ROMSDAL
STED/LOKALITET:	TINGVOLL

GODKJENT /APPROVED	**PROSJEKTLEDER NORSØK /PROJECT LEADER NORSØK**
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NAVN / NAME	NAVN / NAME

Preface

Incineration of spent laying hens implies high costs for the farmers, significant losses of valuable plant nutrients such as nitrogen and phosphorus, and negative environmental effects. This is a poor practice, and alternatives should be sought for.

Using hens for feed has many benefits, and e.g. by developing new products such as food oil and hydrolyzed proteins from slaughtered hens, the interest in such utilization may increase. However, handling and transporting old hens for slaughter implies significant stress, especially since there are only a few slaughterhouses for poultry in Norway and transport distances may become very long. Egg producers with a long distance to the slaughterhouse, and producers wanting to prioritize animal welfare, may find an interest in killing the birds on site and use the bodies for fertilization. Also with utilization based on hydrolysis, sediments and other by-products will be produced which are well suited for fertilization.

Norwegian Centre for Organic Agriculture (NORSØK) has been a partner in a 3-year project (2015-2017) funded by the Regional Research Council of Mid-Norway, with the objective to improve the utilization of dead laying-hens. The project title was "Helhetlig bioØkonomisk utnyttelse av verpehøNE", in English "Complete and Bio-economical Exploitation of Laying Hens", and it was coordinated by SINTEF Ocean AS, Dr. Ana Carvajal. NORSØK was responsible for studying various fractions of dead hens, to see how they would behave in soil during the initial phase of decomposition, and how they would function as a fertilizer for plant growth. This report describes the results of these studies.

Tingvoll – December 2017
Anne-Kristin Løes

Contents

Introduction

Egg production in Norway

As compared with many other European countries, egg production in Norway is still quite decentralized with about 2000 producers applying for public support. The maximum amount of laying hens without concession is 7500 animals. However, some producers have larger herds, up to 36 000 birds. About 3.5 million laying hens are killed each year. The average body weight is about 1.8 kg. The interest for utilizing laying hens for food production increased in 2017 after a series of programs made by "Forbrukerinspektørene" ("The Consumer inspectors") (NRK, 2017). However, so far only a minor proportion of hens are slaughtered, and it is still questionable whether slaughtering of old hens will become a significant way of utilization. Rogaland is the county with the largest number of egg producers in Norway. In this region, the private company "Rogaland pelsdyrfôr AS" has been permitted by the regional food safety authority to use healthy, recently killed (by gassing) laying hens from the region, up to 120 km away, as feed for fur animals, after grinding, acid-preservation and a test for *Clostridium*-bacteria (Løes 2015). When food utilization is not an option, solutions should be sought for alternatives to incineration.

The HØNE project and the fertilization studies

The project «Helhetlig bioØkonomisk utnyttelse av verpehøNE» (Utilizing the whole lying hen with a bio-economy perspective) was funded by the Regional Research Council of Mid-Norway during 2015-2017. SINTEF Ocean AS, together with NIBIO, NORSØK, NMBU and industry partners in Trøndelag studied new food applications from slaughtered laying hens, based on hydrolysis. SINTEF Ocean has a broad experience in hydrolysis of fish, and this knowledge now shows its potential with other materials rich in fat and proteins such as poultry. At NORSØK, we studied two kinds of substrates derived from killed laying hens:

- Chopped killed hens (with head, legs, feathers and intestines)
- Sediments after hydrolysis of oil and soluble proteins from slaughtered laying hens (without heads, legs, feathers and intestines)

The sediments were tested as fertilizers in a pot experiment with ryegrass, to study whether this substrate was comparable with traditional mineral fertilizer. For chopped hens, the research question was how much soil would be required to mix with chopped hens to avoid odor nuisance during decomposition, and how the material would behave during putrefaction in soil. The idea was that it could be possible on a farm with laying hens, e.g. in a former storage room for solid manure, to mix soil and chopped hens and let the material decompose until the mix was not attractive for wild predators anymore, and could be spread in field and ploughed down. 7500 killed hens comprise 13.5 tons of organic matter. This volume may be treated by a chopper within a reasonable amount of time and is small enough to be stored in a traditional manure basement storage, or possibly an old silage tower. Such building elements are available on many farms.

In our study, the nitrogen (N) concentration in chopped, complete hens was found to be 2.8 % (17.4 % proteins; analyzed at SINTEF). With a typical N application, e.g. for cereals of 120 kg N per ha, about 4.3 tons of chopped hens per ha would be required for fertilization to cover the N demand. Only 3.15 ha would be required to utilize the N from 7500 laying hens with an average weight of 1.8 kg as a fertilization for cereals.

Aims and hypotheses

The aim of the fertilization studies conducted at NORSØK was to assess how two types of material from killed laying hens would function as a fertilizer or soil amendment. The same soil was used for all studies. The largest study was conducted with sediments after hydrolyzation of proteins and oils from slaughtered laying hens. Such sediments still contain valuable nutrients, and were compared with mineral N fertilizer in a pot experiment with ryegrass, being repeatedly harvested (3 times). We expected that the mineral N fertilizer would give initially more rapid growth, since this fertilizer was solubilized by the application and nitrate and ammonium are supposed to be directly available to plants. Further, we expected that the sediments would also increase plant growth, possibly to somewhat larger extent than the mineral N fertilizer after three harvests, since the sediments also contain some additional nutrients such as phosphorus and calcium.

Two smaller studies were conducted with chopped, complete laying hens (including heads, legs, feathers and intestines). In a study with large pots and no plants, we tried to observe the decomposition of material from chopped hens when mimicking a soil to material ratio that could possibly be used in field. We repeatedly sifted the soil-hen mixtures over 6 months, recording and briefly describing the amounts of particles not passing the sift. We hypothesized that all organic material would be decomposed during the study, with only small remains of bones and possibly feathers being left.

In the final study, small pots were filled with soil and high amounts of chopped hen material were added. Two main "treatments" were compared: Thoroughly mixing the soil and the chopped hen material, versus "burying" the material by putting it between two layers of soil. The ratio of chopped hen material to soil was much higher in this study than in the large pots. The small pot-study was conducted in a climate chamber. We expected that the odor would be very awful, possibly hampering that the study could go on for the planned period of 4 months, mimicking a Norwegian summer period. We expected that the soil would be an efficient agent to reduce the odor, so that the treatments with higher proportions of soil would smell somewhat less bad than the other treatments, and that mixing the material thoroughly with soil would possibly reduce the odor more than burying the material in soil. However, we were fully aware that odor is a complicated characteristic to measure, so the study was primarily intended as an observation of what would actually happen if the amount of chopped hen material in an amount of soil became extremely high. Would bad odors hamper any further steps in such a direction, or could we possibly design a later experiment in larger scale?

Methods

Substrates and conversion factors

For all studies described here, sifted topsoil (0-20 cm) from a field called “Sagmyra” on Tingvoll farm (location of NORSØK) was used. This soil has about 70 % sand, 23% silt, 7% clay, 12% organic matter, 40 mg extractable P (P-AL) per kg soil (low to medium) and a pH of 5.5. We used this soil because it was quite low in P and hence expected to show good effects of applied fertilizers, and because we were well informed about the soil characteristics after many years of experimental work with this soil. With the high content of organic matter, the volume weight of the soil was 1 kg per dm^3, and the factor used for converting fertilization per pot to fertilization per ha of topsoil (0-20 cm) was 2000 kg of soil per ha (1 kg/dm^3 x 0.2 m x 10 000 m^2). Hence, with fertilization levels set to 200, 400 and 600 kg N per ha, the amounts of N to be applied per kg soil was 0.1, 0.2 or 0.3 g. This fertilization level might appear high in comparison with a fertilization of 120 kg N per ha for cereals. However, fertilization levels are usually higher in pot experiments than in the field, ryegrass is a crop which can take high N fertilization, and we applied the N only at the start of the experiment while we cut the grass three times. The moisture content in the soil by potting, 26 %, was 44 % of field capacity as measured by filling 5 pots with 600 g of sifted soil, carefully saturating them with water and then let them drain for about 1 hour, until no more free water was visible under the pot. On average, 444 g of dry soil could hold 349 g of water, which means that at field capacity in this soil, the water content is about 44%.

Killed, complete hens were chopped at SINTEF Ocean AS, Trondheim to an average fragment size of about 1.5 cm. Samples were frozen and transported to Tingvoll for further testing. The dry matter content in this material was 42%.

Sediments from slaughtered hens were also provided from SINTEF Ocean AS, as frozen samples. Before hydrolysis, which occurred in November 2016, the hens were milled. Two types of materials were available where one had been milled to a finer texture than the other. A mixture of 1:1 (by weight) of milled hens and water was mixed with 0.1% enzyme solution, a 50/50 mix of papain and bromelain, for 1 hour at 50°C. Then the enzyme was inactivated by heating to 90°C, and the mixture centrifugated. The remaining sediments after centrifugation are here called Sediment 1 for the most finely ground, and Sediment 2 for the more coarsely ground material. Ashes comprised about 21% of the dry matter (DM), and proteins 62-64% of the DM in these sediments (Table 1). Based on the protein content and a factor of conversion of 6.25 (16% of the protein is assumed to be N), the N content in Sediment 1 was 9.9% of the dry matter, and 10.2 % in Sediment 2. Chemical analysis was carried out at the analytical laboratory of Trondheim municipality.

Calcium nitrate ($CaNO_3$) purchased as a commercial fertilizer Calcinit (YaraLiva) was used for comparison with the sediments. Calcinit contains 19% calcium and 15.5% N, 14.4% as nitrate and 1.1% as ammonium, and dissolves readily in water.

Table 1. Chemical characteristics and contents of minerals in fine and more coarsely milled sediments from slaughtered laying hens. Sediment 1 was most finely milled. DM= Dry matter. Concentrations of nutrients are given in grams per kg body weight.

	pH	DM %	Ashes %	Fat %	Protein %	P g/kg	Ca g/kg	Mg g/kg	K mg/kg	S g/kg
Sediment 1	6.67	32.4	6.7	1.5	20.06	34.7	68.6	1.48	3.70	5.91
Sediment 2	6.65	34.1	7.7	1.3	21.78	34.6	69.3	1.50	3.83	6.36

Soil analysis

Soil samples, sometimes including sediments or residual material of chopped hens, were analyzed for basic soil characteristics (“pakke 1”) at Eurofins, Kristianstad, Sweden. This pack of analysis comprises soil pH (soil: water 1:2.5 w/w), ignition loss to determine the content of organic matter, and extraction by ammonium-acetate lactate (AL) of phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) to assess concentrations of plant-available macro nutrients, given in mg per 100 g air-dried soil. In the pot experiment with ryegrass, all 80 pots were analyzed. In the study of decomposition with large pots, no soil samples were analyzed. In the decomposition study with small pots, composite samples of each treatment were taken at the end of the study.

Pot experiment with ryegrass

Plastic pots with aeration holes in the bottom were filled with a piece of paper towel to avoid soil loss, and then carefully filled with 520 g sifted experimental soil distributed over three portions. Between each portion, the pot was gently kicked towards the table 10 times, while turning it a quarter of a round for each kick. This was done to ensure even physical conditions for plant growth. 50 ml of water per pot was used to dilute the applied fertilizers and distribute them into the soil. All water applied was de-ionized. After applying the diluted fertilizers, 80 g of soil was added to each pot and the kicking procedure was repeated. This was done to avoid direct contact between fertilizers and seeds. On this soil surface, 30 seeds of annual (westerwold) Italian ryegrass (*Lolium multiflorum* Lam. *alternativum*) were placed per pot, and covered with 30 g of finely sieved soil. Then, pots were covered by plastic foil and left for germination. Filling the pots with soil occurred on February 28, application of fertilizers on March 3, and placement of seeds on March 7, 2017. On March 14, the seeds had germinated and the plastic was removed. The ryegrass was harvested at three dates; March 31, April 19 and May 15, 2017. At harvest 1 and 2, plants were cut 4 cm above the soil surface. At harvest 3, plants were cut at the soil surface.

Picture 1. Pots with soil amended with various fertilizers, with or without ryegrass, grouped in trays housing 10 pots to be sampled on the same date. Date March 24, 2017; about 10 days after germination.

3 fertilizers, Sediment 1, Sediment 2 and calcium nitrate ($CaNO_3$), with 3 levels of N application corresponding to 200, 400 and 600 kg N per ha, were compared. In addition, we had a control treatment with no fertilization, altogether 10 treatments. All fertilizer was given at the start of the experiment. For each treatment we prepared 8 pots, and used 5 pots to grow ryegrass, whereas 3 pots without plant growth were used to study soil characteristics over time. One pot per treatment with and without plant growth were sampled for soil analysis on harvest date 1 and 2. On the final harvest date, the remaining 3 pots with plants

and the remaining set of pots without plants, were sampled for soil analysis. The pots were grouped into trays comprising one pot from each treatment, to be sampled on a certain date. Plant roots were removed before the soil was sampled for analysis.

The bottom of each tray was covered by a textile cloth to ensure even distribution of applied water. Water was only applied to this cloth, not to single pots. Watering occurred three times a week (Monday-Wednesday-Friday). At each occasion, the initial weight was recorded and water was applied up to 8 kg per tray for pots without plants, and 8100 g for pots with plants. The trays were placed on a table in a green house, and rotated 180° three times per week (Monday-Wednesday-Friday). The location of each tray on the table was also systematically changed, to level out possible effects of location of the trays on the table.

Some weeds germinated along with the ryegrass. These plants were lifted from the soil by forceps and left to decompose on the soil surface of the pot.

For statistical analysis of the results of the pot experiment, one-way variance analysis was conducted with Minitab software, using the general linear model procedure, with one factor (treatment) and 3 levels of this factor. For comparison of means, Tukey's t-test was used at the 5% level of significance.

Large pots: Decomposition in soil of chopped laying hens

Pots with an inner height of 18 cm, corresponding to a topsoil layer, were filled with 4200 g of sifted experimental soil. Paper towels were put in the bottom of the pots and later replaced by a nylon net. Portions of chopped laying hens corresponding to a fertilization level of 600, 1200 or 1800 kg N per ha were mixed into the soil in a basin, before the pots were filled again. Originally, we intended to use the same levels of N which were used in the pot experiments with the sediments; 200, 400 and 600 kg N per ha. However, the amounts of chopped hen material then became so small that we feared that we would not reveal any material at all by sifting. Hence, we tripled the amounts, and the "fertilization" levels then comprised 45.3, 90.6 and 135.9 g of chopped hens per pot.

Picture 2. Sifting the contents of large pots with soil and chopped hen material applied to correspond to a fertilization of 600, 1200 or 1800 kg N per ha. June 28, 2017.

On March 9-10, 2017, we prepared five pots of each fertilization level plus a control treatment with no addition of chopped hens; in total 20 pots. Pots were harvested at various time intervals, to assess if the amount of material derived from the chopped hens decreased over time. Originally, we planned to sample one set of pots destructively about once per month, because the sifting did most likely affect the decomposition of the particles. However, at the first harvest, we decided to put the material back into the pot and the pot back into the testing room, to compare pots siftd several times with pots not being siftd before. One set of pots were harvested at March 31, one at April 20, one at May 15 and the remaining two sets at June 28. A final sifting of all pots was conducted on October 20, 2017. The total experimental period was close to 7 months.

At each harvest date, and before addition of the chopped hens, 2 x 10 g of soil were taken from the pots to measure pH and red-ox. This was done by hand-held electrodes (VWR pH10, VWR ORP15) in a suspension of 10 g soil to 25 g de-ionized water, well stirred and stored overnight in a refrigerator. The pots were kept in a room with a temperature about 15 °C, with no cover. On April 20 and June 28, water was added to the pots up to the initial weight, to maintain a level of humidity satisfactory for decomposition. The pots were treated in random order, to avoid that a consciousness of the N level would affect how the soil was sifted.

Small pots: Putrefaction of chopped laying hens

In this study, the proportion of soil was minimized, to study extreme ratios of chopped hens to soil. Mixtures of soil and chopped hen material were placed in pots equal to those used in the pot experiment with ryegrass. The pots were placed in a climate chamber where temperature was controlled, and set to mimic the temperatures in soil at 10 cm depth in Trøndelag (Kvithamar) from May 15 to September 15 in monthly intervals; being 10.3, 14.0, 15.1 and 13.2°C. The experiment was conducted between March 10 and July 25, 2017.

Chopped material and soil was mixed in two ways: Either by placing the chopped material in nylon net bags, with 40 % of the soil weight under and 60% above the net bag, or by mixing the chopped material thoroughly with soil. For the maximum amount of chopped material, 1:1 (w:w), the practical feeling was that the soil could not absorb more of the chopped hen-material if the aim was to cover this material with soil. The mixture then was a soft pasta (Picture x). In addition to this extreme ratio, we added the ratios 1:2 and 1:3 (chopped material: soil). We also studied net bags containing amounts of chopped hen material equal to the amounts added to the large pots in the decomposition study; 600. 1200 or 1800 kg N per ha. These treatments are referred to as Small bags in Table 2. All pots contained 540 g of material at the start of the experiment, and there were four replicate pots per treatment, altogether 40 pots.

In addition to the pots, 6 small aluminum beakers were filled with 18 g of chopped hen material, to study how this material behaved when not mixed with soil. All pots and beakers were covered with plastic sheets to reduce desiccation during the experimental period, and water was added to the initial weight at two occasions.

Table 2. Overview of treatments in a study of putrefaction of chopped laying hens with temperature conditions mimicking summer period of 4 months in soil at 10 cm depth (10-15 °C).

Treatment	Amount per pot, chopped hen	Amount per pot, soil	Placement
Control		540 g	
Mixed 1:1	270 g	270 g	Mixed
Mixed 1:2	180 g	360 g	Mixed
Mixed 1:3	125 g	405 g	Mixed
Net bag 1:1	270 g	270 g	Net bag buried
Net bag 1:2	180 g	360 g	Net bag buried
Net bag 1:3	125 g	405 g	Net bag buried
Small bag 600	5.8 g	534.2 g	Small net bag buried
Small bag 1200	11.6 g	528.4 g	Small net bag buried
Small bag 1800	17.5 g	522.5 g	Small net bag buried

On March 16, March 24, March 31, April 4, April 24, June 26 and July 25 the pots were weighed, visually described and photographed. Pots and beakers were added deionized water up to the initial weight on two occasions during the study. At the end of the experiment, pots were emptied and the residues of chopped hen material described. Samples were taken for soil analysis. Since this was a preliminary study, only routine soil analysis was applied.

Picture 3. Left: Chopped, complete laying hens with feathers, intestines, heads and legs. Middle: Chopped hens in net bags to be covered with soil for putrefaction over 4 months in a climate chamber. Right: Thorouigh mixture of soil and choped hen material (1:1, w/w).

Results

Pot experiment with ryegrass -plant yields

Fertilization seemed to be beneficial for germination, since the number of plants was somewhat lower in the control treatment (*P*=0.003). The average values, counted at the first harvest, were 24 plants in the Control treatment, 26 plants with $CaNO_3$, 28 with Sediment 1 and 27 with Sediment 2.

Plant growth was significantly better with sediments than with $CaNO_3$, especially at the first harvest (Picture 4, Picture 5, Fig. 1). Sediments 1, which was most finely grinded, had a significantly better effect than Sediment 2, and for both sediments there was a positive effect of increasing N level. With $CaNO_3$, there was a negative effect of increasing N level.

Picture 4. Pots from the control treatment (to the left) and Sediment 1, with increasing N-levels towards right. Date March 31, 2017; first harvest.

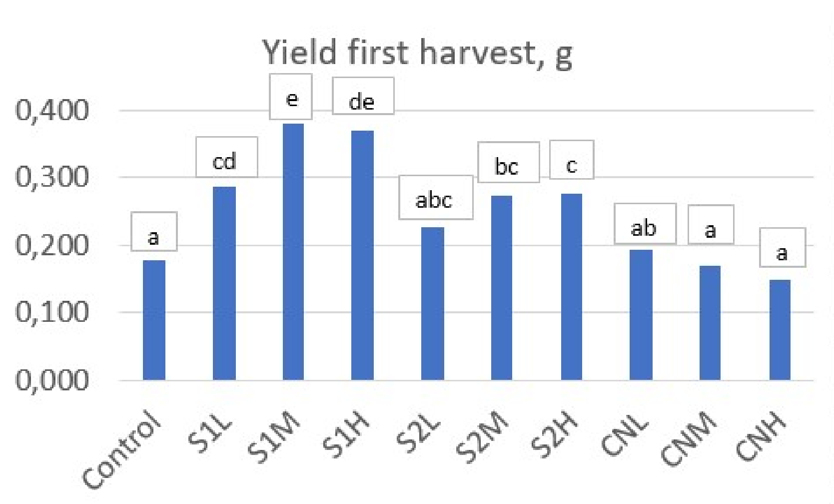


Figure 1. Mean yields (5 pots harvested per treatment) of the first harvest of ryegrass, g dry matter produced per pot, plants cut at 4 cm. Columns with different letters are statistically significantly different at 5% level. S1= Sediment 1 (finely grinded), S2= Sediment 2 (less finely grinded), CN= CaNO3, L= low, M= medium and H= high level of N corresponding to 200, 400 and 600 kg N per ha.

Picture 5. Pots from the control treatment (to the left), and towards right, low (front), medium and high (back) levels of Sediment 1, Sediment 2 and $CaNO_3$. Date March 31, 2017; first harvest.

At the second harvest, the growth with Sediment 2 was quite equal to the growth with Sediment 1, whereas the plant growth with $CaNO_3$ still lagged somewhat behind (Figure 2). At the third harvest, the lowest level of fertilization did not yield more dry matter than the control. At the higher levels of fertilization, yields were higher, but not significantly different between the treatments (Figure 3).

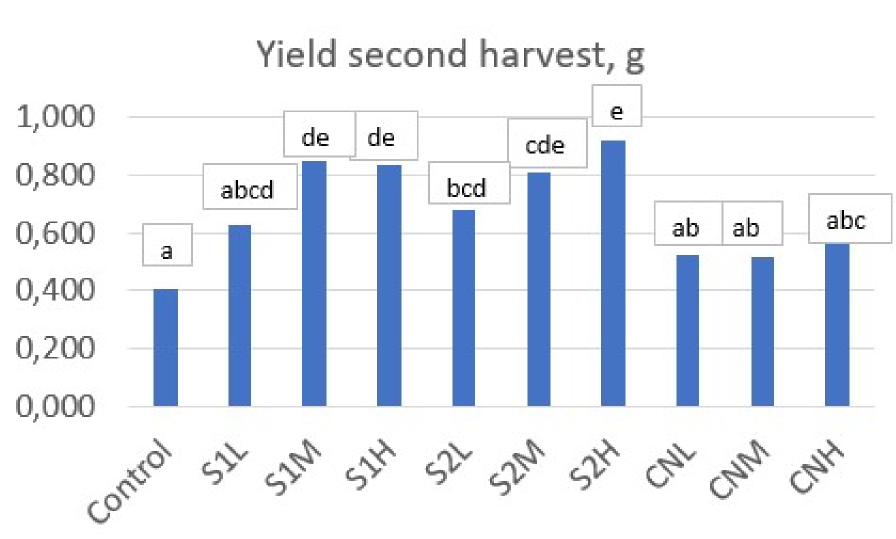


Figure 2. Mean yields (4 pots harvested per treatment) of the second harvest of ryegrass, g dry matter produced per pot, plants cut at 4 cm. Columns with different letters are statistically significantly different at 5% level. S1= Sediment 1 (finely grinded), S2= Sediment 2 (less finely grinded), CN= CaNO3, L= low, M= medium and H= high level of N corresponding to 200, 400 and 600 kg N per ha.

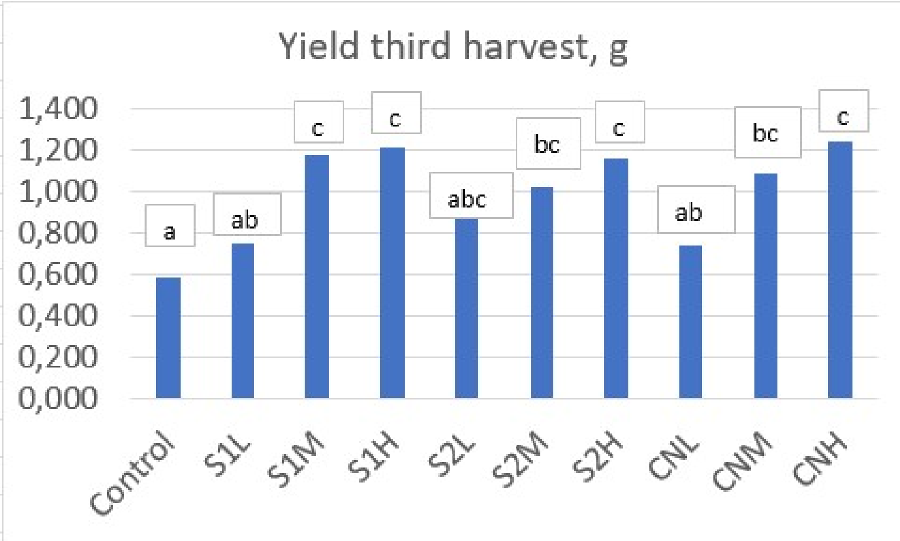


Figure 3. Mean yields (3 pots harvested per treatment) of the third harvest of ryegrass, g dry matter produced per pot, plants cut at the soil surface. Columns with different letters are statistically significantly different at 5% level. S1= Sediment 1 (finely grinded), S2= Sediment 2 (less finely grinded), CN= CaNO3, L= low, M= medium and H= high level of N corresponding to 200, 400 and 600 kg N per ha.

Converted to yields in DM per ha and summarized over three harvests, the yield levels were satisfactory (Figure 4). There was a clear effect of higher N application, but less increase from the medium to the high level than from low to medium level. The high N-level produced close to twice as much dry matter as the control. Both sediments were excellent fertilizers, producing higher yields than the $CaNO_3$ treatments.

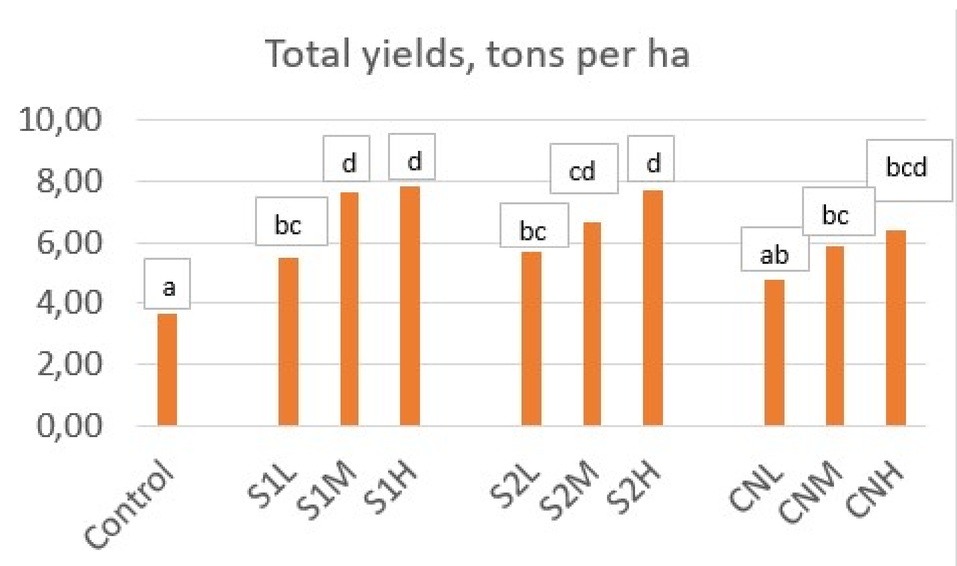


Figure 4. Sum of three harvests, converted to tons of dry matter per ha. Columns with different letters are statistically significantly different at 5% level. S1= Sediment 1 (finely grinded), S2= Sediment 2 (less finely grinded), CN= CaNO3, L= low, M= medium and H= high level of N corresponding to 200, 400 and 600 kg N per ha.

Pot experiment with ryegrass – soil analysis

The P-AL concentration was measured at each harvest, in pots with and without ryegrass plants. Due to the high content of organic matter (11%), we expected that the P-AL concentration would increase slightly over time in pots without plants, due to mineralization of organic P. In the control treatment, P-AL was 4,0 mg per 100 g soil at the first harvest, increasing to 4.2 by the second and 4.3 by the third harvest. This low increase is reasonable. With ryegrass plants present in the control treatment, the average P-AL value was 3.9 at first harvest, sinking to 3.8 at the second and 3.7 at the third harvest. These values are for single pots (no replicates) and must be interpreted with care, but the decrease corresponds with plant uptake of P.

For the final harvest, three replicate pots with plants were harvested. The variation between pots receiving the same fertilizer treatment was larger than the differences referred above. The average values are shown in Figure 5. Grinding of the sediment seemed to increase the P-AL concentration of the soil. The finest sediment increased soil P-AL significantly, both in the soil and in soil where plants were grown. Hence the sediment likely brought more P than the plants could take up. The coarser sediment brought as much P, but it did not affect P-AL concentration to the same extent. Plants given $CaNO_3$ produced good yields of dry matter without application of any P. We could expect that this would decrease the soil P-AL concentration, but that was not the case (Figure 5). On the contrary, the P-AL seems to have increased with higher $CaNO_3$ application. We may speculate that the N fertilization has increased mineralization of organic P, but it may also be a result of random variation.

The soil pH was slightly higher in all treatments with plants. The value varied between 5.0 and 5.5, and the average value with plants was 5.28, whereas without plants it was 5.13. We could possibly expect that treatments with plants would get slightly higher values for soil organic matter than treatments without plants, but the values for soil organic matter, as measured by ignition loss, did not vary between treatments with and without plants in any consistent way. On average for all treatments, it was 12.1%. For potassium (K), plant uptake was clearly demonstrated by decreasing soil K-AL values in plant treatments. On average for all treatments with no plant growth, the K-AL concentration was 6.4, whereas it decreased to 3.5 mg per 100 g soil in treatments with plants. Similarly, for magnesium (Mg), Mg-AL was slightly higher in all treatments with no plants, on average 6.2 mg per 100 g soil as compared with 5.5 with plant growth. For calcium (Ca), significant amounts were applied with the fertilizers, which was also reflected in the soil analyses. The Ca-AL concentration was 160 mg per 100 g soil in the control treatment with plants, and 150 without plants. This indicates that the soil has sufficient Ca. The average values across treatments increased from 130 with plants, to 143 without plants. Values were on average somewhat higher with application of $CaNO_3$ than with sediments. For CaNo3, Ca-AL with plants was 157 and without 173. For Sediment 1, these values were 139 and 148, and for Sediment 2 138 and 154.

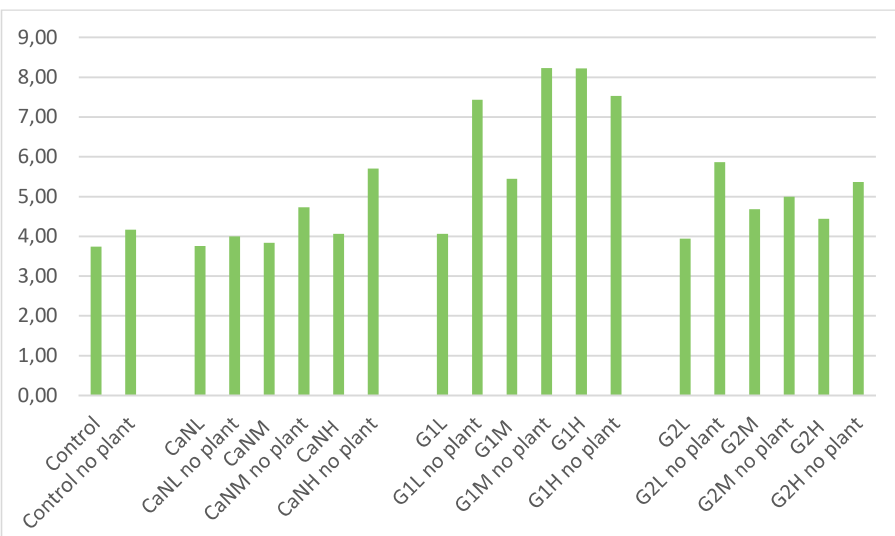


Figure 5. Soil P-AL concentrations (mg per 100 g soil), average values for three harvest dates per treatment and N level, with and without plants. CaN= $CaNO_3$, S1= finely ground sediment, S2= more coarsely ground sediment, L = low, M = medium, H= high amount of fertilizer.

Decomposition in soil of chopped laying hens

A few indications of biological activity were recorded. Some weeds germinated, but died off due to lack of light in the storage room. For some pots with chopped hens added, white springtails were observed in the plates placed under each pot to take care of excess liquid by watering. Further, a white mold could be observed in some of the fertilized pots, especially where particles of hens were located close to the soil surface. On October 20, the weight loss, not corrected for soil taken out to measure pH, varied from 3.1 to 15.2 % of the initial weight. For the pots sampled five times for pH, the soil removing comprised 2.3% of the average initial weight of soil. Hence, the decomposition of organic matter was most likely not restricted by too dry conditions in this study, since a quite wide range of water contents have been shown to be satisfactory for decomposition (Gabriel & Kellman 2011).

Even if the soil was sifted before filling into the pots, gravels were still present, and affected the amount of recovered material of chopped hens. The sifting contributed to reduce the size of chopped particles, increased the contact between soil and chopped hen particles and brought fresh air into the soil. This contributed to reduce the weight of recovered material in pots by each sifting. On the other side, chopped hen particles were moist and made soil stick to them, which significantly increased the weight of recovered material.

The amount of chopped hen material recorded by sifting decreased over time (Table 3), but the average values give a somewhat rough picture. After 3 weeks (March 31), the weight of recovered material was larger than the weight of material applied on March 9 for two treatments, and for the lowest application level this was also the case on April 20. Later, the values decreased strongly. Sifting the soil had a significant effect on the recorded weight of recovered material (Table 4). In the pots which were sifted for the first time on June 28, the amount of recovered material was comparable to values found by the first sifting on earlier sifting dates. One fungal structure with a fresh weight of 2.5 g was found in a control pot on October 20 explaining the average value of 0.5 on this date in the Control treatment (Table 4).

Picture 6. Particles of chopped hens covered with soil, remaining in the sift on June 28, 2017.

The soil pH decreased over time in the study (Table 5). Addition of chopped hens to the soil also had a clear acidifying effect, increasing by larger amounts of organic material applied.

The red-ox potential seemed to differ slightly between treatments in the beginning (Table 4), but there was no indication that addition of chopped hens affected this measure. Most likely, the variation is due to variation in water content of the soil.

Table 3. Mean values of amounts of chopped hens (g per pot) applied on March 9, and recovered on March 31, April 20, May 15, June 28 and October 20 by sifting of soil from pots stored indoor at about 15 °C.

Treatment	**9.3 (applied)**	**31.3**	**20.4**	**15.5**	**28.6**	**20.10**
Control	0	0	0	0	0	0.5
600 kg N/ha	45.3	78.7	57.0	20.9	23.9	4.6
1200 kg N/ha	90.6	144.7	72.5	48.1	38.7	21.1
1800 kg N/ha	135.9	111.52	110.0	56.3	40.6	33.6

Table 4. Values per pot (g) of amounts of chopped hens applied on March 9, and recovered on other dates by sifting of soil from pots stored indoor at about 15 °C. Missing observation = m

Treatment	**Pot**	**9.3**	**31.3**	**20.4**	**15.5**	**28.6**	**20.10**
600 kg N/ha	1	45.3	78.7	43.8	20.6	12.7	1.7
	2	45.3	--	70.15	31.3	m	1.5
	3	45.3	--	--	10.9	5.5	1.1
	4	45.3	--	--	--	48.7	10.8
	5	45.3	--	--	--	30.0	8.2
1200 kg N/ha	6	90.6	144.7	72.7	48.0	19.2	11.1
	7	90.6	--	72.4	43.4	24.3	10.6
	8	90.6	--	--	52.9	33.5	23.2
	9	90.6	--	--	--	79.9	39.6
	10	90.6	--	--	--	36.5	20.8
1800 kg N/ha	11	135.9	111.5	76.2	63.9	31.5	24.1
	12	135.9	--	143.9	62.3	31.5	31.2
	13	135.9	--	--	42.7	19.8	11.9
	14	135.9	--	--	--	52.2	45.3
	15	135.9	--	--	--	65.1	55.7

Table 5. Mean values for pH (soil: water 1:2.5 (w/w), 2 parallel measurements per pot, of soil before mixing with chopped hen material on march 9, and of soil- chopped hen material mixtures after storage at 10-15 °C on March 31, April 20, May 15, June 28 and October 20, 2017.

Treatment	**9.3**	**31.3**	**20.4**	**15.5**	**28.6**	**20.10**
Control	5.50	5.35	5.28	5.28	5.16	5.02
600 kg N/ha	5.49	5.08	5.07	4.94	4.69	4.82
1200 kg N/ha	5.38	5.46	4.74	4.58	4.35	4.46
1800 kg N/ha	5.43	5.87	4.79	4.47	4.32	4.31

Table 6. Mean values for red-ox potential (soil: water 1:2.5 w/w), 2 parallels per pot, of pots harvested on March 31, April 20, May 15 and June 28, with various addition of chopped hens.

Treatment	**9.3 (soil)**	**31.3**	**20.4**	**15.5**	**28.6**
Control	297	314	280	253	295
600 kg N/ha	334	300	288	245	293
1200 kg N/ha	338	314	293	253	292
1800 kg N/ha	326	304	282	253	291

Putrefaction of chopped laying hens – odor and visual observations

In general, the odors produced during the study were not as bad as expected. This was partly because of the low initial temperature, since the odor became was stronger with higher temperature. When the pots were harvested in late July, the odor was unpleasant, but not so bad that we had to use masks or work outdoor. Soil is an efficient substrate to mask odor, or possibly to make unpleasant odor disappear.

The first week the chamber was quickly observed daily. No odor occurred until March 16, when a weak smell of organic acids was observed from the aluminum beakers with chopped hens and no soil. Small, white spheres, likely from fungi, had formed on the material. By March 24, the color had changed more towards grey, and a thin, dark grey mold was about to be formed. The white spheres had also attained a greyish color. Areas where liquid was accumulating were observed (Picture 7). The odor now reminded about a refrigerator in need of being cleaned, probably derived from organic acids. However, it was not directly uncomfortable to do the observations. At the end of the study, the chopped material had dried out and was sticky, resembling modelling clay, and the color had turned towards greyish brown (Picture 8). Some mold was visible, and the smell was sharp from ammonia, reminding of rancid food.

Picture 7. Chopped hens stored at 10.3° C from March 10 to 24, 2017.

Picture 8. Chopped hens stored at monthly temperature intervals 10.3, 14.0, 15.1 and 13.2°C from March 10 to July 25, 2017.

From the pots containing chopped hen material and soil, no smell could be observed until March 24. By then, a smell of dead hens was identifiable from some of the pots with large buried net bags. The smell of dead hens is not easy to describe, but easy to distinguish when one has become familiar with it. It reminded of the smell of the chopped material in the beakers, but was less sharp. It was clearly a smell of hens, in the same way as manure is easy to identify for various animal species. For the pots where chopped material and soil was mixed, a weak smell of dead hens was identifiable from the treatment with the highest ratio (1:1). For lower ratios, the pots had a weak, but pleasant smell reminding of a basement where raw potatoes are being stored.

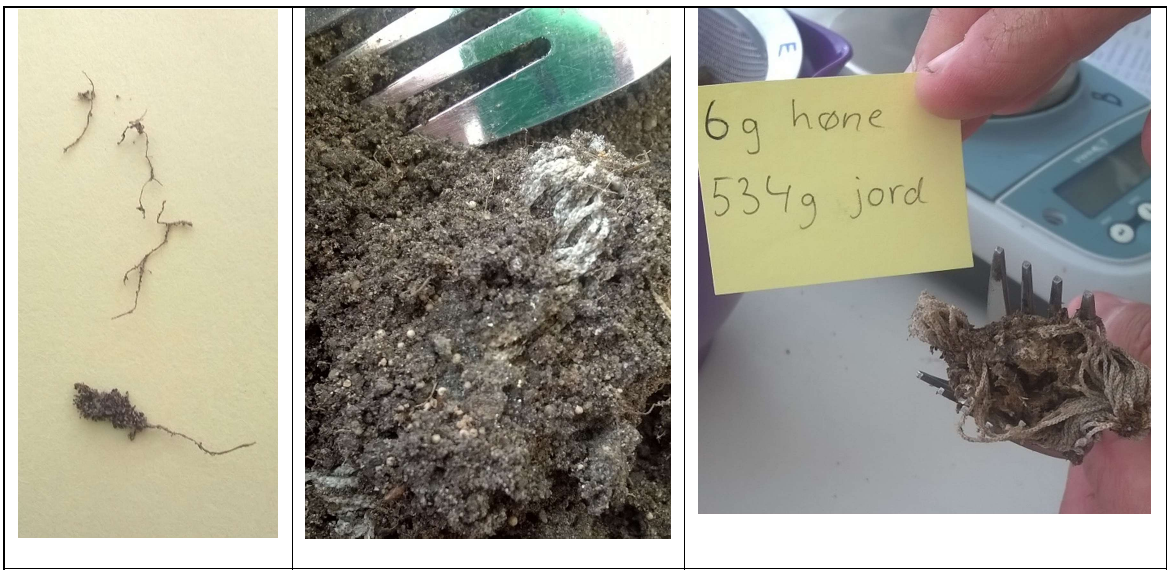
Over time, the smell became sharper, reminding of ammonia, also in the pots, but the smell was always much weaker than from the beakers.

In the pots with large amounts of chopped material, a mold had formed already on March 16. For the buried material in net bags, mold occurred where net bags touched the soil surface (e.g. pot 17, to the right of pot 16 downwards on Picture 9). In the pots where soil and chopped material was thoroughly mixed, a delicate white mold covered the whole surface of the 1:3 (e.g. pot 11) and 1:2 pots (e.g. pot 15), whereas in the 1:1 pots, this mold occurred in small heaps with spots of bare soil in between. On March 24, the mold had developed to become a thick cover (Picture 9). The water visible on the mold is an artefact caused by some run-off of evaporated water accumulated on the plastic cover, when this cover was removed.

Picture 9. Pots 11-20 (numbers starting in the left front corner, going backwards and forwards again) on March 24, 2017. Pots 11 and 12 contain chopped hens mixed with soil 1:2; pots 13-16 chopped hens mixed with soil 1:3 and pots 17-20 chopped hens in net bags with soil in ratio 1:1 (w/w).

At the end of the study, pots with addition of chopped hens in small net bags corresponding to 600, 1200 and 1800 kg N per ha showed a very interesting phenomenon. On top, the soil surface did not reveal any indication of hiding material from chopped hens. Around the net bag however, surrounding soil had formed a sphere weighing about 50 g (picture x), where fungal structures were identified such as hyphae and white spheres (Picture 10). The size of these soil spheres increased with increasing amount of chopped material, from on average 48 g for addition of 6 g per pot, to 81 g for addition of 12 g and 125 g for addition of 18 g chopped material per pot. Hence, about 7-8 g soil per g of applied chopped hen material was fixed into a strong aggregate. The residues left in the small net bags were grey and dry (Picture 11). Whereas the outer part of the soil sphere was easy to loosen, significant force was required to loosen the net bag from the soil, which was stuck on to it. In one case, several parallel hyphae were observed in a soil sphere where 12 g soil, per pot had been applied (Picture 12).

Picture 10. Sphere of soil formed around a net bag containing 6 g of chopped hen material, during about 4 months at 10-15 °C.



Picture 11. Fungal hyphae (left) and white spheres (middle) observed inside the soil sphere. To the right, the contents of the net bag with the chopped hen material.

Picture 12. Bundle of hyphae found on July 25, 2017 in a soil sphere surrounding a net bag containing 12 g of chopped hen applied to the soil on March 10, 2017.

In the pots where extreme amounts of chopped hens had been added, an aggregating effect on the soil was also found, but in a completely different manner. Pots where chopped material was buried in net bags had only some, brownish mold on the soil surface (Picture 13), but the whole content of the pot formed one “cake” when the pot was emptied (Picture 14). Soil stuck to the surface of the net bags, but delicate spheres were not present. The degree of decomposition seemed higher for the lowest ratio of chopped material to soil (Picture 14 left), where the material was dry and grey and resembled the material in the small net bags, whereas with higher proportions of chopped hen in the soil, the material was yellowish and moist. In spite of the not very delicate appearance of this material, the smell was not as bad as could have been expected. One might have expected that it would be a tough job to put the nose above the net bags from the 1:1 pots, but this was actually no problem. The smell was from ammonia, in pots with addition of 180 and 270 g material per pot, whereas with the lowest amount of 125 g chopped hen to 405 g soil the smell was from soil and hens. On the other side, the odor seemed to stick to clothes and skin, possibly due to a combination of fatty substances and dust.

Picture 13. Soil surface of the four replicate pots where 270 g chopped hen material per pot was buried in net bags, with 270 g soil to cover the net bag.

Picture 14. Net bags containing chopped hen material with the ratio of 1:3, 1:2 and 1:1 of chopped material to soil (w/w) from left to right. The chopped material was buried in the soil in net bags, with soil around, from March 10 to July 25, 2017.

The main difference between the pots where soil and chopped material was thoroughly mixed, and the pots where the material was buried in net bags, was the vigorous development of mold on the soil surface. Initially this mold was delicate white, then changed to a brown color reminding of chocolate, and then in some pots developed a white mold again whereas others stayed brown (Picture 15). The clayish structure of the soil, which was obtained during mixing was still recognizable. Some pots with the highest addition of chopped material (1:1) was infected by fly larvae. When the 1:1 pots were emptied, the whole content formed a cake, difficult to crunch. When the cake was broken, the inside showed that much of the chopped hen material was still present in the soil (Picture 16). For ratios 1:2 and 1:3, the soil had some ability to crumble, but much material was still present (Picture 17). The smell was from ammonia, but not very strong. For the 1:1 ratio, the smell was awful, resembling hen's manure, and the content did not crumble.

Picture 15. Mold of different color formed on pots with 135 g of chopped hen material to 405 mg of soil, thoroughly mixed and stored at 10-15 °C from March 10 to July 25, 2017.

Picture 16. Contents of a pot with the ratio of 1:1 for chopped hens material and soil, after storage from March 10 to July 25, 2017.

Picture 17. Contents of a pot with the ratio of 1:2 for chopped hens material and soil, after storage from March 10 to July 25, 2017.

Putrefaction of chopped laying hens – soil analysis

At the end of the incubation period for the pots where very large amounts of chopped hens were mixed with soil, the control treatment had significantly higher pH than was observed for the pots which were used for growing of ryegrass. Whereas soil pH in the ryegrass study varied between 5 and 5.5, measured by Eurofins, and in the ryegrass study it varied between 4.3 and 5.5, measured at Tingvoll, pH was 7.1 in the control treatment (Table 7), and varied between 6.3 and 7.2 in the other soil samples from the putrefaction study. This is a bit surprising since the soil used was well mixed before the studies started, and de-ionized water was used to replace water lost by transpiration. The water content of the soil when the experiment started was about 25%. The chopped hen material had a much higher water content, of 66% and hence the conditions were quite anoxic in the treatments where chopped hen material and soil was thoroughly mixed. The plastic cover over the pots might have created a nice environment for denitrification, which increases soil pH according to the following chemical reaction, where CH_3OH indicates a source of organic matter:

$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$

The soil has shown a significant potential for denitrification in a former study in field, which may be due to the high content of organic matter (Løes et al., 2014). However, in the treatments where small net bags containing chopped hen material was buried, the soil pH varied from 6.3 to 6.7. It is difficult to explain why the effect of denitrification to increase soil pH would be lower from these pots than from the control pots. Possibly, there are other explanations to this result.

During the decomposition of organic matter, protons are released which acidify the environment. This may explain slightly lower pH values in treatments with additions of chopped hen material, but the pH values in all treatments where large proportions of hen material was applied, was quite close to the control value. This may be due to nitrification, since the environment in these pots were likely more anoxic due to wetter conditions and large amounts of N-rich material was available.

Table 7. Chemical characteristics of soil sampled from pots with soil only (control), or soil mixed with various amounts of chopped hen material, either thoroughly mixed, or by burying of net bags, with ratios ranging from 1:1 to 1:3 (chopped hen material/soil by weight); or by burying of small net bags with amounts of chopped hen material corresponding to 600, 1200 or 1800 kg N/ha. "Sample" indicates where in the pots the samples were taken. Top, below and around indicate above, below or around the net bag but not from soil attached to the net bag; "on" indicates soil attached to the net bag. VolW = volume weight measured in laboratory, IG loss = organic matter (%) measured by loss of ignition. Each value is an average of 4 replicate pots.

Treatment	Sample	VolW	pH	P-AL	K-AL	Mg-AL	Ca-AL	Na-AL	IG loss
Control		1.1	7.1	4.1	6.6	5.7	130	<5.0	10.7
Mixed 1:1		0.90	6.8	130	160	19	420	78	26.6
Mixed 1:2		0.96	7.0	150	120	20	400	58	15.5
Mixed 1:3		0.93	7.1	67	83	14	290	40	14.6
Buried 1:1	top	1.0	6.8	120	150	20	130	70	16.8
Buried 1:1	on	1.1	7.0	84	130	9.2	130	61	13.8
Buried 1:1	below	1.1	6.8	110	130	6.8	100	63	12.1
Buried 1:2	top	1.1	7.0	81	100	15	140	50	13.7
Buried 1:2	on	1.1	7.1	34	93	7.7	140	44	12.7
Buried 1:2	below	1.2	7.1	37	96	7.0	130	45	11.7
Buried 1:3	around	1.1	7.2	23	72	7.0	130	32	12.6
Buried 1:3	on	1.0	7.1	69	83	13	150	40	13.5
Small bag 600	around	1.1	6.5	3.6	8.2	5.4	120	<5.0	11.0
Small bag 600	on	1.1	6.5	11	21	9.0	150	10	11.7
Small bag 1200	around	1.1	6.5	3.6	9.0	5.5	120	<5.0	11.7
Small bag 1200	on	1.1	6.7	10	23	7.5	130	11	12.1
Small bag 1800	around	1.1	6.4	4.0	12	6.2	130	6.5	11.6
Small bag 1800	on	1.1	6.3	14	24	8.7	150	11	11.6

For organic matter, the content in the control pot was somewhat lower (10.7%) than for the control pots in the ryegrass study (12.1% with no plant growth). This may be due to decomposition of organic matter during the study, even if it seems strange that the decomposition was higher under a plastic cover in the incubation chamber than in the growing room where the temperature was above 20 C. The reason may be that the growing period was significantly shorter, 65 days for the ryegrass study compared with 135 days for the incubation. The content of organic matter was higher than the control in all other soil samples from this study. The high additions of chopped hen material to the mixed treatments was reflected in higher contents of organic matter, up to 26.6%. The volume weight decreased with addition of chopped hen material in the mixed treatments, which is reasonable since the content of organic matter increased in the soil. For the buried net bags, organic matter was higher in the top layer than in the soil sphere sticking to the net bag and its content, for the treatments with the largest proportions of chopped hen material (Buried 1:1 and 1:2). This was a bit surprising, but possibly the growth of fungi in the top layer has increased the organic matter content to this extent. We had expected a higher content of organic matter in the soil sticking to the net bags than in the soil surrounding these spheres, due to the intensive growth of fungi that we observed. This was found for the soil layer beneath the spheres. For the treatment Buried 1:3, it was higher in the soil sticking to the net bags. For the small net bags, the content of organic matter was slightly higher in one treatment.

The P concentration increased significantly with addition of chopped hen material, demonstrating the value of this material as fertilizer. The concentration increased even in the layer above the sol sticking to the net bags (Table 7). This is in line with the increase in organic matter content in the top layer in the treatments Buried 1:1 and 1:2. It was a bit surprising that we did not find a gradient with P-AL being higher in the soil sticking to the net bags than in the soil above the net bag (Buried 1:2), but for the treatments with small net bags as well as the treatment Buried 1:3, P-AL was significantly higher in soil sticking to the net bag, whereas the soil around the spheres had P-AL values comparable to the control soil. Since the chopped hen material was moist, we could possibly expect a transport of P from liquids downwards while the cells were decomposing. Some of the pots with large additions of chopped hen material actually shown some leaching, and aluminum foil was wrapped around the bottoms of the pots to prevent this. After this wrapping, there was no excess of liquid leaching from the pot + foil system. Possibly, the transport of liquids was upwards because the chamber was ventilated. Free water films on the plastic sheet indicates this. This may contribute to explain the high P-AL concentrations in the upper soil layers in treatments Buried 1:1 and 1:2. Potassium is more mobile in soil than phosphorus. For this element, concentrations increased even more with addition of chopped hen material that for P, and the differences between the layers in all the Buried-treatments were smaller than for P.

The concentrations of AL-extractable magnesium, calcium and natrium were also significantly increased by application of chopped hen material (Table 7), and the differences in concentrations follow the same pattern as found for P and K: More nutrients found in the top layer and close to the net bags. High concentrations of natrium is not favorable for plant growth, but in practice this cation is easily removed by precipitation and leaching.

Discussion

Pot experiment with ryegrass

Despite that the same amount of N was applied, sediments performed better than $CaNO_3$, especially at the first two harvests. Sediment 1, which was more finely grinded, initiated growth more quickly than Sediment 2, but the total plant yields were equal. The finer structure has probably increased the plant availability of nutrients. The P in the sediments may explain the better growth with these fertilizers, especially since the test soil had a low concentration of P. $CaNO_3$ does not add any P to the soil. It is somewhat surprising that the positive effect of $CaNO_3$ on plant growth was slower than for the sediments, since the N in this fertilizer is soluble and expected to be 100 % plant available, whereas the N in sediments is organically bound in proteins and we would expect that a mineralization should occur before the N became plant available. The theory of plant nutrition says that nutrients are taken up by plant roots as ions, and studies of plants in nutrient solutions confirm that plants may absorb nitrate and ammonium. However, research has also shown that plants may absorb small molecules of organic N such as amino acids from decomposed soil proteins (Näsholm et al. 2008). This study may be an example of this process. It may also be an effect of high P supply, but if P was that much limiting plant growth, we could have expected to find some indications of P deficiency, especially for plants grown with $CaNO_3$ at the final harvest. Further, increased yields with increasing levels of $CaNO_3$ is difficult to explain if P was the major factor to limit plant growth.

AL-extractable P increased with additions of sediments, and much more when finely ground (Sediment 1). However, with no plant growth the P-AL concentration seemed to increase also with application of $CaNO_3$. This is a surprising result and difficult to explain. However, extraction with ammonium-acetate lactate was developed as a method to characterize plant availability of nutrients in clay soils, and are less reliable for soils with high contents of soil organic matter (Egnér et al 1960). A further study of P dynamics in this soil, as well as with the applied sediments, should include more soil analysis, such as Olsen-P which is based on a weaker extraction agent and may reveal more information, especially when combined with stringer extractants.

Decomposition in soil of chopped laying hens

Sifting the soil to identify the amount of recovered material seemed to increase the rate of decomposition significantly. However, the sifting itself might have contributed to reduce the particle size so that particles passed the sift, but possibly were not 100% decomposed. The pH decreased with addition of chopped hens, probably due to production of organic acids. Further studies are required to check whether this decrease is permanent or temporarily. Measurement of red-ox potential did not reveal any interesting information.

The method applied was simple, but not very precise. Possibly, the practical conclusion to be learned from this simple study is that repeated mixing and aeration of the soil can increase the rate of decomposition, and hence such management should be considered if the aim is to establish a procedure for utilizing soil to decompose organic matter rapidly. The soil was not sterilized before the experiment, and more biological activity could possibly have been expected, e.g. earthworms. However, former studies have shown that the dominating species of earthworms in the present soil do not easily survive in pot experiments. Hence, it was not very surprising that earthworms were not found during the study, in spite of that cocoons might well have been present.

Putrefaction of chopped laying hens

This study revealed an interesting phenomenon, that soil would stick to net bags filled with chopped hen material after 135 days of incubation at a temperature resembling conditions in topsoil in Mid-Norway from middle May to middle September. The firm spheres seemed to be kept together by fungi. We speculated that the nutrient concentration of the soil would possibly be higher in the soil in these spheres, possibly because fungal hyphae could transport nutrients from the nutrient rich material in the net bag towards the less nutrient rich soil. For the small net bags, corresponding to the N levels studies in the large pots with soil sifting, this expectation was actually confirmed. With additions of much higher volumes of chopped hen material, the changes in nutrient concentrations were somewhat more difficult to explain. If nutrient concentrations were higher towards the bottom of the pots, we could have explained the increases by the slight leaching which occurred. However, it seems that the transport of water was rather upwards since free water was observed on the plastic cover each time we observed the pots. If such a study shall be repeated, it will be important to control the water movements in the system. It would also be interesting to use more than one soil type, and to include a control with sterilized soil. If the spheres only are formed in a biologically active soil, this indicates that soil biology is related to the forming of very solid soil aggregated linked to the decomposition of clumps of organic material.

The main result of this study was that the odor was much less problematic than expected, and that soil seemed to be able to reduce odor and absorb liquids from quite high additions of chopped hen material. It would be very interesting to proceed with a study in larger scale, to observe how fast chopped hens may decompose e.g. with a ratio of soil/hen of 10:1. For 13.5 tons of chopped hens, corresponding to a normal herd of 7500 hens, this would demand 135 tons of soil. Each year, about 100 000 tons of valuable soil material is deposited from Norwegian potato and vegetable packaging (Egelyng 2017), to reduce the risk of spreading pathogens. Combining soil/sludge from this industry with chopped hen material could be a very good idea of converting “waste” products into a valuable resource. The product after a thorough decomposition process should be sanitized, and then has a potential to become a highly efficient organic fertilizer.

Conclusions

Residual sediments after hydrolysis of proteins and oils from grinded material of slaughtered laying hens, are a very efficient fertilizer. If hydrolysis of oil and proteins is initiated on a large scale, it should be well possible to utilize the sediments in agriculture. However, the prize of mineral fertilizers is low, and it needs to be assessed whether the prize that can be achieved for sediments as fertilizers is high enough to cover the costs of storage and distribution, possibly also of drying and pelletizing the sediments since freezing them is no option in large scale.

Material from killed, chopped hens is very rich in nutrients. Such material is degraded in soil over time, and mechanical treatment of the soil seems to increase the rate of decomposition. Soil seems to be an effective agent to reduce odors from chopped hens during putrefaction. Further studies in larger scale are required. The current disposal of 3.5 millions of laying hens annually is a big waste of resources, and initiates significant costs for the farmers. If each hen costs about 7 NOK in destruction costs and transport, about 20 million NOK could be used annually to support farmers in developing a system for converting the hens into a valuable fertilizer product, possibly combined with soil sludge from potato package plants or other available sources of soil, e.g. derived from maintenance of drainage systems.

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