Effects of feeding and manure management interventions on technical and environmental performance of Indonesian dairy farms

Marion de Vries, Bram Wouters, Deni Suharyono, Amin Sutiarto, Sehati Efri Berasa

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Effects of feeding and manure management interventions on technical and environmental performance of Indonesian dairy farms

Results of a pilot study in Lembang Sub-District, West Java

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3 Trouw Nutrition Indonesia

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The aim of this pilot study was to evaluate effects of feeding and manure management interventions on the technical, economic, and environmental performance of Indonesian dairy farms, and to assess the adoption potential of these interventions. Various interventions were tested on 18 practical dairy farms in Lembang Sub-District in West Java, Indonesia. Results showed that ration balancing, mineral supplementation, feeding high quality compound concentrate feed, and (vermi-) composting have potential to improve the profitability of dairy farming, health of dairy cows, and/or reduce environmental pollution of dairy farming.

Het doel van deze pilot studie was om effecten van diverse voer- en mestmaatregelen op de technische, economische en milieu prestaties van Indonesische melkveebedrijven te evalueren, en het adoptiepotentieel van deze maatregelen te verkennen. Maatregelen werden getest op 18 praktijkbedrijven in Lembang Sub-District in West Java, Indonesië. Resultaten lieten zien dat rantsoenoptimalisatie, mineralensupplementatie, voeren van een hoogwaardiger mengvoer, en (vermi-) compostering potentie hebben om de rendabiliteit, diergezondheid, en/of milieuprestaties van melkveebedrijven te verbeteren.

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Key messages

This pilot study evaluated effects of feeding and manure management interventions on technical, economic, and environmental performance of 18 dairy farms in Lembang Sub-District, West Java.

Results of this study showed:

- Feeding dairy cows according individual requirements (‘ration balancing’) can reduce feed costs. Based on modelling results, total greenhouse gas (GHG) emissions decreased by 0-12% in farms that implemented ration balancing without increasing the total feed and fodder supply;
- Mineral supplementation to the cow diet had a positive effect on the hair coat condition of cows;
- Feeding a higher quality compound concentrate feed with mineral/vitamin premix increased milk yields of lactating cows in mid lactation. GHG emissions increased due to higher emissions from production of compound feed ingredients and from manure management;
- Costs of manure management were lowest for manure discharging and daily spread to agricultural land, and highest for composting and vermi-composting. Due to the revenues from compost and worms, however, vermi-composting was profitable on all pilot farms, whereas composting was not always profitable.
- Shifting from discharging or daily spread to composting or vermi-composting reduced the amount of cattle manure discharged into the environment and reduced overfertilization of land close to cow barns. As a consequence, GHG emissions decreased by 0-20% on these farms.
- More than 80% of the pilot farmers indicated that it was very likely that they would start or continue with: using the high quality concentrate feed, mineral supplementation, feeding more green fodder, ration balancing, and applying manure close to the cow barn.
- To a lesser extent, pilot farmers indicated that it was likely they would start or continue with: introduction of new fodder species, composting, vermi-composting, selling or giving away manure, managing manure with a group of farmers, and manure application far from the cow barn. Almost half of the pilot farmers indicated it was unlikely they would start with fodder conservation, mainly because of the lack of input materials (maize, grass).

The following strategies are recommended to improve technical and environmental performance of dairy farms in Lembang Sub-District:

- Provide training and education to dairy farmers about best practices in feeding and manure management, including environmental consequences, for example by means of farmer field schools. To enhance ration balancing, long-term extension should be provided to dairy farmers.
- Conduct additional research to determine the effect of feeding the higher quality compound concentrate feed on milk yield, and on the cost-effectiveness of this intervention.
- Farmers that start to use the high quality concentrate feed should:
    - Receive training in ration balancing to avoid unnecessary high feed costs and environmental pollution due to poor N-use efficiency of cows;
    - Properly manage cattle manure to avoid increased N emissions from manure application;
    - Provide ad libitum water to cows, being a precondition for effective feeding.
- Explore alternative ingredients for the high quality concentrate feed with a lower carbon footprint to avoid increases in GHG emissions.
- Reduce the discharging of manure into the environment, but this should not result in overfertilization of agricultural land close to cow barns. This implies that part of the cattle manure should be used as a fertilizer on other agricultural land, for example in food crop production or on land for fodder production further away from the cow barn.
- Since solid manure is easier to handle and transport than liquid manure, storages for solid manure need to be constructed. This requires access to credit and education about solid manure management.

Summary

The demand for milk and dairy products is growing in Indonesia. At the same time, Indonesia has committed itself to reduce greenhouse gas (GHG) emissions from agriculture as part of its National Determined Contribution. Sustainable increase of milk production in the Indonesian dairy sector requires low-emission strategies that are feasible under local conditions. The aim of this pilot study, therefore, was to evaluate effects of feeding and manure management interventions on the technical, economic, and environmental performance of Indonesian dairy farms, and to assess the adoption potential of these interventions.

Materials and methods
The following interventions were evaluated at 18 practical dairy farms in Lembang Sub-District in West Java, Indonesia:
- Feeding interventions: improving water supply, feeding the mineral/vitamin supplement 'Max All Rum Dai 1.5% DS', feeding a high quality compound concentrate feed, feeding cows according individual requirements ('ration balancing'), growing new fodder species, and fodder conservation.
- Manure management interventions: manure application on land for fodder production, vermi-composting, composting, and giving away or selling manure.

Data was collected from the pilot farms using surveys about farm management, herd characteristics, land use, feeding, manure management, and potential adoption of interventions. In addition, on-farm measurements of milk yield, feed supply, hearth girth, haircoat, and body condition were collected from a sample of 2-6 cows per pilot farm during a period of 12 months. Focus group discussions were held with pilot farmers and stakeholders from the dairy industry and knowledge institutes about the likeliness of adoption of interventions.

Effects of interventions were evaluated in terms of changes in milk production (high quality concentrate feed), hair coat score (mineral supplementation), economic costs and revenues, and GHG emissions (high quality concentrate feed, balanced rations, improved manure management). GHG emissions were modelled using a Life Cycle Assessment (LCA) approach. Effects of introducing the improved feed and water trough, growing new fodder species, and fodder conservation were not quantitatively evaluated, but only qualitatively by means of the survey and focus group discussions.

Results
For ration balancing, most farmers were advised to feed more green fodder and less cassava waste, and to differentiate in the amount of concentrates fed to lactating cows. The number of pilot farmers following up on the ration balancing advice was initially low, and increased over time when additional advice was given. Results showed that ration balancing could reduce feed costs per kg milk by 9% on average, if extra grass is freely available. If extra grass is purchased, feed costs would increase. Total GHG emissions increased by 0-34% on 9 farms that were advised to feed more fodder and/or compound concentrate feed because often cows were underfed in terms of energy and protein. GHG emissions decreased by 2-12% on farms that were advised to feed less fodder and/or compound concentrate feed. Effects of ration balancing on milk yield, revenues from additional milk sold and GHG emissions per kg milk were not evaluated in this study because the sample size was too small.

The average haircoat condition of cows improved with 1-2 points after introduction of the mineral/vitamin premix. The effect on haircoat was expected to be partly due to the premix, and partly due to changes in green fodder supply while changing from the dry to the rainy season.

The average milk yield of lactating cows in mid lactation was 0.7 kg milk higher in the 2 weeks after the introduction of the high quality compound concentrate feed with mineral/vitamin premix compared to milk yield in the 2 weeks before this event ($P<0.05$). Milk yield increased in 22 cows (0.4 to 4.9 kg milk/cow/d) and decreased in 9 cows (0.1 to 2.6 kg/cow/d). On average, revenues from extra milk sold did not compensate for the higher costs of the high quality concentrate feed. With given prices of milk and concentrates, an increase in milk production of at least 0.8 kg milk/cow/d would be required to break even. GHG emissions per kg milk increased by 9% on average, due to increased emissions from feed production (energy consumption of processing corn gluten feed) and increased N_2O emissions from manure application.

Most important changes in manure management on pilot dairy farms were the introduction of composting and vermi-composting, with compost being sold or applied to own land for food crop production. This reduced the amount of cattle feces discharged into the environment by 46% and reduced the amount of nitrogen (N) applied to land for fodder production by 15%, on average. Investment and operational costs of composting and vermi-composting were much higher than for manure discharging and daily spread of manure to agricultural fields. Most important costs were labour costs and costs of inputs for composting. Due to high revenues, vermi-composting was profitable on all farms, whereas composting was profitable on only part of the farms. GHG emissions decreased by 0-20% due to the introduction of composting and vermi-composting, mainly as a result of less overfertilization of land for fodder production.

Effects of introducing an improved feed and water trough, growing new fodder species, and fodder conservation were evaluated in terms of adoption potential only. This evaluation showed that:

- More than 80% of the pilot farmers indicated that it was very likely that they would start or continue with: using the high quality concentrate feed, mineral supplementation, feeding more green fodder, ration balancing, and applying manure close to the cow barn.
- To a lesser extent, pilot farmers indicated that it was likely they would start or continue with: introduction of new fodder species, composting, vermi-composting, selling or giving away manure, managing manure with a group of farmers, and manure application far from the cow barn.
- Almost half of the pilot farmers indicated it was unlikely they would start with fodder conservation, mainly because of the lack of input materials (maize, grass).

Conclusions and recommendations

This pilot study showed that ration balancing, mineral/vitamin supplementation, feeding high quality compound concentrate feed, and (vermi-) composting have potential to improve the profitability of dairy farming, health of dairy cows, and/or reduce environmental pollution of dairy farming. When these interventions are implemented in practice, the following conditions need to be met to ensure improved economic and environmental performance of farms:

- To enhance ration balancing, long-term extension is needed for dairy farmers, because adoption rates are slow.
- Farmers that start to use the high quality concentrate feed should receive training in ration balancing to avoid unnecessary high feed costs and environmental pollution due to poor N-use efficiency of cows. Cattle manure should be properly managed to avoid increases in N emissions from manure application due to the higher protein intake. Also, ad libitum water should be provided to cows, being a precondition for effective feeding.
- To avoid an increase in GHG emissions from feeding the high quality compound concentrate feed, alternative ingredients with a similar feeding value and lower carbon footprint should be explored, and effects of land use and land use change (LULUC) should be included in the calculation of the carbon footprint.
- When discharging of manure into the environment is reduced this should not result in overfertilization of agricultural land close to cow barns. This implies that part of the cattle manure should be used as a fertilizer on other agricultural land, for example in food crop production or on land for fodder production further away from the cow barn.
- Since solid manure is easier to handle and transport than liquid manure, storages for solid manure need to be constructed. This requires access to credit and education about solid manure management.

This study was a small scale preliminary study conducted in order to evaluate feasibility of interventions ('pilot study'). In future research, experimental research or observational studies with larger samples sizes should be conducted to more reliably quantify effects of ration balancing and feeding a high quality compound concentrate feed on milk yield, profitability and environmental impacts. As most of the mineral N is excreted in urine, options to reduce the discharging of urine and excess N application from urine should be explored.

1 Introduction

Milk consumption in Indonesia has risen in the past decades, as a result of rising incomes, population growth, and urbanization. The increase in consumption of dairy products in South East Asia is expected to continue to grow in the coming decades (by 13% between 2017 and 2026; OECD/FAO, 2017). Besides this, whereas most of the milk processed by the dairy industry is currently imported, the Government of Indonesia aims to increase domestic milk production to about 40% of national industrial demand by 2021 in order to increase its self-sufficiency and reduce its dependency on imports.

At the same time, Indonesia has settled its targets for 4 to 9 Mton reduction of greenhouse gas (GHG) emissions in agriculture towards 2030 compared to the BAU scenario in its Nationally Determined Contribution (NDC, 2016). GHG emissions from Indonesian agriculture in 2010 were estimated at 110.5 Mton CO_2-eq. (8% of national GHG emissions). Indonesian NDC mitigation actions in agriculture focus on four intervention areas: use of low-emission crops, water efficiency, manure management for biogas, and feed supplements for cattle.

Dairy farming in Indonesia is concentrated on Java, particularly in West and East Java, and takes place on small-scale dairy farms applying zero-grazing. Most farms have little land for forage production, and productivity is below potential due to poor feeding, poor reproduction and animal health problems (De Vries and Wouters, 2017). This situation leads to challenges of obtaining sufficient and good quality fodder and recycling of manure as a fertilizer. Forage supply throughout the year is a challenge in regions with high livestock stocking densities, both in terms of quantity and quality. On many farms, manure management is poor, and manure pollutes water streams and rivers, while only a small part of manure is used to fertilize crop production. These challenges are common to many regions with a high livestock density in Southeast Asia.

Because of the large contribution of dairy production systems to climate change (Gerber et al., 2013), options for mitigation of GHG emissions need to be explored. Dairy cattle produce methane (CH_4) from enteric fermentation, and methane and nitrous oxide (N_2O) from manure storage and application. Besides this, dairy production also drives additional emissions from feed production, processing, transport, and land use change. Increasing milk yield per cow is considered a promising strategy for reducing emissions per unit of milk or meat output (i.e. 'emissions intensity') even though absolute emissions per animal may increase. Previous research showed that milk yield per cow explained 57% of the variance in GHG emission intensity among dairy farms in Lembang Sub-District (de Vries et al., 2019). The latter study also showed that potential mitigation options beyond milk yield increase include changes to the dairy cow feed ration and manure management on dairy farms.

1.1 Objective

A next step in identifying locally suitable GHG mitigation options is to evaluate effects of feeding and manure management interventions in practice. To this end, several interventions were tested on 18 practical dairy farms in Lembang Sub-District in West Java, Indonesia.

Objectives of this pilot study were:
1. to evaluate effects of feeding and manure management interventions on technical, economic, and environmental performance of dairy farms, and;
2. to evaluate likeliness of adoption of these interventions.

2 Materials and methods

2.1 Scope of the study

A pilot study[1] was carried out between February 2018 and December 2019 on 18 small-scale dairy farms in Lembang District, West Java. The 18 pilot farms were delivering milk to the largest dairy cooperative of West Java: KPSBU Lembang. The pilot farms were selected in January-February 2018 by project staff members in collaboration with the dairy cooperative KPSBU, based on the following criteria:

- Dairy farm with lactating cows and delivering milk to the dairy cooperative KPSBU;
- At least one pilot farm per milk collection center in Lembang Sub-District;
- Farmer is already managing (i.e. not discharging) at least part of the manure[2];
- Farmer is motivated to (further) improve feeding and manure management on his/her farm;
- Farmer is able to invest in facilities to improve feeding and manure management.

In the first year of the pilot study (2018), 3 dairy farmers stopped participating. These farms were replaced by 3 new pilot farms. In the second year (2019), 1 dairy farmer stopped participating, leaving 17 farms in the pilot study.

2.2 Interventions evaluated in the pilot study

Various interventions for improving feeding and manure management were evaluated on the pilot farms. These interventions had been identified in farmer and stakeholder workshops in previous years (2016 and 2017) and were expected to contribute to reduction of greenhouse gas (GHG) emissions contributing to climate change (De Vries et al., 2017).

In the pilot study, farmers were free to choose feeding and manure interventions for their farm. Improved feed and water troughs, minerals, and higher quality concentrates were implemented by all farmers, while fewer farmers started to use new fodder species, introduced ration balancing, and improved manure management on their farm. Trainings and demonstrations were given about fodder conservation, but this was not implemented by any of the farmers (more details about adoption of interventions can be found in paragraph 3.3).

2.2.1 Feeding interventions

Feeding interventions evaluated in the pilot study were:

- Improving water supply by installing an improved feed and water trough;
- Mineral supplementation;
- High quality compound concentrate feed;
- Balanced rations;
- Improving fodder supply by:
  - Growing new fodder species;
  - Fodder conservation.

[1] A pilot study is a small scale preliminary study conducted in order to evaluate feasibility of the key steps in a future, full-scale project.
[2] A few pilot farms were selected that were not managing manure (i.e. discharging manure).

Improved feed and water trough

Water supply of cows is insufficient on many farms in Lembang Sub-District (De Vries and Wouters, 2017). Water is often provided irregularly by bucket or containers placed next to the cow. Continuous access to water is a pre-condition to make sure that other feed interventions will have a maximum effect. Also feed leftovers should be removed regularly and the feed trough should be cleaned. Therefore, on the pilot farms an improved feed and water trough was installed for a maximum of 6 cows in the period July till September 2018, consisting of an elevated water tank with communicating drinking bowls for every 2 cows. The improved feed and water trough allows ad libitum access to water and easy removal of feed leftovers and cleaning of the feed trough. Fifty percent of the installation costs (about IDR 1.5 million per cow) was financed by the project, and 50% by the farmers.

Mineral supplementation

An adequate mineral supply is important for milk production but particularly for a good reproductive performance. The direct effect of a good mineral supply can be observed among others by the appearance of the hair coat. A rough, faded coat indicates mineral deficiency, undernutrition, or poor health. In the concentrate produced by KPSBU in Lembang no mineral/vitamin premix is added but farmers are advised to buy and add by themselves a mineral/vitamin mixture to the ration. Often mixtures bought by farmers are of unknown composition or farmers do not add any mineral/vitamin mixture to the ration. TrouwNutrition Indonesia, one of the partners in the project, produces a mineral/vitamin premix *Max All Rum Dai 1.5% DS* (abbreviated as 'Maxcare' in this report) for ruminants.

Between October 2018 and February 2019 the mineral/vitamin premix Maxcare was fed to cows in the sample on 18 pilot farms. About 145-150 g of premix was added per day to the concentrate feed of each cow. The mineral premix Maxcare was given for free to the pilot farmers and farmers were trained in the importance, effects and use of minerals in general, and how to use and add the premix to the feed ration during the trial.

High quality compound concentrate feed

Most dairy coops in Indonesia produce compound concentrate feed for their members and sell it on short term credit to their members. Most dairy coops including KPSBU offer only one type of compound concentrate feed to their members. This type of concentrate is in general of average to poor quality as prices of the feed are kept relatively low to accommodate farmers' wishes to keep the prices low for long time without price fluctuations caused by the varying cost price of raw materials. The standard concentrate feed produced by KPSBU was composed of some raw materials with varying nutrient content and rather low protein content (14-16% CP per kg) and no addition of a mineral/vitamin premix. The standard concentrate was composed of the following raw materials: wheat pollard (43%), palm oil meal (18%), corn gluten feed (17%), salt (8%), dregs of soy sauce (5%), $CaCO_3$ (3%), rice bran (3%), corn bran (2%), and soy bean meal (2%).The project decided to demonstrate and test the effect of feeding a higher quality compound concentrate feed composed of raw materials with a stable nutrient content, a protein content of about 20% CP per kg and the addition of a mineral/vitamin pre-mix of well-known composition (Maxcare mineral/vitamin pre-mix produced by Trouw Nutrition Indonesia). The high quality concentrate was composed of the following ingredients: corn gluten feed (88.5%), wheat pollard (6.7%), soy bean meal (3.3%), premix Maxcare (1.5%). The high quality concentrate feed was produced at the feed plant of KPSBU under supervision of the project and Trouw Nutrition Indonesia. For a period of 3 months (September-December 2019) the pilot farmers were supplied with the high quality concentrate at the same price as the standard concentrate. Milk production and feed rations fed before and after the introduction of the concentrate feed were recorded by the farmers. In the month after the introduction of the high quality concentrate no other feeding advice was given so that the possible immediate effect of the high quality concentrate on milk production could be established. Later on in October 2019 a new feed advice taking into account the feeding value of the high quality concentrate was provided to the farmers.

Balancing rations
On many farms the feeding situation (ration, feeding practices) is limiting milk production. Often the ration is not meeting the cow's requirements in terms of fodder, energy, protein and minerals/vitamins; in other words, the feed ration is not balanced. In general 'flat feeding' is applied which means that differences in requirements of individual cows because of milk yield, lactation stage and body condition are not taken into account on most farms. Flat feeding of concentrate feeds can lead to over- and under-feeding of individual cows and will result in a less efficient feed nutrient utilization. Furthermore poor feeding practices such as feeding too little fodder in relation to concentrates and wet by-products also leads to unbalanced rations. Dividing total daily amounts of concentrates into smaller meals per day by increasing the frequency of feeding is another point of attention. This will reduce the risk of ruminal acidosis and improve the cow's health in general.
In this study balancing rations was aimed at feeding lactating and dry cows according to requirements of fodder (at least minimum requirement of fodder on dry matter (DM) basis compared to concentrates and wet by-products), energy, and protein requirements, based on milk yield, lactation stage and taking into account body condition. Only a predefined sample of cows with access to an improved feed and water trough was included in the pilot (cows selected for 'longitudinal data collection').
In 2019 advice was given four times to the 17 pilot farmers to optimize the feed rations, taking into account availability and accessibility of feed resources. Before the advice was given the milk production, lactation stage, body weight, and BCS of individual cows, and actual feed ration were recorded. Amounts of feed were weighed by the farmers and dry matter contents and nutrient contents were estimated based on a limited number of analyses and expert's best guess (see De Vries et al., 2019). Based on this information an advice was provided to balance the ration regarding energy and protein requirements of the individual cows based on NRC standards (NRC, 1978) which are still in use as standard in Indonesia. In addition the balance between roughage and concentrate feed was taken into account, requiring at least 40% on DM basis of the ration should consist of roughage (fodder).

Growing improved fodder species
On most of the dairy farms fodder consists of home grown Napier or King grass, road side grass, vegetable waste, banana stems, and rice straw. The feeding value is not optimal due to the low quality of the fodder (rice straw) or the sub-optimal stage of cutting (Napier/King grass). A limited number of seedlings of fodder species with better feeding value, i.e. fodder grasses Mulato II grass, Dwarf Napier grass, and the legume Indigofera, were distributed among pilot farmers during a training on improvement of fodder supply.

Fodder conservation
Fodder conservation by means of silage making of grass or maize was identified as an option to improve fodder supply and quality during the dry season when much low quality rice straw is fed. Silage making was demonstrated to the pilot farms on 3 occasions (2 times ensiling of maize, 1 time ensiling of grass), in which grass or maize was stored in blue drums (about 80 kg per drum) and big bags (about 500- 600 kg per bag). In general ensiling of chopped whole crop maize (this includes the cob with grain) will result in a product with relatively high feeding value compared to tropical grass silage. The supply of maize in Lembang is depending on traders who sell at a minimum amount while prices are high due to handling and transport costs. In addition proper ensiling requires an investment in a chopper, drums and big bags including a plastic liner. For ensiling grass also molasses is required to get good silage.

2.2.2 Manure management interventions

In Lembang Sub-District most dairy farms discharge at least part of the cattle manure to the environment (De Vries and Wouters, 2017). Discharging of cattle manure can cause local nuisance and pollution of ground and surface waters, potentially leading to eutrophication of aquatic ecosystems and contamination of drinking water sources (e.g. Budisatria et al., 2007). Livestock manure disposal is currently actively discouraged in West Java because of ambitions of the Indonesian Government to clean the Citarum River. Effects of discharging manure on GHG emissions are highly uncertain (De Vries et al., 2019), and are likely to vary considerably depending on the location, weather conditions,

and the fate of the discharged manure. Not only the direct discharging of manure but also overfertilization of crops may lead to leaching and runoff of nutrients and gaseous N emissions (mainly NH_3 and N_2O). Manure application rates on fodder crops close to the cow barn are often extremely high because land size is small (De Vries and Wouters, 2017). Often part of the land for fodder production is located far away from the cow. To avoid overfertilization, part of the manure should be sold or given away to other sectors (e.g. vegetable farms). This requires other manure management practices to produce a product that is stackable and easy to handle and transport.
In this study most of the pilot farms already managed manure to a certain extend because this was one of the selection criteria (paragraph 2.1). During the pilot study, part of the farmers constructed manure storages on their farms for composting or vermi-composting[3], enabling them to sell the compost or to apply the compost on their own land for food crop production. Fifty percent of the construction costs was financed by the project, and 50% by the farmers.

2.3 Data collection

A baseline survey was conducted at the start (Feb 2018), and an endline survey at the end of the pilot study (Jan 2020). During the pilot study, effects of feeding the mineral/vitamin premix Maxcare were measured by means of haircoat scoring and a survey (Oct 2018-Feb 2019). In addition, two surveys about manure management (Feb 2019, Sept/Oct 2019) and two surveys about adoption of feeding and manure interventions were conducted (Oct 2019, Nov 2019). Longitudinal data was collected at the cow level during one year from a sample of 2-6 cows per farm (Jan-Dec 2019).

2.3.1 Baseline and endline survey

The baseline survey and endline survey were identical surveys conducted on the pilot farms in February 2018 and January 2020, respectively, to collect data on farming practices, herd performance, land use, feeding and manure management, economics and labor. Besides an interview, milk yield and weight of feed ingredients were measured during a 1-day farm visit. The survey was developed in a PhD research on the same topic in the same area (Al Zahra and Apdini et al., in preparation), and implemented by enumerators of the University of Padjajaran (UNPAD) in Bandung.

2.3.2 Haircoat scoring

Effects of feeding the mineral/vitamin premix Maxcare were measured by scoring the hair coat of each cow before, at the middle, and after the trial. The scoring was done every time by the same person (staff member in the project). Haircoat scoring consisted of a score on a scale of 1-3: score 1 reflecting poor condition (hair coat is dull, rusty/ reddish color of the black spots); score 2 reflecting moderate condition (hair coat is fairly clean (not reddish, but not shiny)) and score 3 reflecting good condition (hair coat very clean and shiny). In addition farmers’ opinions about the effects of the mineral supplementation were collected after the trial.

2.3.3 Manure management survey

A questionnaire with more detailed questions about manure management was developed by Wageningen Livestock Research, and implemented on the pilot farms by 2 local enumerators (employees in the project) in February 2019 and September-October 2019. In the first survey farmers were asked about their manure management before the pilot project started, while in the second survey farmers were asked about the new situation and implemented changes.

[3] Composting is the thermophilic process of microbial degradation, stabilization, and sanitization of organic wastes under aerobic and/or anaerobic conditions, whereas the vermi-composting process involves mesophilic bio-oxidation and sanitization of organic wastes under aerobic conditions by earthworms (Swati and Hait, 2018).

2.3.4 Longitudinal data collection

On each pilot farm, a sample of 2-6 cows was used for testing feeding interventions, and monitored intensively. The sample size was based on the number of cows that had access to the improved feed and water trough. In some farms all the cows participated, while in the larger farms only part of the herd was included. The cows in the sample could change during the year due to culling, purchasing or entering of new cow (calving of pregnant heifer). Data collected from each cow in the sample included: daily milk yield (kg/day), amounts of feed fed (kg/day), heart girth (cm), body condition score, hair coat score, and feed costs per feed ingredient (IDR/kg). Milk yield and feed records were collected on a daily basis by farmers. Other data were collected every two months by a local staff member of the project.

2.3.5 Adoption survey and focus group discussion

Surveys were conducted about adoption of feeding and manure interventions among the 17 pilot farmers (November 2019) and stakeholders (October 2019; representatives of dairy cooperative KPSBU, Frisian Flag Indonesia, IPB agricultural university, Trouw Nutrition Indonesia, CCAFS-SIDPI project staff). In addition, a focus group discussion (FDG) was conducted with pilot farmers in December 2019 to deepen our understanding of drivers and barriers to adoption of interventions.

2.4 Data analysis

Effects of interventions were evaluated with regard to milk production (improved concentrate feed), hair coat score (mineral supplementation), economic costs and revenues, and GHG emissions (improved concentrate feed, balanced rations, and improved manure management). Effects of interventions on milk production could be evaluated for improved concentrates only because for other interventions no effects on milk production were expected (manure management) or effects could not be evaluated in a scientifically sound way (ration balancing, mineral supplementation). Effects of introducing the improved feed and water trough, growing new fodder species, and fodder conservation were not quantitatively evaluated, but only qualitatively by means of the adoption survey and the focus group discussion.

2.4.1 Milk production

A Paired-Samples T test (2-tailed) was conducted to compare milk yield per cow in the 2 weeks before and 2 weeks after the introduction of the improved concentrate (with 1 week of habituation in between). Fourty-nine lactating cows were fed improved concentrates on pilot farms, but only 31 cows were included in the final analysis. For the other 18 cows, data was missing or seemed unreliable (5 cows), or the stage of lactation could influence milk yield (5 dry cows, i.e. cows that dried off between 4 weeks before and 8 weeks after introducing improved concentrates; and 8 cows in early lactation, i.e. cows less than 10 weeks in milk at the time of introducing the improved concentrate feed). Milk yield strongly increases during early lactation, and decreases/ends when cows are dried-off. The 31 cows included in the analysis were housed in 12 of the 17 pilot farms.

2.4.2 Cost-benefit analysis

The increase in costs of compound concentrate feed due to introduction of the high quality concentrate was compared to the increase in returns from milk sales (both in IDR per cow/d). On average the 31 lactating cows in the sample received 7.3 kg concentrate/cow per day. Farmers did not change the amounts of concentrate they used in the weeks before and after the introduction of high quality concentrate. The price of high quality concentrate was 600 IDR/kg higher than the standard concentrate due to use of more expensive ingredients. The milk price was 5300 IDR per kg milk.

For balanced rations, the average feed costs per cow of the actual feed ration fed in January 2019 was compared to the average feed costs per cow based on the expert's feeding advice (n=18 farms, 69 cows including dry cows). Actual feed rations were based on an inventory per cow before the advice was formulated. Prices of different feedstuffs were day prices (average prices as stated by the farmers at the moment of the inventory) and for purchased green fodder a price of 300 IDR per kg was used. The actual ration was compared to the feeding advice rather than the changes observed in practice, because in practice farmers often did not follow-up on the advice. For the same reason, changes in milk yield could not be evaluated.

Costs of manure management and revenues from sold cattle manure were compared for the situation before and after the pilot study. Data were based on the manure management surveys that were conducted on the pilot farms. Costs of manure management included fixed costs (storage facility, PVC pipes, small equipment) and operating costs (composting inputs, packaging materials, labour, fuel, land rent). Revenues included manure sold (fresh feces, compost, or vermi-compost) and worms sold. As labour often concerned family labour, the cost-benefit analysis was conducted in two ways: i) including fixed costs and operating costs, ii) including cash expenses only (i.e. composting inputs and packaging materials).

2.4.3 Life Cycle Assessment

A life cycle assessment (LCA) was carried out to estimate GHG emissions of milk produced on each of the 17 dairy farms (CO_2, CH_4, and N_2O emissions). All processes up to the dairy farm gate (i.e., cradle-to-farm gate) were included in the LCA. This included production of farm inputs and on-farm production activities, but excluded transport and processing of the milk. Only the sample of cows monitored in the pilot survey during 1 year (January-December 2019) were included in the LCA, therefore the herd size evaluated in the LCA was smaller than the true herd size in 8 farms. Since we focused on emissions related to milk production, system boundaries included young stock kept for replacement of dairy cows, but excluded surplus calves and cows kept for fattening purposes. One pilot farm was excluded from the LCA because emissions from manure management and fertilizer application could not be properly estimated (farm participated in collective manure management, i.e. with a group of farmers), leaving 16 farms in the final analysis. GHG emissions related to land use and land use change (LULUC) were not included in the LCA.

For each farm, GHG emissions were quantified using the Global Livestock Environmental Assessment Model (GLEAM; MacLeod et al., 2017). In GLEAM, GHG emissions are calculated based on IPCC Guidelines (IPCC, 2019), based on an attributional approach and using Tier 2 methods where data permit. The GLEAM model consists of five modules: i) the herd module characterizing herd structure, dynamics, and production, ii) the manure module specifying the proportion of manure in each manure management system, iii) the feed module specifying the total herd feed ration and CO_2, CH_4, and N_2O emissions arising during feed production, processing and transport, iv) the system module calculating digestible energy and N content of the ration, nutrient retention in animal products, volatile solids, and emissions arising from enteric fermentation (CH_4), manure management (CH_4 and N_2O), energy use in housing (CO_2), and the production, processing, and transport of feed (CO_2, CH_4, and N_2O) using Tier 2 approaches (IPCC, 2014, updated 2019), and v) the allocation module allocating GHG emissions to milk and live weight using biophysical relationship allocation (Thoma et al., 2013). Salient features of the GLEAM model are described in MacLeod et al. (2017) and De Vries et al. (2018).

The system module in GLEAM was adjusted to enable calculation of emissions related to specific MMS that are found in Lembang Sub-District, based on the following assumptions (see overview of assumptions on methane conversion factors, N_2O emission factors, and indirect N loss fractions of MMS in Table 1):

- For manure discharged into the environment, CH_4 and N_2O emission factors of "pasture/range/paddock" were used (IPCC, 2019) with an N leaching fraction of 0.65;
- For vermi-composting, CH_4 emissions, direct N_2O emissions, and indirect N_2O emissions were assumed to be 30%, 24% and 15% lower than in intensive, thermophilic composting (Nigussie et al., 2016);
- For feces stored in sacks, IPCC emission factors of a liquid/slurry storage of 1 month with cover were used;
- For anaerobic digestion, IPCC emission factors of an anaerobic digester with 'high leakage, low quality technology, low quality gastight storage technology' were used (IPCC, 2019);
- For digestate stored or discharged after anaerobic digestion, the CH_4 conversion factor of anaerobic digestion was used for CH_4 emissions, and the N_2O emission factors of storing or discharging manure for N_2O emissions.

Table 1 *Assumed methane conversion factors (MCF; climate zone warm tropical, montane), direct N_2O emission factors, and indirect N loss fractions (volatilization of NH_3 and NO_x, and N leaching) of manure management systems (MMS).*

Manure management system	MCF	Direct N_2O emissions	Indirect N loss NH_3/NO_x	leaching	Source
Daily spread	1	0.00	0.07	0	IPCC, 2019
Solid storage	5	0.01	0.3	0.02	IPCC, 2019
Composting intensive (frequent turning)	1.5	0.005	0.5	0.06	IPCC, 2019
Vermi-composting	1.14	0.0035	0.425	0.051	Nigussie et al., 2016; IPCC 2019
Feces stored in sacks (1 mo)	25	0.005	0.1	0	Expert opinion; IPCC 2019
Discharged manure	0.47	0.006	0.21	0.65	Expert opinion; IPCC 2019
Anaerobic digestion, digestate stored or discharged	10.85	---------------See MMS above------------			IPCC 2019

Data Inventory

Primary, farm-specific data was used for the following input parameters: number of mature cows, heart girth measurements (for estimation of live weights), milk yield per cow, amounts of feed supplied, fractions of animal excreta per manure management system, and amounts of manure and synthetic fertilizer applied on homegrown forage.

Herd size was based on the sample of mature cows monitored in the longitudinal data collection from January to December 2019, with numbers of young stock estimated based on rate parameters of reproduction, growth, and mortality (based on expert opinion or literature; De Vries et al., 2019). Annual milk production per cow was derived from the daily milk yield records. Live weights of cows were estimated based on heart girth measurements, using the following equation (Yan et al., 2009):

$$LW = 6.373 * HG - 662.6$$

, where LW = live weight (kg) and HG = heart girth (cm).

Amounts and types of fodder, by-products and concentrate feed per cow were based on the daily data collected in the longitudinal data collection, whereas feed rations of young stock were based on data collected in the baseline and endline survey. The composition of compound concentrate feed and information about production locations were derived from the local dairy cooperative KPSBU. Two types of compound concentrate feed were evaluated: the standard type used in KPSBU (wheat pollard (43%), palm oil meal (18%), corn gluten feed (17%), salt (8%), dregs of soy sauce (5%), CaCO3 (3%), rice bran (3%), corn bran (2%), soy bean meal (2%)) and improved quality concentrate formulated in this pilot study (corn gluten feed (88.5%), wheat pollard (6.7%), soy bean meal (3.3%), premix Maxcare (1.5%)).

The fraction of animal excreta per manure management system (MMS) was based on farmers' estimates in the manure management surveys. MMS included daily spread, solid storage, composting, vermi-composting, liquid storage, anaerobic digestion, exit livestock (manure sold or given away), and discharged manure (a description of these MMS can be found in IPCC, 2019). In case of manure discharging, farmers flushed feces and urine from the cow barn, which were either washed away directly to ground- and surface waters or lied deposited next to the barn, depending on the location and weather conditions (e.g., dry vs. rainy season).

Farm-specific nitrogen (N) application rates on homegrown forage were calculated based on Tier 2 estimates of N excretion rates in feces and urine, the share of feces and urine applied on land, areas of agricultural land, and N losses (assuming 7%, 28% and 32% N loss for daily spread, digestate and solid storage of feces, respectively, and 14% N loss for daily spread of urine; IPCC, 2019). The amount of synthetic fertilizer (exclusively urea) applied on forage was based on farmer estimates (manure management surveys).

Where primary data were not collected or biased, secondary data (i.e. readily available data) were used from existing databases, expert opinion, or the literature: fat and protein contents of milk (local dairy cooperative KPSBU), reproduction parameters (Anggraeni and Rowlinson, 2005; Opio et al., 2013), nutritional values of feed ingredients (de Vries et al., 2019), crop yields (Badan Pusat Statistik, FAOSTAT), fertilizer and pesticide use, data for field work emissions, energy use of road transport, allocation of processed crops (Opio et al., 2013; EcoInvent (using Simapro); FeedPrint (Vellinga et al., 2012)), market prices (KPSBU), and assumptions on rice cultivation (pers. comm. Huib Hengsdijk, November 2017). Data sources are described in more detail in De Vries et al. (2019).

Evaluating effects of interventions using LCA
LCA evaluates GHG emissions on an annual basis. Therefore, effects of interventions found in the different trials (as measured shortly before and after the intervention) were extrapolated to simulate potential changes in GHG emissions on an annual basis.
For high quality compound concentrate feed:
- The average increase in milk yield due to introduction of the improved concentrates (0.7 L/cow/d, see Results section) was extrapolated to an annual basis, corrected for dry period, i.e. an annual milk yield increase of 204 L/cow/y;
- For the reference situation, milk production levels recorded on pilot farms were corrected for the milk yield increase (possibly) caused by introduction of the improved concentrates on farms. In other words, reference milk yields were reduced for the period September-December 2019, assuming the same reduction in milk yield for each farm (67.9 L/cow/y);
- LCA was used to estimate carbon footprints of the standard type of concentrate feed used by KPSBU and the improved concentrate feed.

For balanced rations:
- The advised feed ration of lactating cows was the average of 4 times feeding advice by a feed expert in 2019 (January, July, September and November 2019);
- The reference feed ration of lactating cows was average of all feed records collected daily in the longitudinal data collection in 2019;
- The advised ration and reference ration were compared in terms of GHG emissions per farm/year. Equal milk yields were assumed in both scenarios because effects of ration balancing on milk yield were be evaluated in this study.

For improved manure management:
- Manure management practices and N application rates before and after the pilot project were compared in terms of GHG emissions, assuming other farm characteristics remained the same.

3 Results

3.1 General description of farms in the pilot study

3.1.1 Farm characteristics

Characteristics of the 14 dairy farms that continuously participated[4] in the pilot study are shown in Table 2. At the start of the pilot study in February 2018, these farms kept 5.6 cows on average, and lactating cows produced 16.0 kg milk/cow on the test-day. On average farms used 0.6 ha of land for growing fodder, most of which was rented land. Feed rations of lactating cows mainly consisted of home grown grass, cassava waste, tofu waste, rice straw, and compound concentrate feed.

At the end of the study in January 2020 farmers kept more calves and bulls on average, rented less land (decreased in 6 farms), and fed less home grown grass, more road side grass, more rice straw, and less cassava waste, compared to February 2018. The likely reason that farmers fed more road side grass and rice straw was a lower availability of home grown grass (seasonal effect). The reduction in cassava waste likely resulted from the balanced rations advice (intervention in this study). Premix was not fed separately at the end of the study, but was included in the compound concentrate feed. The average number of cows and average milk production level were slightly lower at the end of the study, compared to the baseline situation.

Table 2 *Characteristics of 14 pilot farms at the start ('baseline'; February 2018) and at the end ('endline'; January 2020) of the pilot study.*

	Baseline		Endline	
	Average (SD)[1]	Min-max[1]	Average (SD)[1]	Min-max[1]
Herd size (heads)				
Mature cows	5.6	3-14	5.3	2-13
- lactating	4.7	2-12	4.6	1-13
- dry	0.9	0-3	0.7	0-2
Heifers	0.9	0-2	1.0	0-5
Calves	1.1	0-4	2.4	0-7
Bulls (>1y)	0.1	0-1	0.4	0-2
Average milk production (kg/lactating cow/d)	16.0	10.5-19.5	15.7	9-25
Average lactation number (n)	3.9	2.1-8.3	3.8	2-7
Land used for growing fodder (ha)				
Owned	0.2	0-1.2	0.2	0-1.2
Rented	0.4	0-2.0	0.3	0-2.0
Feed ration lactating cows (kg fresh/cow/d)				
Home grown grass	31.8	6.7-74.5	26.6	10-54
Road side grass	1.3	0-11.3	3.0	0-15
Legumes	1.6	0-11.4	0.0	0
Rice straw	6.7	0-21.3	8.1	0-20
Other fodder	0.5	0-6.5	0.0	0
Cassava waste	12.3	0-28.0	6.0	0-21
Tofu waste	9.7	0-29.1	10.8	0-27
Beer waste	1.0	0-6.9	0.0	0
Compound concentrate feed				
- high quality[2]	5.7	0-9.5	3.4	0-6
- low quality[2]	1.2	0-9.8	3.4	0-10
Premix fed as separate supplement	1.6	0-12.9	0	0

[1] Between farms (not between cows)

[2] In 2018 two types of concentrates were available at the dairy cooperative KPSBU Lembang (high and low quality). In 2019 only type of concentrates was available. The 'high quality' in the endline refers to the improved concentrate developed in this pilot study, with premix included.

[4] During the pilot period (February 2018 until December 2019), 4 of the 18 dairy farms selected for pilot project dropped from participation and 3 dairy farms joined the project.

3.1.2 Characteristics of cows in study sample

In total 74 mature cows were included in the sample in the 12-month longitudinal data collection (January-December 2019). The sample size fluctuated over the year and varied between farms. In the start of the year there were more cows in the sample than at the end of the year (on average 3.9 vs 3.3 mature cows per farm). On average over the 12 months, 3.5 cows per farm were present in the sample (Table 3).

Table 3 *Characteristics of cows (dry and lactating) in study sample on pilot farms.*

	Average (SD)	Range (min-max)
Sample size (N cows per farm)	3.5 (1.5)	1-7
Average milk production (kg/cow/year)[1]	5120 (1510)	724-8110
Average lactation number (N)	3.7 (2.4)	0-12
Feed ration (kg fresh/cow/d)		
Home grown grass	21.7 (14.4)	
Road side grass	3.8 (7.2)	
Rice straw	10.6 (6.2)	
Cassava waste	4.0 (4.8)	
Tofu waste	15.0 (10.6)	
Banana waste	1.5 (2.7)	
Vegetable waste	2.1 (4.1)	
Concentrates	6.7 (1.4)	

[1] Milk yield of cows present at the farm during the whole monitoring period (365 days).

Average annual milk production (including the dry period) of the 49 cows that were present during the whole monitoring period was 5120 kg milk per cow/year, ranging from 724 to 8110 kg milk among cows (Table 3). Average milk production varied slightly over the year with production levels being highest in the months January-March (Figure 1), which is the period with the highest availability of green fodder.

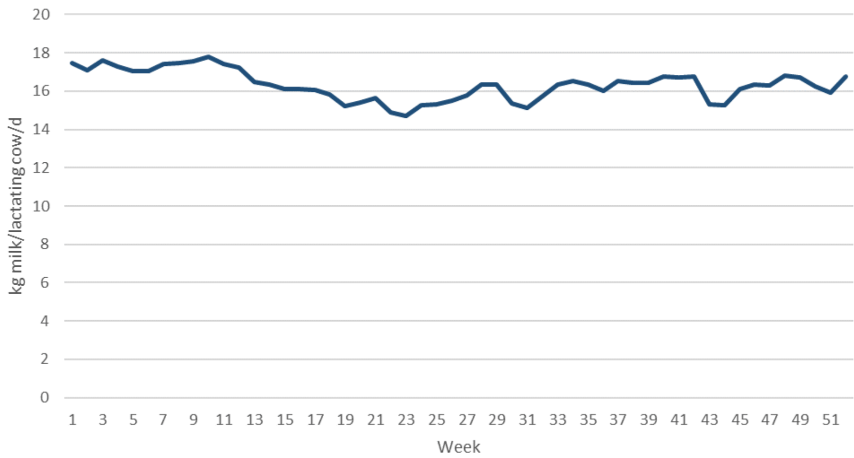

Figure 1 *Average milk production per lactating cow/day in the sample between January and December 2019.*

Feed rations mainly consisted of home grown grass, tofu waste, rice straw, and concentrates (Table 3). The amount of home grown grass strongly decreased from July onwards, and was replaced by rice straw during the dry season.

3.2 Effects of interventions

3.2.1 Mineral supplementation

Results show that the hair coat condition was very poor at the start of the trial on most farms (Figure 2). A number of farmers was supplementing with a mineral mixture with not well known composition.

Given the poor hair coat score at the start this supplementation seemed to have little effect on the hair coat of the cows. After the introduction of the mineral/vitamin pre-mix "Maxcare" the hair coat condition improved significantly (Figure 2). On all farms the average hair coat score of the cows improved with 1-2 points. For a large part the improvement in hair coat score can likely be attributed to the mineral/vitamin pre-mix. However, feeding conditions in terms of better supply of green fodder improved also during the trial period due to the change from dry to wet season. The effect of mineral supplementation on other aspects (e.g. cow fertility) could not be assessed in a quantitative way due to the short trial period.

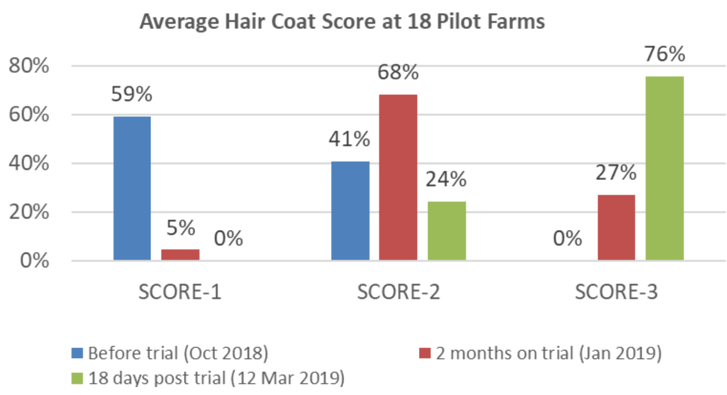

Figure 2 *Average haircoat score of sample cows on the pilot farms before, during and after supplementation with the mineral/vitamin premix "Maxcare".*

3.2.2 High quality compound concentrate feed

Effects of feeding high quality compound concentrates with the premix "Maxcare" instead of the conventional type of concentrates was evaluated for a sample of 31 cows in mid lactation. Average milk yield was 0.7 kg per cow/d (SD = 1.6) higher in the 2 weeks after introduction of the high quality concentrate than before this event (15.6 vs 16.3 kg milk/cow/d; t = -2.37, P = 0.025). The variation between cows was large, however, as shown in Figure 3 and by the large 95% confidence interval (CI) around the mean increase of 0.7 kg milk: 0.09 to 1.26 kg milk/cow/d. Milk yield decreased in 9 cows, and increased in 22 cows (Figure 3). At the farm level, average milk yield per farm increased on 8 farms, and decreased on 4 farms.

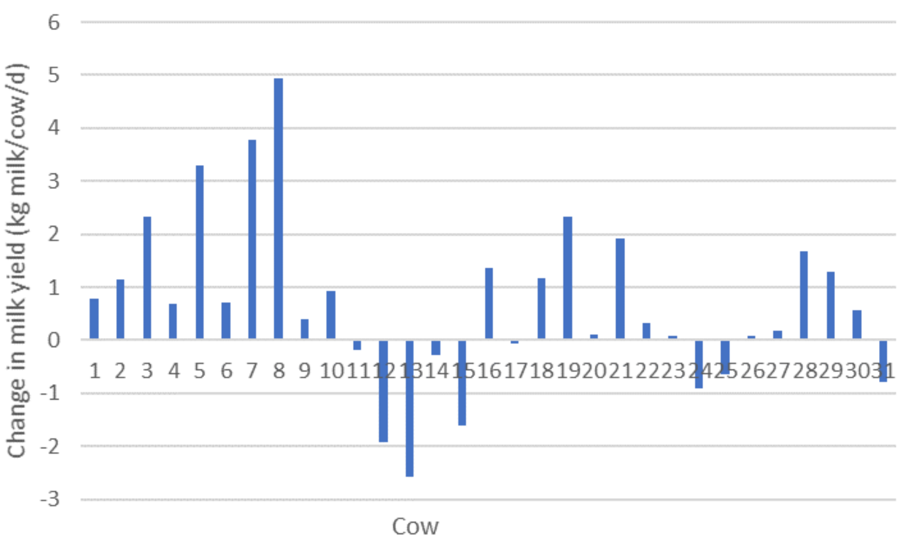

Figure 3 *Change in milk yield per cow (kg/cow/day) after introducing the higher quality compound concentrate feed.*

Costs and benefits
On average the 31 lactating cows in the sample received 7.3 kg concentrate/cow/day. Farmers did not change the amount of concentrate used in the weeks before and after the introduction of high quality concentrate. The price of the high quality concentrate was 600 IDR/kg higher than the standard concentrate due to use of more expensive ingredients. This amounted to an increase in costs of 4347 IDR per cow per day. The average increase in milk production of 0.7 kg milk/cow/d in combination with a milk price of 5300 IDR per kg milk yielded extra revenues from milk of 3598 IDR per cow/d. These results suggest that the use of the improved quality concentrate is not directly profitable for an average dairy farm. With the given prices of milk and concentrates, an increase in milk production of at least 0.8 kg milk/cow/d would be required to break even. The use of the high quality concentrate was profitable on some of the pilot farms that realized an increase larger than the breakeven value of 0.8 kg milk.

Greenhouse gas emissions
Replacing the standard concentrate feed by the high quality concentrate feed increased GHG emissions per kg milk (i.e. GHG emission intensity) by 9% on average (Figure 4). The increase was due to: i) higher emissions from feed production, and ii) higher emissions from manure. The main ingredient of the new concentrate, corn gluten feed, carried relatively high CO_2 emissions from processing. Corn gluten feed (CGF) is a by-product of the wet-milling of maize grain for starch production. The drying of CGF is very energy consuming, which leads to a relatively high CO_2 footprint per kg feed (1.5 kg CO_2-e/kg DM). Emissions from manure were high due to increased N excretion in feces and urine, which was caused by a higher crude protein content of the high quality concentrate feed. The increase in milk production reduced GHG emission intensity, but this did not compensate for the increased emissions from feed production and manure application.

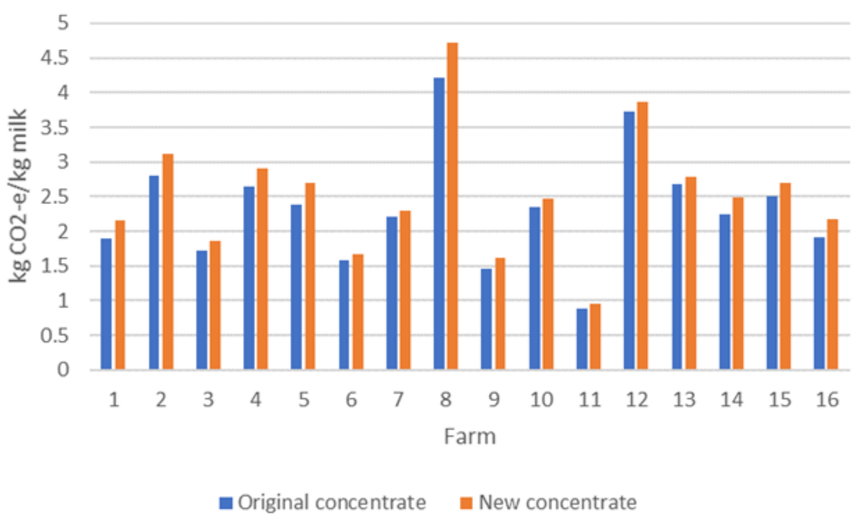

Figure 4 *Average GHG emission intensity (kg CO_2-e/kg milk) of pilot farms feeding the standard compound concentrate feed and the new, high quality compound concentrate feed.*

Figure 4 shows a relatively high GHG emission intensity for Farm 8, and a relatively low emission intensity for Farm 11. Emissions in Farm 8 were high due to a very high manure application rate on this farm (5751 kg N/ha/y). Farm 11 was owned by a farmer with 1 cow with a relatively high milk production (6500 kg milk/y). Since she did not have land for fodder production, all manure (and emissions) was used in horticulture, and the feed ration mainly consisted of feed ingredients with a relatively low carbon footprint: roadside grass, tofu waste, and vegetable waste.

3.2.3 Balanced rations

The number of farms that followed up on the advice to adjust the amount of compound concentrate feed to the milk production level of cows increased over time (Figure 5). After the first advice in January 2019, 3 farmers slightly differentiated between lactating cows in the amount of compound concentrate and wet by-products fed, and 12 farmers did not differentiate between cows. In

November 2019, after having received 4 times advice, 9 farmers differentiated in the amounts of compound concentrates fed to the cows, however some still did not fully follow the advice and made only small differences in the amounts of concentrate fed to their cows. Already before the pilot most farmers differentiated in the amount of concentrate fed to dry cows and lactating cows, with dry cows being fed about 40-60% of the amount fed to lactating cows. Based on the advice the amount of concentrates fed to dry cows was reduced further.

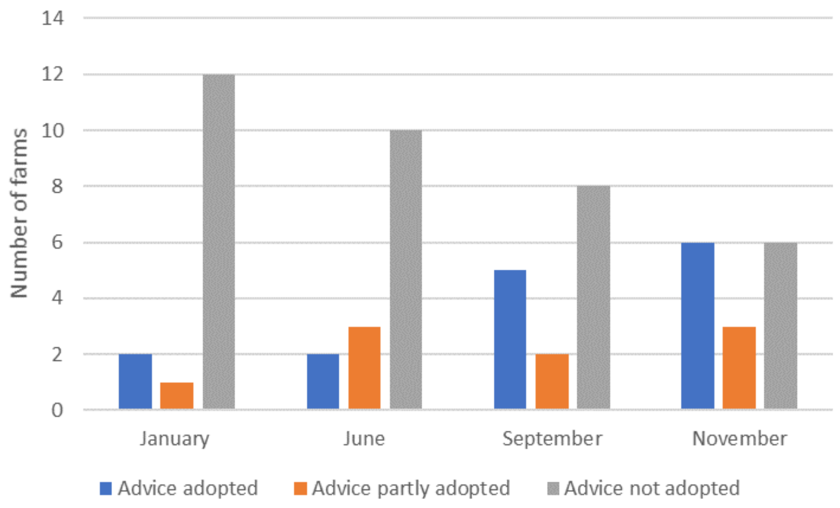

Figure 5 *Number of farms that followed up on the advice to adjust the amount of concentrate fed to milk production levels of lactating cows ('partly adopted' means farmers only slightly differentiated in the amount of concentrate per cow; about 1 kg or less).*

Table 4 shows the average ration offered to the cows based on daily recording and the difference with the rations that were advised 4 times (January, June, September and November 2019) for the cows on the 17 pilot farms. The total amount of dry matter offered to the cows was estimated at 17.5 kg dry matter (DM) per cow per day for the average actual ration and 18 kg DM for the advised ration. These amounts seemed adequate for a cow with an average body weight of 450-500 kg and a milk production of 4000-5000 kg milk/y, although DM intake (rather than supply) could not be assessed as feed residues were not monitored. DM intake was expected to be much lower, particularly due to large amounts of residues of rice straw (dry season) and unpalatable stems of king grass (rainy season). While DM supply seemed adequate, cows seemed underfed in terms of energy and protein because of the low quality of the feed ration, particularly in the dry season because of the high amount of rice straw fed.

Table 4 *Actual and advised feed ration per cow (kg fresh per day, lactating and dry cows) based on farmers recording (actual ration) and average of 4 advices (advised ration) in 2019.*

Feed	Actual feed ration (kg/cow/day)		Advised feed ration (kg/cow/day)	Difference (advised-actual; kg/cow/day)
	Average	Min-max	Average	Average
Green fodder (home grown grass and road side grass)	26.65	1.29 - 75.33	27.55	+0.90
Rice straw	10.07	0 - 29.89	11.57	+1.50
Vegetable waste	3.05	0 - 8.05	2.26	-0.79
Banana stems/leaves	1.45	0 - 14.53	1.62	+0.17
Tofu waste	13.71	0 - 26.65	13.02	-0.69
Cassava waste	4.70	0 - 18.50	1.85	-2.85
Beer waste	0	0 - 0.16	0.16	+0.16
Compound concentrate	6.71	4.62 - 8.90	6.85	+0.14

Feed costs
The comparison between feed costs of the advised feed ration and the actual feed ration in January 2019 showed that the advised feed ration could result in slightly lower cash expenses per cow/day and lower cash expenses per kg milk[5] (Table 5). The reduction in cash expenses was mainly due to feeding lower amounts of cassava waste. If additional grass is not freely available and therefore purchased, however, total feed costs would slightly increase (Table 5).

Table 5 *Average feed costs per cow (n=18 farms, 69 cows including dry cows) of the feed rations as applied by farmers and the advised rations in January 2019.*

	Actual feed ration (average (SD))	Advised feed ration (average (SD))
Average milk production (kg/cow, incl. dry cows)	15.6	15.6
% fodder in the ration on dry mater basis (based on estimated dry matter contents)	40.8 (9.1)	45.4 (8.9)
Average amount of concentrate per cow (kg/day)	9.22 (2.09)	9.64 (1.94)
Average amount of concentrate per kg milk (kg/day)	0.58 (0.20)	0.60 (0.13)
Average feed costs per cow (IDR/day), assuming no extra costs of grass (cash expenses only)	40357 (8873)	39276 (8084)
Average feed costs per kg milk (IDR/day), assuming no extra costs of grass (cash expenses only)	2611 (556)	2371 (519)
Average feed costs per cow (IDR/day), assuming grass is purchased	51429 (13455)	52514 (11614)
Average feed costs per kg milk (IDR/day), assuming grass is purchased	3226 (1108)	3235 (600)

Greenhouse gas emissions
Feeding according to the balanced rations advice increased total GHG emissions by 4% on average, ranging from 34% increase to 12% decrease between farms. GHG emissions increased on 9 farms that were advised to feed more fodder and/or compound concentrate feed in total, whereas emission decreased on 6 farms that were advice to feed less fodder and/or compound concentrate feed in total. For example, the farmer with the largest increase in GHG emissions (34%) was advised to feed almost 4 times more fodder and to double the amount of concentrates.

In this study we did not evaluate potential effects of feeding advice on (longer-term) milk yields and animal health, and associated benefits in terms of GHG emissions per kg milk (GHG ‘emission intensity’). This is discussed in more detail in the Discussion section.

3.2.4 Improved manure management

Most pilot farms already managed (i.e. not discharging) manure to a certain extend before the pilot started because this was a selection criterion. Manure management on pilot farms was thus different from the manure management on most dairy farms in Lembang, in which more manure is discharged into the environment (De Vries and Wouters, 2017).

Before the pilot study, most of the pilot farms spread manure or digestate to land for forage production on a daily basis (n=12 farms) and/or discharged (part of the) manure (n=7 farms; Figure 6a). Five farms stored feces on a manure heap. About half of the feces was applied to own land for forage production, 11% was sold, and 34% was discharged into the environment. A small amount of feces was applied on own land for food crop production. Urine was not separately managed and removed by flushing: when feces were discharged urine was discharged too (on average about 50% of urine per farm), and when feces were applied on land via daily spread urine was applied too (about 50%).

The estimated amount of N applied on land for forage production before the pilot was very high: on average farmers applied 1420 kg N/ha per year[6] (1286 kg N/ha in feces and urine, and 135 kg N/ha in synthetic fertilizer), ranging from 0 to 5751 kg N/ha/y. The amount of N per ha was likely underestimated because often other dairy farmers also applied manure to the same land. N application was mainly high in farms with a high cattle density per ha applying manure and digestate to land on a

[5] Potential effects on (long-term) milk yields and associated financial benefits were not evaluated.
[6] Based on N excretion rates, share of feces and urine applied on forage, area of agricultural land, and N losses.

daily basis. Two farms did not apply manure to land because land was not available close to the barn. Ten of the 16 farmers applied synthetic fertilizer (urea) on land for forage production.

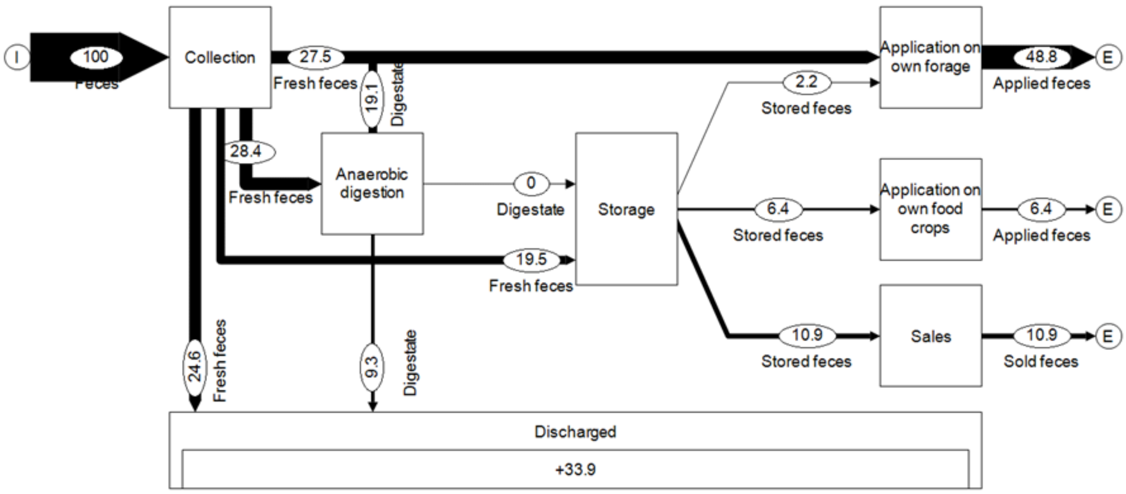

Figure 6a *Average mass flow of feces (%) on the 16 pilot farms before the pilot started (based on farmer estimates).*

Most important changes in manure management during the pilot were the introduction of active composting (7 farms) and vermi-composting (4 farms). In these farms the compost was sold or applied to own land for food crop production. As a consequence, the amount of feces discharged and applied to own land for forage decreased by 46% and 29%, respectively (Figure 6b). This resulted in a 15% lower average amount of N applied on land for forage production (on average 1212 kg N/ha/y). The percentage reduction was not the same as the reduction in amount of feces applied, because only feces were collected for composting, and not urine, and also synthetic fertilizer was applied.

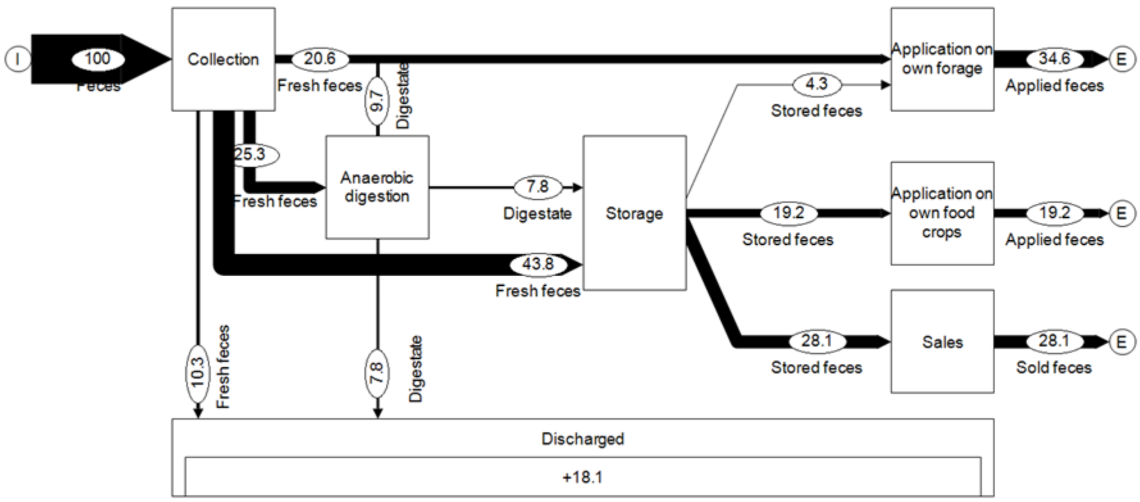

Figure 6b *Average mass flow of feces (%) at the end of the piloting period (based on farmer estimates).*

Costs and benefits

Discharging and daily spread were the least costly, and vermi-composting and composting were the most costly types of manure management. High costs of vermi-composting and composting were caused by labour costs (74% of average total costs) and costs of inputs for composting (17%; Figure 7). Forty-two hours of labour per month were spend on vermi-composting and composting activities, versus 2.5 hours for discharging or daily spread (mainly collecting manure and mixing feed for the anaerobic digester). The most common input for composting was chicken manure mixed with rice husks from broiler farms ("postal"). The price of purchased postal varied between farms (Table 6).

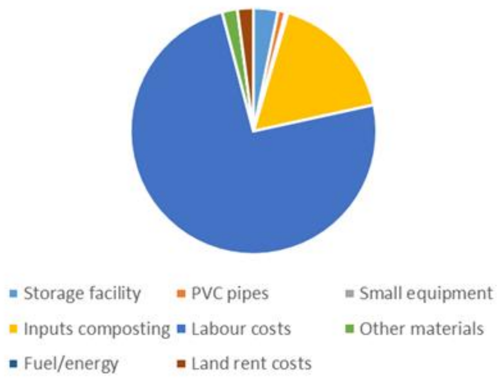

Figure 7 *Average contribution of cost items to total costs of manure management (n=16 farms).*

Revenues per kilogram of cattle manure product were highest for vermi-compost and compost, and lowest for fresh cattle feces (Table 6). Prices of compost and vermi-compost varied between farms. In one farm, vermi-compost was exchanged with grass. Vermi-composting was profitable in all 3 farms, mainly due to high revenues from worm sales. Composting was not always profitable, particularly when labour was included as costs (Figure 8). The time spend on composting varied largely between farms: between 16 and 93 hours per month. Most time was spend on collecting feces, mixing and turning, and applying the compost to farm land. When labour was not included as costs (labour was often family labour), composting was profitable at 2 of the 3 farms; in the other farm composting was not profitable due to a low price of compost sold (333 IDR/kg; Figure 8). The relatively high profit in Farm 1 in Figure 8 was because of 3 reasons: relatively low labour costs, a high price of compost sold, and a relatively high amount of compost sold (economy of scale).

Table 6 *Prices of inputs for composting and sold cattle manure products.*

	Minimum (IDR/kg)	Maximum (IDR/kg)	n farms
Composting inputs:			
Broiler manure ("postal")	364	1000	7
Burned husks	666	666	1
Products sold:			
Fresh feces in sacks	40	63	2
Compost	333	800	3
Vermi-compost	360[1]	1000	3
Worms	20000	20000	4

[1] Price is based on the amount of elephant grass the farmer received in exchange for vermicompost (about 125 kg vermi-compost was exchanged with about 120 kg grass), and the reported price of grass in the rainy season (375 IDR/kg).

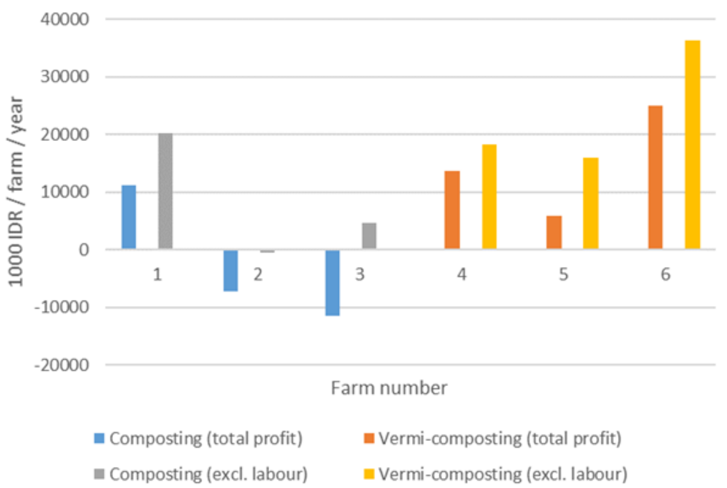

Figure 8 *Profit from composting activities in 3 pilot farms (producing compost only) and vermi-composting activities in 3 other pilot farms (producing compost and worms). Per farm, profit is shown with and without labour costs.*

Greenhouse gas emissions
Improved manure management practices on pilot farms led to 4% lower GHG emissions on average, ranging from 0 to 20% between farms (Figure 9). On the 5 farms with the largest reduction percentage, this was caused by a reduction in the amount of cattle manure applied on land for forage production. On these farms, average GHG emissions were reduced by 13%. The relatively high emission intensity of Farm 8 in Figure 9 was due to a very high manure application rate on this farm (5751 kg N/ha/y) before the intervention.

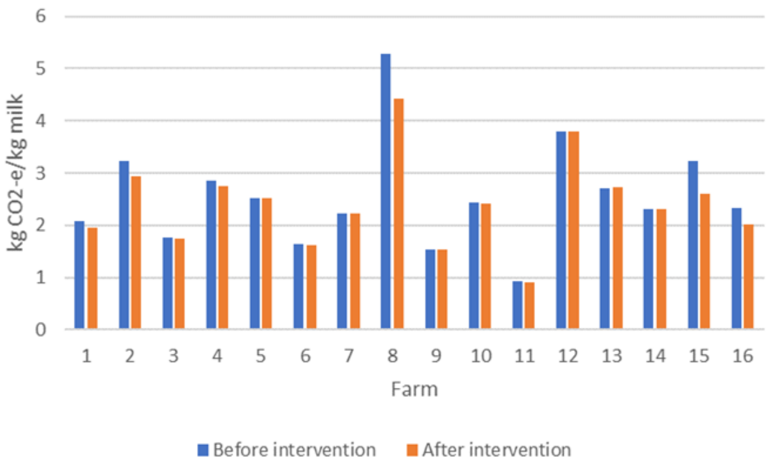

Figure 9 *Average GHG emission intensity on pilot farms (kg CO_2-e/kg milk) before and after introducing improved manure management practices.*

3.3 Adoption of interventions

3.3.1 Feeding interventions

More than 80% of the pilot farmers indicated that it was 'very likely' that they would start or continue with improved quality concentrates, mineral supplementation, feeding more green fodder, and balanced rations (Figure 10). For new fodder species most farmers indicated it was 'likely' that they would start or continue this practice. During the pilot study the number of seedlings distributed to pilot farms was limited, however, and the time of planting was not optimal (towards end of rainy season). This may have influenced the perception of farmers. Ensiling roughage, particularly grass, was considered an 'unlikely' option by part of the farmers, though other farmers indicated it was 'likely' they would adopt this practice.

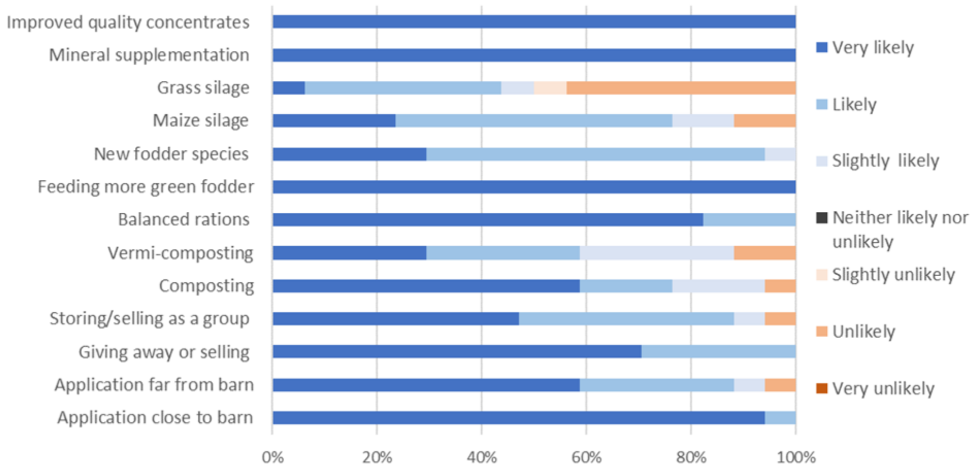

Figure 10 *Farmers' responses (n=17) of the likeliness of adopting improved feeding and manure management practices.*

Stakeholders were less optimistic about adoption of feeding interventions than farmers (Figure 11). Like the farmers, they were most optimistic about adoption of improved quality concentrates and mineral supplementation, but they were less optimistic about feeding more green fodder, balanced rations and new fodder species. Similar to the farmers, most stakeholders were pessimistic about silage making. With regard to manure management, they were most optimistic about application close to the barn, composting, vermi-composting and storing/selling as a group, and relatively pessimistic about manure application far from the cow barn.

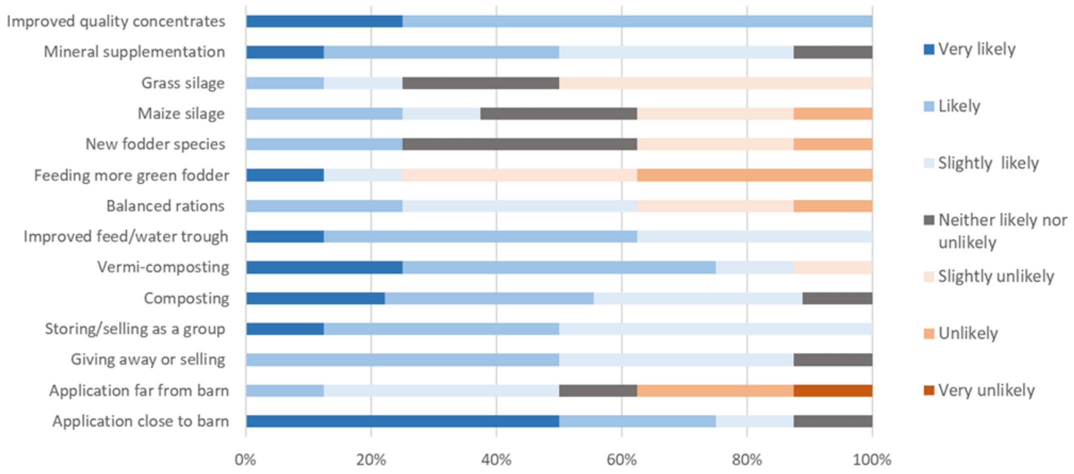

Figure 11 *Stakeholders' responses (n=8) of the likeliness that farmers would adopt improved feeding and manure management practices.*

Perceived benefits and barriers to adoption

All pilot farms had installed an improved feed and water trough, which was a precondition for good feeding practice and sufficient water supply during the project. Farmers indicated that the improved feed and water trough was beneficial for ad libitum water supply, working easier and faster, and improving cow health. Barriers included high investment costs, appropriate installation, lack of spare parts, and water supply. A revolving fund for investment in a feed and water trough is available at the dairy cooperative KPSBU, but stakeholders indicated the available budget per farmer is too low, and many farmers do not know about the fund. Furthermore, the construction of the trough is often not appropriate.

Pilot farmers indicated the main benefit of feeding the higher quality compound concentrate feed was an increase in milk production, or stable milk production despite a lack of forage. Some farmers argued they could reduce the amount of other feeds, particularly wet by-products, due to feeding improved concentrates. Furthermore, farmers indicated that the appetite of cows increased and cow health improved. Challenges included extra effort to transport concentrates, and familiarizing cows with new feed. Stakeholders indicated it is difficult to change farmers' habits.

For mineral supplementation, main perceived benefits were improved health of cows, more regular heat, more active cows, and better recovery after calving. Besides this, 83% of the farmers noticed an improved appetite of their cows, 78% of the farmers noticed a better health condition of the cow in general, and 72% of the farmers claimed improved cow fertility in terms of a better conception. Two third of the farmers also claimed a higher milk production and improved hair coat of the cows. A limited number of farmers experienced less problems with retained placenta (33%) and improved hoof health (17%). Some negative aspects mentioned were more cow aggression (22% of farmers) and more cases of diarrhea (17% of farmers). Farmer found it cumbersome to add the mineral pre-mix to the concentrate feed and preferred to have it added to the compound concentrate feed[7]. Except for 1 farmer, all farmers wanted to continue feeding the premix even if they had to pay for it.

For balanced rations, farmers indicated the main benefits were reduced feed costs and improved health of cows. Some farmers claimed milk yield increased. Farmers said that feeding more green fodder improves cow health (particularly digestion), appetite and milk production. Other feeds could be reduced, such as rice straw. Some farmers indicated cows are more calm and comfortable. Despite the positive attitude of farmers towards balanced rations in the survey, in practice only part of the pilot farmers started feeding according to individual cow requirements. For green fodder farmers indicated challenges include the lack of green fodder in the dry season. Farmers also indicated that increasing the feeding frequency to four times per day is challenging. Stakeholders emphasized the difficulty to change farmers' habits in feeding and the lack of knowledge about quality of feed ingredients. They suggested farmer education could help to increase knowledge of farmers.

Although farmers were somewhat less motivated to start or continue with new fodder species (Figure 10), they indicated other fodder species could be beneficial to the health of cattle. A few farmers indicated feeding new fodder species could improve milk production and milk quality. Challenges include the lack of land, supply of planting material, labour required for uprooting and planting, and the initial lower yield after establishment. A legume such as Indigofera being a tree crop however can be planted around the field borders.

Farmers were least motivated to start or continue with silage. Farmers indicated grass silage could be an important feed stock for the dry season, and excess grass in the rainy season could be used to provide feed stock in the dry season. Particularly making grass silage was considered unlikely, however, mainly because it requires a large grass stock and/or land for increased grass cultivation. In addition, making grass silage requires much time and labour, as well as additional ingredients (such as molasses) and equipment (chopper). Making grass silage was considered more difficult than making maize silage. Farmers suggest parties renting out land for grass production are needed to overcome the main issue of a lack of forage land and forage stock.

Farmers indicated maize silage improves health and productivity of cows, and is easy to feed. It is perceived as a high quality feed for the dry season, which can replace rice straw and shortage of grass. Similar to grass silage, barriers to produce maize silage include the low supply of maize, lack of land for planting maize, required investment in equipment (e.g. chopper), and limited storage space.

3.3.2 Manure management interventions

Compared to feeding interventions, pilot farmers were less optimistic about the likeliness of adopting manure management interventions (Figure 10). More than 80% of the farmers indicated that it was very likely they would start or continue with applying manure close to the barn, and more than 50% of the farmers indicated that it was very likely they would start or continue with composting, giving away or selling manure, and applying manure far from the barn. Vermi-composting and storing and selling as a group were indicated as likely options by fewer farmers.

Stakeholders were more optimistic about adoption of manure management interventions than feeding interventions (Figure 11). They were most optimistic about application of manure close to the barn, composting, and vermi-composting. Application of manure far from the barn was considered less likely to half of the stakeholders.

[7] Some months later the premix was added to the high quality compound concentrate feed produced by the dairy cooperative KPSBU.

Perceived benefits and barriers to adoption

Pilot farmers indicated the main benefit of applying manure close to the barn are increased growth and quality (greener, softer stems) of grass. In addition, they reported soils are more fertile and grass growth is less affected by drought in the dry season. They also indicated using cattle manure reduces the need for chemical fertilizer, and causes less environmental pollution. Challenges included permission of land owners for pipes passing through their land, and the investment costs of the piping system. Farmers suggested a credit fund for investment in piping systems should be available through the dairy cooperative, and manure management on dairy farms should be monitored. Stakeholders indicated many dairy farms do not have land close to the barn.

Main benefits of applying manure far from the barn according to pilot farmers were increased grass growth, more fertile soils, and reduced use of chemical fertilizer (particularly urea), saving costs. Many farmers indicated the importance of reducing the use of chemical fertilizer. The main barrier to applying cattle manure on land far from the barn is the effort required for collecting and transporting manure to land. Both the distance and ease of access to land are barriers. Stakeholders suggested the value of manure compared to urea should be increased. It was not clear, however, if stakeholders referred to (awareness of end-users about) the fertilization value of manure compared to urea, such as nutrients and organic matter, or to the low price of (subsidized) synthetic fertilizers in Indonesia. Stakeholders emphasized education is needed about environmental impacts of fertilization practices and the value of animal manure.

Giving away or selling manure to other farmers was mainly considered as a source of additional income for the family. Some farmers indicated that this helps to keep barns cleaner and reduces environmental pollution. In some cases, dairy farmers were paid in kind by means of grass. Market demand and manure transport costs are considered important barriers, although currently the pressure from the government and Citarum Harum program is forcing dairy farmers to change. Stakeholders suggested composting is important to sell cattle manure, and requires that knowledge about compost making is shared. Farmers indicated managing manure as a group could reduce the labour of handling manure, and as a group more stock can be supplied to meet demand. However, often farmers do not want to work together as a group. Farmers indicated that the dairy cooperative should take initiative in creating manure management groups.

Farmers indicated the main benefits of composting include the higher selling value compared to fresh manure and additional income by selling compost (mainly to vegetable or flower farmers). Some farmers said it was beneficial to create a fertilizer stock, either for own use or for sales, and to keep the barn clean. Also compost was said to be easy to transport and apply to land (light, easy to handle), and to reduce the use of chemical fertilizer. According to farmers, barriers to composting were the lack of space in the barn, slow drying in the rainy season, labour requirements, transport to the buyer or field, and the lack of land for application. Some farmers did not have sufficient cows (cow dung) to produce compost. Stakeholders were concerned about the demand for compost, though it was recognized that horticulture requires large volumes of it. They emphasized the need for guaranteed supply to buyers, and sufficient and stable quality of compost. To this end, a relation needs to be built with the horticultural sector, awareness of governments needs to be increased, and dairy farmers need time to get knowledgeable and experienced.

For various dairy farmers vermi-composting was not feasible because of a lack of space and time/labour, or insufficient cow dung. For those who started vermi-composting, they indicated the main benefit was the additional income, both from selling worms and high quality organic fertilizer (compost). However, the market for vermi-compost is not stable, and transport costs of vermi-compost are sometimes too high. Farmers suggested vermi-composting groups should be made, initiatives are needed to make vermi-compost market prices more stable, and stated the dairy cooperative KPSBU should play a role in marketing vermi-compost and involve KPSBU extension workers.

4 Discussion and conclusions

The aim of this study was to evaluate effects of various feeding and manure management interventions on herd performance, cost and revenues, and GHG emissions of 18 dairy farms in Lembang Sub-District in West-Java, and to evaluate adoption of these interventions. In this study only effects of balanced rations, mineral supplementation, high quality concentrates, and improved manure management were quantitatively evaluated. Results of this evaluation showed that:

- Balanced rations can reduce cash feed expenses per kg milk, but farmers were hesitant to implement the feeding advice;
- The mineral/vitamin premix supplied in this study had a positive effect on the hair coat condition;
- Introduction of the high quality compound concentrate feed with mineral/vitamin premix increased milk yields of lactating cows in mid-lactation, but it is still uncertain to what extent, and whether this intervention is cost-effective. GHG emission intensity increased due to this intervention;
- Introduction of composting and vermi-composting reduced the amount of manure discharged into the environment and reduced overfertilization of fields for forage production, and resulted in lower GHG emissions from dairy farms. Vermi-composting was cost-effective, but composting was not always cost-effective.

Effects of introducing an improved feed and water trough, growing new fodder species, and fodder conservation were not quantitatively evaluated. All interventions were evaluated in terms of likeliness of adoption, which showed that:

- Feeding interventions most likely to be adopted were the high quality compound concentrate feed and mineral supplementation, followed by feeding more green fodder, balanced rations, and introduction of new fodder species;
- Manure interventions most likely to be adopted were application close to the barn, selling or giving away manure, and composting. Some interventions such as vermi-composting are less suitable for specific farm types or local conditions.

4.1 Methodological limitations of the study

There are a number of methodological limitations of this study. First, this study was a pilot study, which is a small-scale preliminary study conducted in order to evaluate feasibility of the key steps in a future, full-scale project (Thabane et al., 2010). Like in any pilot study, evaluating effects of interventions under practical conditions is subject to external factors that can cause bias in the results of the study. This is even more a problem when sample sizes are small. Knowing that there is some extent of uncertainty, results in this study should be interpreted with care. To more reliably quantify causal effects of interventions, experimental research should be conducted. This can also include interventions that were not qualitatively evaluated in this study, such as effects of ad libitum water provision compared to limited water supply.

Second, although the daily collection of milk yield and feeding records over one year likely yielded much more reliable results than farmer recall or milk sales data, these data may still have been subject to reporting bias, for instance because farmers may have lost motivation to record the data on a daily basis. Besides this, survey data may have been subject to recall bias[8] and, as is common in developing countries, availability of secondary data (i.e. readily available data) was limited. More information and a discussion about this issue can be found in De Vries et al. (2019).

[8] Recall bias is an error that occurs when respondents do not remember past events or experiences accurately or omit details (Spencer et al., 2017).

Third, for various parameters in this study secondary data were used to estimate effects of interventions of milk yield, feed costs, and GHG emissions, but this is less accurate than primary data. For CO_2 emissions related to feed processing, for example, data were mainly based on FeedPrint databases (Vellinga et al., 2012) whereas primary data could be collected from local producers and processors to more accurately estimate emissions of feed ingredients. With regard to manure management systems, methane and nitrous oxide emissions were mainly based on default values in IPCC (2019; see Table 1) which have a high degree of uncertainty.

Fourth, effects of land use and land use change (LULUC) were not included in the carbon footprint of feed ingredients. There is a large variation in LULUC of feed ingredients, which may affect conclusions with regard to low-emission feed ingredients. For ingredients of the high quality concentrate feed evaluated in this study GHG emissions from LUC are particularly high for soy bean meal, and lower for CGF and wheat pollard (Table 6). In future studies on low-emission feeding in Indonesian dairy farms effects of LUC should be included.

Table 6 *Carbon footprint (CFP) of feed ingredients of the improved concentrate feed evaluated in this pilot study, subdivided by process[1]. Source: FeedPrint (Vellinga et al., 2012).*

Ingredient	CFP Cultivation (g CO_2-e/kg)	CFP Processing (g CO_2-e/kg)	CFP LUC (g CO_2-e/kg)
Corn gluten feed	486	1185	42
Wheat pollard	209	36	11
Soy bean meal	373	88	3577

[1] CO_2 emissions related to transport are left out of this table.

4.2 Effects of feeding and manure management interventions

Results showed that the introduction of balanced rations on pilot dairy farms could reduce feed costs per kg milk by 9% on average. This was mainly due to the reduction in cassava waste which was expensive compared to other concentrate feed (tofu waste, compound concentrate feed) when taking into account the feeding value. Eliminating cassava waste from the diet did not have much effect on GHG emissions because its carbon footprint was assumed to be low.

Part of the farms were advised to feed more fodder and/or compound concentrate feed because cows were underfed in terms of energy and protein. This advised change in feed ration was not evaluated in terms of effects on milk yield because the sample size was too small. If milk yield would increase, additional revenues from sold milk and a reduction of GHG emissions per kg milk can be expected. To properly evaluate economic and environmental effects of ration balancing in Indonesian farms, a much larger sample of farms is needed than our present sample of 18 farms. In this way, effects on in milk yield can be more reliably evaluated. For example, a recent study in India showed GHG emissions per kg milk (‘GHG emission intensity’) reduced by 31% after implementing a 3-year ration-balancing program for 163.540 dairy cows (Garg et al., 2018). In this study total lifespan milk yields increased significantly, by 52-75%, which likely contributed to the strong reduction in GHG emission intensity. Similar to our study, absolute CH_4 and N_2O emissions from lactating cows increased. The reduction of absolute emissions in the study of Garg et al. was mainly due to the balanced feeding of heifers, dry cows, and unproductive cows in the herd.

On the other part of the pilot farms that were advised to feed the same or less fodder or concentrate, absolute GHG emissions decreased by 0-12%. The reduction in GHG emissions was mainly due to a reduction in the amount of compound concentrate feed per farm. Assuming that milk yield levels remained the same (this was inherent to the advice), this can be translated to the same reduction in GHG emission intensity (i.e. GHG emissions per kg milk).

Introduction of the high quality concentrate feed with mineral/vitamin premix increased milk yields of lactating cows in mid-lactation by 0.1 to 1.3 kg/cow/d (95% CI). We expect that the average increase of 0.7 L/day is somewhat underestimated because cows in early lactation were not included in the analysis, while particularly for fresh cows improved concentrates can have a positive effect during the whole lactation. For cows at the end of the lactation period feeding a higher quality concentrate has little effect. For these cows, feeding a lower quality concentrate is more cost-effective. Due to the uncertainty in the size of (short- and long term) effect, it was not clear in this study whether this intervention is cost-effective. Monitoring a much larger group of farms starting to feed the high quality concentrate or conducting experimental trial can help to draw more valid conclusions on the causal inference and the size of effect of this intervention. Farmers that start to use the high quality concentrate should be educated in feeding cows according to individual requirements to avoid unnecessary high feeding costs, and ad libitum water provision should be implemented on these farms, being a precondition for effective feeding.

Despite the increase in milk yield feeding a higher quality concentrate feed resulted in increased GHG emission intensities due to increased emissions from compound concentrate production and from manure application. Even at a milk yield increase of 1 kg per cow per day, this would not compensate for the increased emissions from compound concentrate production and from manure application. If emissions from compound concentrate feed production and N excretion rates would not increase, the higher quality concentrate could reduce GHG emission intensity of pilot farms by 2-5% (assuming a milk yield increase of 0.7 L/cow/day). To lower GHG emission intensity from compound concentrate feed, alternative concentrate ingredients should be used with a lower CFP and a similar feeding value. Alternative ingredients might be difficult to obtain or expensive. Besides this, to avoid higher N excretion due to the higher crude protein content of improved concentrates, cows should be fed concentrates according to their individual requirements. Results of this study also emphasize the importance of proper manure management when the crude protein content of feed rations is increased: if not managed properly, the increase in N excreted in feces and urine will lead to even higher amounts of N applied on farm land, and associated N emissions, leaching and run-off.

Results of improved manure management practices showed that the currently most common types of manure management practices in Lembang Sub-District, daily spread and discharging into the environment, are the least costly manure management options. Applying N via daily spread appeared more cost-effective than applying N via urea, whereas applying N via composted feces was more expensive than applying N via urea or daily spread. Daily spread and discharging manure are causing large environmental impacts, however, in terms of overfertilization of farm land, pollution of soils, ground- and surface waters, and increased GHG (N_2O) emissions. Although GHG emissions associated with daily spread are low (IPCC, 2019), this study showed extremely high amounts of N were applied on land for fodder production via daily spread (ranging up to 5751 kg N/ha/y) leading to high GHG emissions in some farms. GHG emissions from manure application include direct N_2O emissions from the soils on which the manure is applied, and indirect N_2O emissions due to N volatilization into NH_3 and NO_x, and N leaching and runoff. The discharging and overfertilization of land are consequences of the extremely high livestock densities per area of land, and land often being located far away from cow barns.

To reduce the amount of manure discharged into the environment and overfertilization of land for fodder production alternative destinations for manure are required. Possible options for dairy farms in Lembang are (De Vries and Wouters, 2017): i) application on own land for fodder production located further away from the barn, which is often not fertilized by animal manure but only by urea, ii) application on own land for food crop production, and iii) selling or giving away manure to vegetable or flower farms, or traders for application outside the dairy sector. In all cases manure needs to be stored and treated in order to transport and handle the manure. In this study pilot farms mainly chose for the second and the third option, by selling compost and vermi-compost or applying compost on own land for food crop production.

The introduction of composting and vermi-composting caused a reduction in total GHG emissions from pilot farms mainly because of less overfertilization of land for fodder production. Although vermi-composting is profitable and emissions from vermi-composting are lower than from composting (e.g. Nigussie et al., 2016), vermi-composting is not a solution for all dairy farms because farms often do not have the space and the worm market is limited. Composting was not always cost-effective, which suggests that more research and extension is needed to ensure composting is profitable to dairy farmers (e.g. reducing cost of labour and inputs, good market prices, generating economies of scale). In addition, more passive forms of (cold) composting require less labour and inputs, and may be more suitable to some end-users.

Manure management practices on pilot farms were different from most dairy farms in Lembang, in which more manure is discharged into the environment (De Vries and Wouters, 2017). Given the fact that daily spread onto agricultural land is the cheapest manure management solution, there is a risk that the current efforts enforcing farmers to stop discharging will result in overfertilization of fields close to cow barns. Alternative options shown in this study are composting, giving away or selling manure, and applying manure far from the barn. In addition, land consolidation (i.e. readjustment of land parcels) should be considered. In the 3 farms in this pilot study that changed from mainly discharging of manure to composting and vermi-composting, GHG emissions reduced by 2-9% and 20%, respectively. Assumptions on CH_4 and N_2O emissions from discharged manure were highly uncertain, however, particularly because emissions may vary considerably depending on the location and weather conditions and the fate of the discharged manure (De Vries et al., 2019).

In this study only changes in the management of feces were evaluated, whereas most of the mineral N is excreted in urine. Most of the urine on dairy farms in Lembang is discharged into environment or directly applied to land for fodder production via daily spread (De Vries and Wouters, 2017), often contributing to environmental pollution of ground and surface waters, and N_2O emissions. Options should be explored to collect, transport, and apply urine as a fertilizer on land for food crop production or on land for fodder production located further away from the cow barn.

4.3 Adoption of interventions

Farmers indicated that they would likely start or continue with high quality concentrates, mineral supplementation (all farmers), feeding more green fodder, balanced rations, introduction of new fodder species, and manure management improvement (fewer farmers). In practice during the project all farmers adopted improved quality concentrates and mineral supplementation, which was partly because these interventions were fully subsidized, but farmers also claimed that milk production increased and cow health improved, and they would continue with the high quality concentrate if they had to pay a higher price. In December 2019 the dairy cooperative KPSBU in Lembang decided to start producing the high quality concentrate with the premix 'Maxcare' for its members, giving farmers more choice in types of compound concentrates differing in quality and price. For the high quality concentrate to be cost-effective farmers should be educated to feed according to individual cow requirements (balanced rations).

The number of pilot farmers following up on the advice to feed concentrate according to individual cow requirements increased over time. The reason that some pilot farmers did not follow-up on the advice to differentiate in the amount of compound concentrate feed between cows was not clear, and farmers did not indicate any barriers to adopt this advice. Possibly farmers feared a drop in milk production, or, as indicated by stakeholders, changing farmers' habits in feeding is difficult. Stakeholders suggested farmer education could help to increase farmers' knowledge about ration balancing. The number of pilot farmers that implemented ration balancing increased slowly over time, which indicates the need for long-term support on ration balancing rather than a single advice.

Compared to feeding interventions, pilot farmers were less optimistic about the likeliness of adopting manure management interventions. This is partly due to the fact that, contrary to feeding interventions, manure management interventions are not always suitable to farms. For example, a vermi-composting unit requires much space, which is often not available. As a consequence, only few farmers indicated they would adopt this type of manure management. Hence, the likeliness of adoption score can reflect farmers' perceptions of advantages and disadvantages of the intervention, but also about the suitability of the intervention to specific farm types or conditions. It is important, therefore, to develop different types of manure solutions suitable to the diversity of farms present in Lembang.

More than 80% of the farmers indicated that it was very likely they would start or continue with applying manure close to the barn. This was no surprise, because most of the dairy farmers in Lembang owning or renting land close to the barn already apply cattle manure on this land (De Vries and Wouters, 2017). A more interesting and auspicious result was that more than 50% of the farmers indicated it was very likely they would start or continue with composting, giving away or selling manure, and applying manure far from the barn; practices which are uncommon to dairy farming in Lembang (De Vries and Wouters, 2017). These cases provide evidence in practice that barriers can be overcome (e.g. labour requirements and costs of manure management, market demand). Upscaling of improved manure management practices requires capacity building, access to credit, enhancing collaboration between the dairy sector and the horticultural sector, and creating awareness at the policy level.

4.4 Recommendations

The following recommendations were drawn from this study:

- Balanced rations can reduce feed costs per kg milk but farmers find it difficult to abandon habits in feeding, even if the change does not require additional feed or fodder supply. Long term extension should be provided to farmers to enhance ration balancing on dairy farms.
- A higher quality concentrate feed with premix can increase milk yield, but more research is needed to quantify the size of effect and, thus, cost-effectiveness of this intervention. Farmers using the high quality concentrate should be educated in feeding cows according to individual requirements to avoid unnecessary high feeding costs, and environmental pollution. Alternative ingredients with a lower carbon footprint should be explored to avoid an increase in GHG emissions. Manure should be properly managed to avoid increases in N emissions due to the higher protein content of feed. Ad libitum water provision is a precondition for effective feeding, and should be implemented on all dairy farms.
- Fodder conservation is not a promising option for small-scale dairy farmers at the moment, mainly because of the lack and costs of input materials (maize, grass);
- Discharging of manure into the environment should be reduced, but should not result in further overfertilization of agricultural land close to cow barns. Particularly when feed quality is going to be improved, proper manure management is needed. Storages for solid manure should be constructed on dairy farms in order to utilize cattle manure on land for food crop production or land for fodder production far from the barn. Training and extension should be provided to farmers to enhance cost-effectiveness of composting.
- In general, for the promising feeding and manure management interventions identified in this study, education is needed about best practices and environmental consequences, for example by means of farmer field schools.

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