Farm management monitor for the dairy: a case study on continued improved milk production

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Introduction

The development of the Far m Management Monitor for Dairy Cattle (Dairy-FMM) started in 2011.

Many interviews with farmers and vets led to the notion that basic Farm Management best can be monitored by collecting and plotting longitudinal data from bulk milk tests on different aspects, hereby reported.

Animal diseases that have a direct impact on the productivity of dairy cattle (Disease State in the graphic). Also diseases that impact the gestation are considered in this group. The antibody-levels in the bulk tank are measured quantitatively monthly or bi-monthly, dependent on the pathogen. The list of tests is reported in table 1

Table 1. Antibody-levels in the bulk tank are measured quantitatively monthly or bi-monthly, dependent on the pathogen

			Scheme											
Test group	Test		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Animal disease	Ab/PCR	BVDV	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	IBR-gB/gE	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	Salmonella Bov	x		x		x		x		x		x	
	Ab	ParaTB	x		x		x		x		x		x	
	Ab	Fasciola	x		x		x		x		x		x	
	Ab	Neospora	x		x		x		x		x		x	
	Ab	Leptospira H/P	x		x		x		x		x		x	
	Ab	Mycopl. Bovis	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	MAA	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	*Schmallenberg*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*

Physiology. Mammalian physiology depicts biochemical pathways for protein-degradation, fatty acid cycle, citric acid cycle, carbohydrate break-down, and many more pathways for the build-up of macromolecules as proteins and DNA. All these processes are directed by enzymes and down a long cascade of switches finally the presence of a limited group of certain positively charged ions are responsible for the proper action of the biochemical pathways (Table 2). This group, the essential minerals enter the mammalian system through the feed, mostly the roughage from around the farm. Next to the essential minerals we can identify two extra elements/compounds also important for the growth (Ca^{2+},PO_4^{3-}).

Table 2 list of positively charged ions responsible for the proper action of the biochemical pathways.

Table 2. List of positively charged ions responsible for the proper action of the biochemical pathways

			Scheme											
Test group	Test		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Feed-uptake	FM	Mg^{2+}	x	x	x	x	x	x	x	x	x	x	x	x
	FM	Se^{4+}	x	x	x	x	x	x	x	x	x	x	x	x
	FM	Zn^{2+}	x	x	x	x	x	x	x	x	x	x	x	x
	FM	PO_4^{3-}/P_i	x	x	x	x	x	x	x	x	x	x	x	x
	FM	Ca^{2+}	x	x	x	x	x	x	x	x	x	x	x	x

Silage. Silage is defined as the feed which is collected from the acres around the farm, pasture, (and purchased from feed-companies) and stored in silos next to (or inside) the farm. Part of this silage is prone to (external) visitors, such as rodents, and local birds and migratory birds, as well as all types of weather conditions. The visitors usually eat from the silage and leave their droppings, and this combined with the ever present traces of bacteria, yeasts and molds are a perfect breeding ground for the rapid growth of bacteria, and thus increasing amounts of mycotoxins. The feed from feed-mills are checked by law for the absence of mycotoxins.

If toxins enter a mammalian system through the silage, most of the toxins are cleared by the liver. Except for Aflatoxin B, which is converted to the less poisonous Aflatoxin M. If Aflatoxin M is found in the bulk milk, most probably other toxins than Aflatoxin B can be found in the silage. This silo should no longer be used for feeding the animals.

Monthly measurements of Aflatoxin M in the bulk milk are a good indicator for the presence of bacteria/toxins in the silage (Table 3):

Table 3. Aflatoxin M in the bulk milk as an indicator for the presence of bacteria/toxins in the silage

			Scheme											
Test group	Test		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Sileage	EIA	Aflatoxin M	x	x	x	x	x	x	x	x	x	x	x	x

Pregnancy/Reproduction/Colostrum quality. Pregnancy/Reproduction/Colostrum quality is an important management basic. The (cattle) dairy exists by the milk produced as a result of annual calving, whereas in the goat dairy, where continuous milking is practiced, a lamb every year is necessary to replace the group of milking goats. Calves and lambs are born with no active immune-system, so they are dependent on colostrum in order to acquire protection to the current diseases on a farm, until they have built up an active immune system. In practice calves are fed replacer milk or milk from healthy cows, until the disease status of mother and calf are known. Lambs usually do not receive colostrum from their mother because some diseases (lentiviruses) are passed vertically through the colostrum, or (ParaTB and others) by oral contacts with (infected). Lambs receive either clean tested colostrum, or, in most cases, replacer milk.

Bulk milk is always pregnant, it only makes sense to test individual animals for pregnancy, preferably in such a manner that the presence of a calf is checked as short as possible after the insemination, in order to keep the dry state later on as short as possible. Proper administration of insemination and short on testing for pregnancy is key in successful farm management.

Table 4. Some dates in the reproduction.

Animal ID	Work ID	Date of birth	Last delivery	Insimination date	Insimination count	Date Sampling	Date result	Result
NLxxx...	7998	05-07-2016	25-12-2023	13-02-2024	1	12-03-2024	15-03-2024	Pregnant
NLxxx...	8102	05-05-2020	05-03-2024					
NLxxx...	8186	05-07-2016	25-12-2023	12-02-2024	1	12-03-2024	15-03-2024	Re-check
NLxxx...	8199	16-07-2015	05-03-2024					
NLxxx...	8271	15-07-2018	05-03-2024					
NLxxx...	8280	15-09-2022	27-12-2023	13-02-2024	1	12-03-2024	15-03-2024	Re-check
NLxxx...	8285	16-07-2015	27-12-2023	13-02-2024	1	12-03-2024	15-03-2024	Pregnant
NLxxx...	8292	03-04-2017	05-03-2024					
NLxxx...	8376	05-05-2020	25-12-2023	12-02-2024	2	12-03-2024	15-03-2024	Pregnant
NLxxx...	8387	16-07-2015	25-12-2023	13-02-2024	1	12-03-2024	15-03-2024	Pregnant
NLxxx...	8391	15-07-2018	05-03-2024					
NLxxx...	8395	03-04-2017	05-03-2024					

Since we supply individual data here, we can add external data that indicate the exact timing of insemination, e.g. data from steppers and other sensors (like temperature).

To this group of data on individual animals also data from stress-sensors, antibiotic use, mastitis cases, or individual biochemistry data, like ketosis-indicators can be added.

All of this in order to give the farmer also on individual animal level maximum information, which he can use to treat individual animals, or supply individual feeding and/or additives and minerals.

Quality of the Drinking Water. Quality of the Drinking Water of the animals usually is a quite forgotten management basic in farming.

Most farms receive their water from drilled wells close to the farm, few cater from the human tap-water because of costs.

The quality of the drinking water depends (very much) on the filtering systems originally installed, and the maintenance thereof. After a while the quality decreases, filters are saturated and the effects on the plumbing systems become evident. Dependent on the presence of minerals in the ground water residues of the minerals (mostly Iron/Fe and Manganese/Mn) form seaweed-like structures which are a perfect landing spot for aerobic bacteria/biofilm, with included nasty enterobacteria, fungi and molds, and coliforms. Each drinking of the animals leads to the ingestion of small amounts of bacteria, causing disorders like arthritis and claw-problems.

In the FMM the drinking water is tested twice per year on the following groups of compounds, as reported in table 5

The output of the Dairy-FMM. In operational output of the Dairy-FMM (bi-)monthly laboratory data are generated, which combined with the past data and the data from the production databases, medical databases and genetic databases, lead to BIG DATA with a wealth of information which allows the farmer and his stakeholders (vets, nutritionists, farm-advisors, milk-collectors and finally, the dairy company) to optimize

Table 5. Ions in drinking water tested twice per year on a specific group of pathogens.

			Scheme											
Test group	Test		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Drinking water	FM	pH	x						x					
	FM	NH_4^+	x						x					
	FM	Cl^-	x						x					
	FM	PO_4^{3-}/P_i	x						x					
	FM	Fe-ttl	x						x					
	FM	Cu^{2+}	x						x					
	FM	Mn^{2+}	x						x					
	FM	NO_2^-	x						x					
	FM	SO_4^{2-}	x						x					
	MB	Coliform	x						x					
	MB	Enterobacteria	x						x					
	MB	E.Coli/Coliform	x						x					
	MB	Yeast and mold	x						x					
	MB	Aerobic bacteria	x						x					

the farming environment for that specific farm (Picture 1). As well as make projections for upcoming events, trends, and comparisons to other farms.

In order to streamline and visualize the output of the Dairy-FMM, a simple dashboard is prepared following each testing-round, where the farmer and his vet (and other stakeholders) have a quick overview of the status.

This dashboard has two views, a farmers' view and a veterinarians 'view (Figure 1).

In the above example the farmer seems to have not-normal results for Salmonellosis, Aflatoxin M1, and low levels of phosphate and magnesium (II). The animal drinking water seems ok.

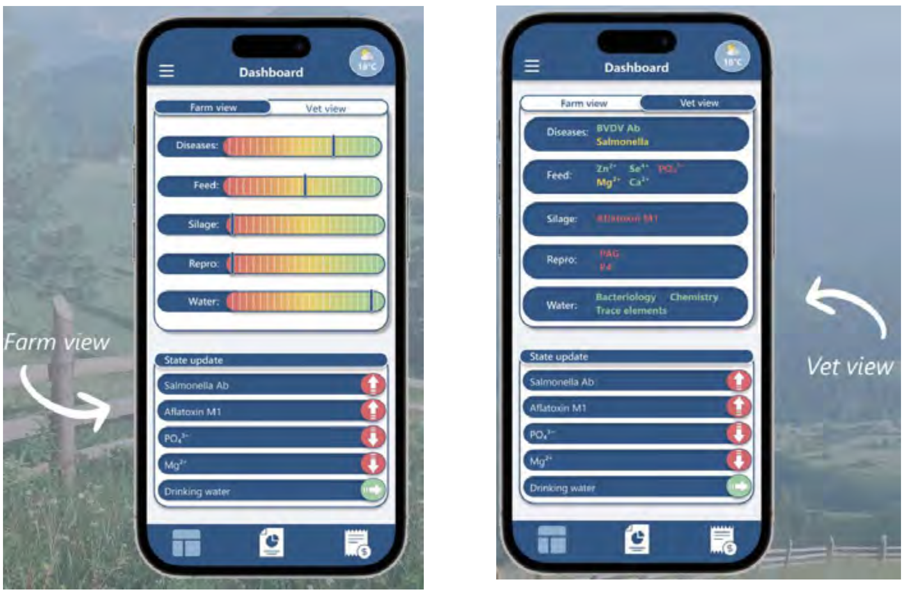


Figure 1. Two views for the dashboard.

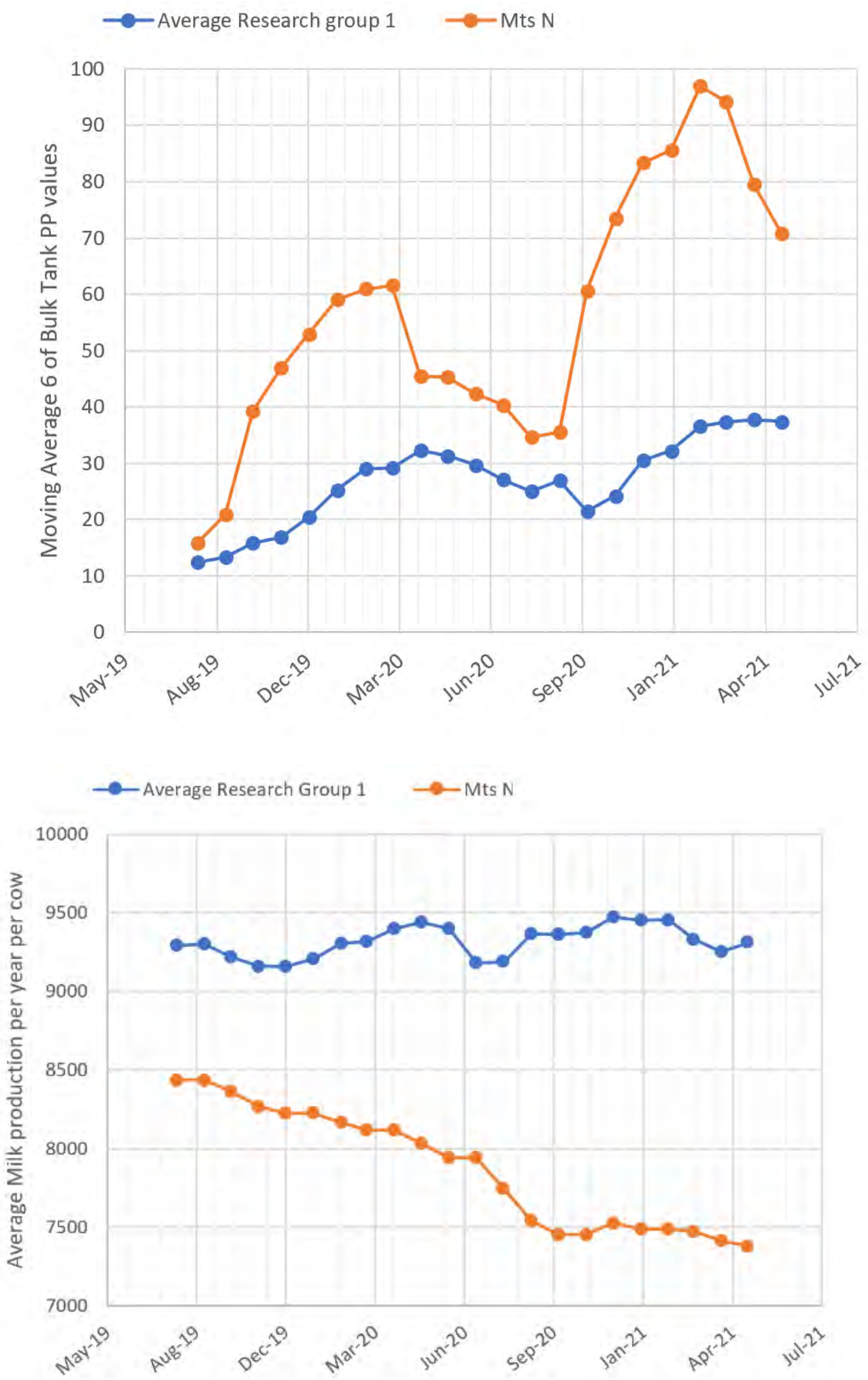
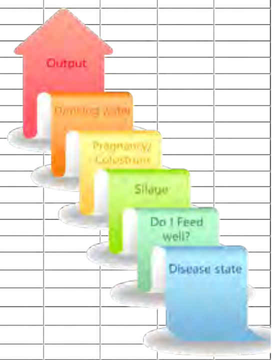


Figure 2. Decreased milk production (red line) due to the presence of Salmonella infections on the farm, compared to the group of farms with no or low levels of Salmonella infections (blue line)

Table 3. operational output of the Dairy-FMM (bi-)monthly laboratory data are generated combined the past data and the data from the production databases, medical databases and genetic databases

Rund/Cattle														
						Scheme								
Test group	Test		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Animal disease	Ab/PCR	BVDV	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	IBR-gB/gE	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	Salmonella Bov	x		x		x		x		x		x	
	Ab	ParaTB	x		x		x		x		x		x	
	Ab	Fasciola	x		x		x		x		x		x	
	Ab	Neospora	x		x		x		x		x		x	
	Ab	Leptospira H/P	x		x		x		x		x		x	
	Ab	Mycopl. Bovis	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	MAA	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	Schmallenberg	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	FMD	x	x	x	x	x	x	x	x	x	x	x	x
	Ab	TB	x		x		x		x		x		x	
	Ab	Brucella Bov	x		x		x		x		x		x	
Feed-uptake	FM	Mg^{2+}	x	x	x	x	x	x	x	x	x	x	x	x
	FM	Se^{4+}	x	x	x	x	x	x	x	x	x	x	x	x
	FM	Zn^{2+}	x	x	x	x	x	x	x	x	x	x	x	x
	FM	PO_4^{3-}/P_i	x	x	x	x	x	x	x	x	x	x	x	x
	FM	Ca^{2+}	x	x	x	x	x	x	x	x	x	x	x	x
Sileage	EIA	Aflatoxin M	x	x	x	x	x	x	x	x	x	x	x	x
Pregnancy	EIA	Indiv.milk	x	x	x	x	x	x	x	x	x	x	x	x
Drinking water	FM	pH	x						x					
	FM	NH_4^+	x						x					
	FM	Cl^-	x						x					
	FM	PO_4^{3-}/P_i	x						x					
	FM	Fe-ttl	x						x					
	FM	Cu^{2+}	x						x					
	FM	Mn^{2+}	x						x					
	FM	NO_2^-	x						x					
	FM	SO_4^{2-}	x						x					
	MB	Coliform	x						x					
	MB	Enterobacteria	x						x					
	MB	E.Coli/Coliform	x						x					
	MB	Yeast and mold	x						x					
	MB	Aerobic bacteri	x						x					

Ab=Antibody/EIA, PCR=DNA-test, EIA=enzymImmunoassay, FM=photometry, MB=microbiology/culturing



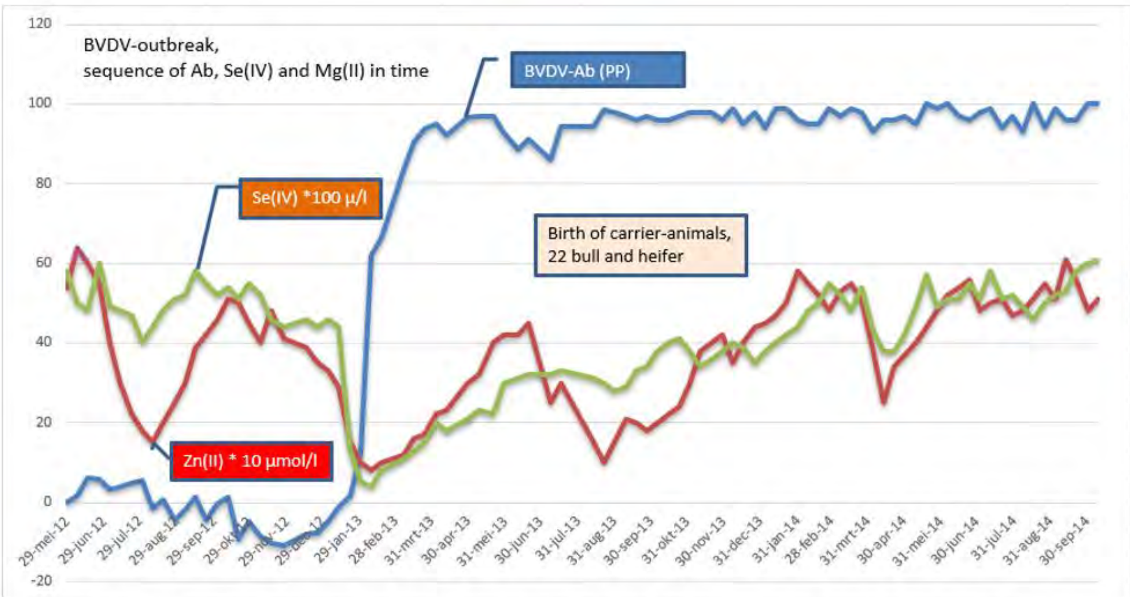


Figure 3. Antibody levels and levels of the essential minerals Zinc(II) and Selenium(IV) during an outbreak of BVDV (Bovine Viral Diarrhea Virus, an abortion causing disease for pregnant heifers).

The stakeholders easily can for instance review the past results of the Salmonella antibody levels in the bulk milk and see increasing farm values (red line), compared to an average of other farmers around (blue line) (Figure 2). The output even gets stronger if the connected milk production data are displayed as well: The farmer and his veterinarian can easily see the decreased milk production (red line, and connected loss of income) because of the presence of Salmonella infections on the farm, compared to the group of farms with no or low levels of Salmonella infections (blue line):

The farmer (orange line) loses about 2000 liter per cow per year because the Salmonella-infection on his farm. In real-time FMM a farm never will get into this heavy state of Salmonellosis. The third test result which is above the zero line of the farm will induce an alert to the farmer and his vet.

Another example of the power of the Dairy-FMM is shown below (Figure 3), the detailed antibody-levels and levels of the essential minerals Zinc(II) and Selenium(IV) in one graph during an outbreak of BVDV (bovine viral diarrhea virus, an abortion causing disease for pregnant heifers).

Because of the presence of the Dairy-FMM at this farm, the farmer was informed immediately of the outbreak, and his veterinarian could take appropriate measures to ensure suppression (by vaccination) of the usual abortions induced by such an outbreak. However, also the nutritionist was made aware of the huge depletion of essential minerals, which in the end undermines the resistance of the cattle to fight disease (additional essential minerals in the mineral-mix helped the animals to regain good levels of minerals).

Benefits of the dairy-FMM. In essence the Dairy-FMM is a preventive monitor: Deviations from a “normal” situation are quickly recognized and appropriate actions keeps the farming at a low-stress level.

Initial results with the Dairy-FMM at experimental farms, compared to farms who do not use the Dairy-FMM show that the levels of milk-production are higher (5-15%) and more constant, insemination rates are low and constant, and the average parity numbers go up. As a consequence the farm potentially can produce the same amounts of milk with less animals, thus give less stress on the environment in terms of nitrogen and methane exhaust. The Dairy-FMM supports sustainable farming as well.

Moreover, there is first evidence of increased numbers of average parity: The average parity numbers increase from 2.6 to 3.0. Consequent use of the Dairy-FMM most probably leads to even more increased parity numbers. Because of the better animal care, the animals produce not only to higher levels, but also live a longer and healthier life.

For the farmer it is of importance that he is informed on the essential basics of farming, which allows him to cultivate trust in his farm-operation, and for his stake-holders (veterinarian, nutritionist, inseminator-professionals, milk-collector and dairy-coop) the transparency of his operation is evident and visible at any time.

By using the Dairy-FMM the farmer adds more value to his operation, and in the end he maximizes the socio-economic value: He has proof of quality for the dairy-sector, as well as his direct environment, thus adding to the feel-good of the entire agricultural sector.

Autocorrelation longitudinal study on a farm with disease-pressures and shortages on minerals in the pasture: Milk production, Selenium (IV)-levels and insemination rates, prior to and following the introduction of the Dairy-FMM.

In the following example of the Dairy-FMM for optimization and control of farming output, we focused on the milk-production, insemination rates, and lactation numbers,

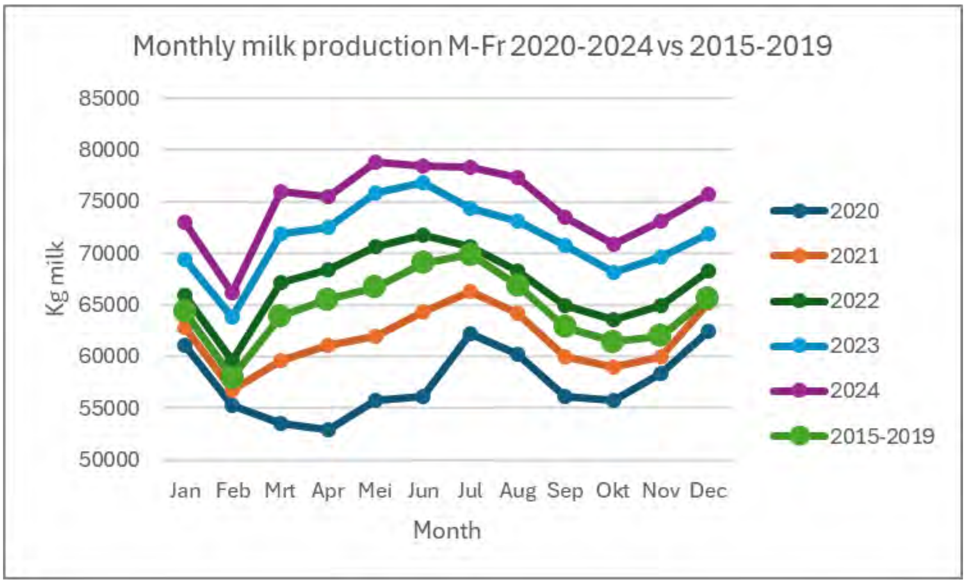


Figure 4. Increased levels of average monthly milk production, once a steady state of monthly testing and actions following the outcome of the monthly testing has been reached.

prior to the start of the implementation of the Dairy-FMM and compare the parameters to the following years, where full action is taken on the flaws detected in the FMM.

At the start of the implementation of the Dairy-FMM we found three diseases present, Salmonella, Fasciola and ParaTB. At a first glance, the milk-production was acceptable (9600 liters/cow/year), the mineral levels were acceptable, except for Se^{4+}, this mineral was (quite far) below the minimum level necessary for good biochemical pathways. The insemination rate was (fairly high at) 3,8. The average parity number as low as 2,4[3]. However, the farm was gaining high, though quite variable milk-yields, and the indicators are not favorable for sustainable farming.

To further characterize the farm (see also Table 5): 80 milking cows ([c]cows per parity), 40 young stock (50%, 30-35%), insemination number is at 3,8 ([h]1,9-2,6) and the Selenium(IV) concentration was at 0.05 µg/l ([h]0,21-0,76 µg/l).

The first optimization was to bring the Selenium(IV) level to values that allow proper biochemical pathways in the animals. The second action was to test herd-covering individual milk samples on the three present diseases, thus identifying potential carriers of the diseases. The antibody-levels found for each of the diseases listed in the Table[d, e, f] gave a first indication of the disease-carrier animals. Follow-up investigation revealed one active Salmonella carrier, 19 latent carriers (the active shedder was removed from the herd immediately). For ParaTB we found 26 shedders of which 6 animals were shedding actively, they were also removed from the herd. 30 milking cows we found to have high titers of Fasciola Hepatica in their blood; the animals were treated by the veterinarian.

As can be seen in Table 5, the Selenium(IV) has been in the necessary range since 2020, and in combination with the control of formerly present diseases the insemination number (AI#) over time went down to 1,9, a good and acceptable average.

The total number of milking cows (MC) in 2020 went down to 72, the reorganization of the herd following the findings of the individual testing, lowers the total number of

Table 5. The antibody levels found for the diseases listed (columns d, e, f) giving a first indication of the disease-carrier animals.

		2015-2019	2020									2024
Parity[a]	AvgMlk/Day[b]	#[c]	Salm Ab[d]	ParaTB Ab[e]	Fasc Ab[f]	2020	2021	2022	2023	2024	Parity	AvgMlk/Day[g]
1	21,8	23	**10** (4)	**5** (0)	**8**	25	24	23	21	19	1	22,4
2	23,4	20	**12** (8)	**6** (1)	**7**	18	17	17	17	16	2	25,1
3	26,0	18	**5** (4-**1***)	**5** (0)	**6**	14	14	15	18	19	3	26,9
4	26,1	10	**5** (2)	**6** (2)	**3**	8	10	11	13	15	4	27,4
5	26,8	4	**1** (1)	**3** (2)	**2**	4	5	7	8	11	5	27,8
5+	**24,7**	**5**				**3**	**4**	**4**	**4**	**4**	**5+**	**25,9**
6	25,8	2	**1** (0)	**1** (1)	**1**	1	2	2	2	2	6	26,2
7	21,0	1	0	0	**1**	1	1	2	1	2	7	25,2
8	25,5	1	0	0	**1**	1	1	0	1	0	8	25,2
9	26,4	1	0	0	**1**	0	0	0	0	0	9	
Ranges[h]	**Milking Cows MC**	**80**				**72**	**74**	**77**	**81**	**84**		
0,21-0,76 µg/l	**Se^{4+}**	**0,05**				**0,35**	**0,40**	**0,33**	**0,45**	**0,31**		
1,9-2,6	**AI#**	**3,8**				**3,2**	**2,7**	**2,2**	**2,1**	**1,9**		
30-35%	Young Stock YS	40				40	42	40	37	33		
	%YS/MC	50%				56%	57%	53%	46%	40%		
Average parity numbers		***2,6***				***2,4***	***2,6***	***2,7***	***2,8***	***3,0***	***Average parity numbers***	
		Latent carriers	(x)									
		Persistent carriers	(**1***)	(x)								

lactating cows, also the average parity number goes down: However, already in the second year of the use of the FMM, this number is at the starting value (2019), ready to increase drastically in the years to come: Here is where most of the milk-increase stems from. More animals in higher parity numbers are at the basis of higher total milk-output. With better insemination numbers the cost for pregnancies goes down, and a longer milking life (higher average parity numbers) allow lower numbers of young stock to maintain, adding to lower cost of feed and maintenance. The %YS/MC decreases from 56% in 2020 to 40% in 2024 (almost at the Dutch average).

About each year (1-2 years), a full herd-screening of the diseases in the FMM (for this farm mostly Salmonella, ParaTB and Fasciola Hepatica), followed by the necessary actions, keeps the pressure of the diseases very low, and, hence, the effects are negligible. Also, keeping track of proper feeding through the testing of the essential minerals in the FMM (and adjustments, if necessary), supports more relaxed management, and increased milk-production to a certain steady-state.

Table… depicts more and more milking cows in the higher parity groups plus the concomitant higher milk-production (average parity of 2,6 in the period 2015-2019, and an average parity of 3,0 in 2024).

The following figure shows the increased levels of average monthly milk production, once a steady state of monthly testing and actions following the outcome of the monthly testing has been reached (Figure 4).

In summary.

Effects of the continuing running of the dairy-FMM shows that the farm has grown from an average milk production per milking cow at the start 2020 (average 2015-2019) of 9.670 liters to an average of 10.936 liters per milking cow in 2024 (+13%)

In addition, the integral cost of farming decreases, since the number of young stock drastically reduces (from 50% of the total animals in the herd, to 40% of the total in 2024), as well as the insemination number decreased of 3,8 in 2019 down to 1,9 in 2024.

The average parity number increased of 2,6 to 3,0, with sufficient headroom for years to come.

Why milk? Milk tests versus blood/ serum/plasma tests.

For testing disease the matrix of choice is blood, for several reasons: a. blood is the main carrier of proteins from the immune-system, b. first onset of antibodies to pathogens is expected in blood, c. most if not all national programs are based on blood (serum/ plasma), d. secured sampling of animals is only allowed by vets, they are trained for these sampling-processes, e. easy logistics, blood, especially serum or plasma are quite stable at room temperature, f. habit, labs are setup for testing blood, hence the vet taps blood and the industry developed primarily blood tests, and f. tapping blood is an earning model for vets. The blood-testing labs are well connected to vets and vice versa, they hold each other upright.

However, milk as a matrix for testing for amongst others disease is also a quite good choice: a. progeny is key in the evolution and milk is meant as a first line protection for a newborn calf, the complete immune-repertoire is present in the milk, also and especially the current farm infections, b. milk samples can easily be taken by anyone skilled in milking, c. usually cheaper to take a milk sample, farmer or milking man can take a sample, d. milk has a well-defined route to the milk testing lab, well controlled for stability, e. milk is as easy as blood for lab tests, albeit most tests are not developed for milk, have no milk-protocols, f. tests usually need no sample preparation for milk, and above all, g. the bulk milk tank antibody levels are a complete, well defined mirror of the farm (a big advantage over pooled blood of individual animals).

Most developed tests use blood as a sample for testing, few (however more and more) tests have a milk protocol. Virtually none of the current tests used in the Dairy-FMM has a bulk milk protocol. The typical requirement of a bulk milk protocol is two-fold. First, a bulk milk protocol should be indicative for the percentage of animals infected (e.g. the percentage of animals who contribute their antibodies to the bulk-tank), and, second, a bulk milk protocol should be able to clearly and early indicate the onset of an infection (e.g. the lowest percentage of infected animals should show up in the bulk-tank).

From milk protocol to bulk milk protocol.

A bulk milk protocol is a sequence of laboratory instructions on how to pre-treat the bulk milk in order to give a precise and quantitative result in the antibody enzyme assay (Table 6). Each of the parameters tested for in the bulk milk, have evaluated

Table 6. An example the validation testing for quantitative results for antibody levels in the bulk milk for Salmonella.

	Average PP Bulk Milk	% of animals infected*	SD	Average-SD	Average+SD	SEM	95% CI	N**
PrioCheck Salmonella Ab (Thermo Fisher, PN 7610770) PP = percentage positivity in Bulk Milk (titer)	128	41,3	13	115	141	1	125-131	87
	94	20,7	15	79	109	2	91-98	87
	54	10,3	14	40	68	2	51-57	87
	27	5,2	8	19	35	1	25-29	85
	11	2,6	5	6	16	1	10-12	85
	2	1,3	4	-2	6	0,4	1-3	84
	-2	0,6	4	-6	2	0	-3--2	85
	SD, standard deviatie (standard deviation of the average of N measurements)							
	SEM, precision of mean							
	95% CI, confidence interval, 95% likeliness that the sample tests in the range							
	* based on the numbers of individual animals with antibodies to Salmonella which account for the indicated PP-value of the Bulk Milk							
	** N numbers of measurements of in total 7 different production-lots							

data on the precision of the test-results as depicted in the table below: Here as an example the validation testing for quantitative results for antibody levels in the bulk milk for Salmonella.

From the table above we conclude that the “sensitivity” of the bulk milk test for Salmonella is at 1.3 % positive animals supplying to the bulk milk. If 1.3% of the animals have levels of antibodies to Salmonella, the bulk milk shows the presence of the bacteria in the infected animals.