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Anionic mineral mixture prevents milk fever and improves farmer income: evidence from a randomized controlled trial

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Abstract The incidence of milk fever, a calcium deficiency disorder in dairy animals, can be prevented by supplementing their feed with anionic mineral mixture (AMM). Using data from 200 dairy farms in Haryana, a state in India, and a randomized controlled design, we find that supplementing animal feed with AMM reduces the incidence of milk fever from 21% to 2%, improves milk yield by 14%, and farmer profit by 35%. The milk yield in India, and therefore the risk of milk fever, is growing; AMM can be an affordable way to prevent milk fever and improve returns.

Keywords Milk fever; anionic mineral mixture; randomized controlled trial; impact evaluation; farmers' income; dairy farming

JEL codes Q10, Q120, Q180, C93

Nutritional deficiency disorders in high-yielding dairy animals, and the associated damages, make for avoidable depletion of scarce resources (Thirunavukkarasu et al. 2010). Nutritional deficiency disorders increase the loss of milk, decrease its availability, and increase the purchase cost to consumers—threatening the nutritional security of the nation (Hogeveen, Steeneveld, and Wolf 2019; Jodlowski et al. 2016; Nilsson et al. 2019).

One such metabolic illness is hypocalcaemia, or milk fever—the decrease in the level of blood calcium, due to the rapid drain of calcium into colostrum, after parturition, or calving (Melendez and Poock 2017; Rodríguez, Arís, and Bach 2017). High-yielding dairy animals are at greater risk of milk fever; for example, crossbred cattle are more susceptible than buffaloes.

Milk fever leads to immune suppression (Kimura, Reinhardt, and Goff 2006). Milk fever also increases the risk of other metabolic disorders, like dystocia, uterine prolapse, ketosis, and metritis. These disorders deteriorate the productive and reproductive performance of dairy animals and lead to economic loss (Goff 2008; Reinhardt et al. 2011; Melendez and Poock 2017; Oetzel and Miller 2012).

The economic literature provides evidence on the spread and persistence of bacterial and viral dairy animal diseases (Hayer et al. 2017; Sok and Fischer 2020) and on the associated losses (Govindaraj et al. 2017, 2021; Barratt et al. 2018). There is evidence in the literature on the control/prevention strategies as well (Hennessy 2007; Wang and Hennessy 2015; Schroeder et al. 2015; Weyori, Liebenehm, and Waibel 2021), but not on the economic effects of preventing nutritional deficiency disorders. And there is little data on the incidence of milk fever in India.

However, the incidence of milk fever has been documented to be 11–12% in the north-eastern states (Paul, Chandel, and Ray 2013), 13–14% in Tamil Nadu

(Thirunavukkarasu et al. 2010), and 10% in Himachal Pradesh (Thakur et al. 2017). In Tamil Nadu, between 2005 and 2008, the loss was estimated at around INR 41 crore (US$ 6 million)[1] (Thirunavukkarasu et al. 2010). In Haryana, during 2020, the loss was estimated at around INR 873 crore (US$ 118 million) (Cariappa et al. 2021a). Therefore, preventing milk fever is indispensable for the success of reproductive and productive performance of dairy animals (Melendez and Poock 2017) and from the economic point of view (Cariappa et al. 2021a).

Complex interactions between risk factors result in metabolic disorders, but these can be prevented by the right management decisions (Krieger et al. 2017), such as feeding dairy animals anionic salts—negative dietary cation–anion difference (DCAD) —before parturition (Blanc et al. 2014). Oral or intravenous calcium supplementation, instantly after calving, is another approach, but its benefits need investigation, because the evidence supporting it is not conclusive (Blanc et al. 2014). Several meta-analyses and systemic reviews of experiments conclude that feeding pre-partum dairy animals anionic feed—negative DCAD —reduces the incidence of milk fever and improves the concentration of calcium and their reproductive and productive performance (Oetzel 1991; Lean et al. 2006; Charbonneau, Pellerin, and Oetzel 2006; Santos et al. 2019; Lean et al. 2019). Only a very few studies beg to differ from these conclusions (Ramos-Nieves et al. 2009; Rajaeerad et al. 2020).

In 2016, the Indian Council of Agricultural Research–National Dairy Research Institute (ICAR-NDRI) developed and commercialized an anionic mineral mixture (AMM)—a powder that can be easily mixed with any feed or fodder and fed to dairy animals—to prevent milk fever (Kamdhenu 2020). Thakur et al. (2017) observe that the incidence of milk fever decreases from 10% among non-users of anionic diets to 2.5% among users, but the study does not quantify the improvement in yield. Except for this observational study, there is no evaluation of the effect of anionic diets on animal health or production parameters outside the controlled setting of the experimental farms of research institutes in India.

Our work is set in five villages of Haryana state, northern India, with 200 animals (100 cows and 100 buffaloes). We use a randomized controlled design to produce internally valid estimates of the effect of feeding farm dairy animals anionic diets to prevent milk fever. We include the economic effects on the incidence of milk fever, milk yield, cost of production, and farmer's net income.

This is the first study to combine an animal nutritional technology and randomized controlled trial to evaluate the economic effect of an animal nutritional technology in the field. In so doing, we complement the literature and contribute to it.

Study design

We begin by determining the sample size using statistical power calculations. No data is available on one primary outcome, the incidence of milk, and so we base our calculation of statistical power on the other primary outcome, milk yield per animal per day—as registered in the pre-analysis plan (Cariappa et al. 2021b). These calculations are designed to give an 80% power—chance to correctly detect the effect when there is an effect—at 5% level of significance.

We obtained the data on the mean of the milk yield in rural Haryana from the IndiaStat database (IndiaStat 2019). We took the standard deviation from a survey conducted in rural Haryana (Lal et al. 2020). We used these parameters and assumed an R^2 of 0.5 in the final impact regression (R^2 in the final regression was around 0.7). According to the power calculation, we required a minimum sample size of 172 animals to detect a statistically significant effect of 10% increase in milk yield between the treatment and control groups.

To account for the possibility of attrition, we selected for our sample 200 animals (100 cows and 100 buffaloes) from 200 different dairy farms: 100 animals (50 cows and 50 buffaloes) for the control group and 100 animals (50 cows and 50 buffaloes) for the treatment group. We sampled an additional 14 animals, in case of replacement.

Because the AMM is aimed at reducing milk fever in high-yielding dairy animals, we needed to work in areas where the milk yield is high and the population of high-yielding animals is large. The funding agency of the study has adopted five villages—Samora, Garhi Gujran, Churni, Kamalpur Roran, and Nagla Roran—

[1]Conversion rate (2020): US$ 1 = INR 74.10

in the Karnal district of Haryana state in India. Karnal is home to around 280,000 high-yield female bovines (110,000 exotic/crossbred cows and 180,000 buffaloes) (Government of Haryana 2020), and so these villages were ideal for our experiment.

We collected data from farmers who owned animals due for parturition in at least a month, not fed any type of anionic diet, and are at high risk of milk fever (animals in 2nd or above parity with peak milk yield of more than 10 kg per day; see the flowchart of the sampling plan in Appendix Figure 1).

We conducted a baseline survey during September 2020; between September and November, we supplemented the AMM intervention to the treatment group. The milk yield peaks 45–60 days post-parturition, and so we conducted our follow-up survey 2–3 months post-parturition, between the last week of January and the first week of February 2021.

Limitations

We purposively sampled high-yielding animals above 2nd parity at high risk of milk fever. The incidence of milk fever at the baseline may have been on the higher side, and we may have overestimated the impact of AMM. The results are true only for the population similar to our sample, not universal. Therefore, a scale-up of this pilot, or a large, cluster-level randomized design, is required to draw generalizable conclusions.

Intervention and design

The AMM is designed to reduce milk fever, and other post-partum problems, in cows and buffaloes. The technology contains Vitamin E, which is useful against oxidative stress in pregnant cows, as it makes them resistant to metabolic disorders and increases reproductive performance (Appendix Figure 2).

Dairy farmers are said to benefit economically because AMM supplementation improves the yield of milk by 10% and its fat content. The AMM also improves immunity and prevents various diseases (Kamdhenu 2020).

The AMM contains 7,640 mEq/L anionic value of sulphur; 5,080 mEq/L anionic value of chloride; 1,340 mEq/L cationic value of potassium, with a total negative DCAD of 11,380 mEq/L, and 10,000 IU/kg of Vitamin E. The recommended dosage of AMM is 50 gram each in the morning and evening three to four weeks before calving.

On the demand side, 77% of the farmers were aware of milk fever, but only around 3% (7 out of 214) knew of AMM; and only one farmer had used it earlier. Around 50% of the respondents reported taking precautionary measures against milk fever in their dairy animals post-partum, like feeding calcium solutions, jaggery, or both. But pre-partum preventive measures are not used, because AMM is not available in the villages, suburban centres nearby, or in the district headquarters (20–25 km from the village). This by default ensured that farmers cannot feed their animals an anionic diet; and that satisfies the inclusion criterion.

We separated the cows from the buffaloes. Then, we randomly assigned the animals to the treatment and control groups using the random number generator in Stata (World Bank 2018).

We gave all the farmers in the treatment group a brochure that explained the type of animal susceptible to milk fever, benefits and dosage of AMM. The brochure was in Hindi, the local language. We explained the benefits of AMM. We told the farmers how to use AMM, and the correct dosage, and the farmers supplemented the diet of all the animals in the treatment group with AMM.

Before we started the intervention, we took the control farmers into confidence and promised to give them the AMM later. This was essential, to avoid resentment against the institute. Also, because the farmers in the treatment and control groups are neighbours and the control farmers could attrite; the study is based on individual-level randomization.

We undertook the follow-up survey 60 days after the animals in the treatment group calved, and soon afterwards supplemented the control animals with AMM. We ensured that the farmers supplemented their animals with AMM properly and on time through regular field visits and telephone conversations.

Data and descriptive statistics

Dairy animals are supplemented with AMM to prevent milk fever and increase their yield.

Our primary outcomes—based on these goals, and as specified in the pre-plan—are the incidence of milk fever and milk yield.

We hypothesize that the AMM will prevent milk fever and reduce the expenditure on health enough—even above the cost of AMM—to increase revenue. Therefore, we test the impact of AMM on variable costs and net returns from dairying. These are our secondary outcomes.

Primary outcomes

Our primary outcomes are the incidence of milk fever (1/0) and average (fat-corrected) milk yield (kg per animal per day).

Incidence of milk fever

Usually, milk fever occurs within 72 hours of calving. The animals cannot stand up; they lie down, with their neck turned to one side and then laterally. In severe cases, the animal's temperature drops below normal, and it loses consciousness; if left untreated, it will succumb (NDDB 2019).

Farmers were asked if they had observed symptoms of milk fever in their animals and if they fell down after parturition at the baseline and follow-up. If the animals had clinical milk fever, we coded 1 for analytical purposes (and 0 otherwise). This is a self-reported measure; we contacted the local veterinarians who treated the animals to confirm the responses.

Milk yield (productivity)

At the baseline and follow-up, we recorded the peak milk yield, and converted it into the average daily milk yield by using the standard conversion factor.

$$\text{Average daily milk yield} = \text{peak yield} \times \frac{200}{\text{lactation length}}$$

Buffalo and cow milk differ in fat content. When analysing the whole sample, we use a 3.5% fat-corrected milk (FCM) yield; in other words, we standardize the cow and buffalo milk at 3.5% fat content when we combine both cows and buffaloes for analysis (Birthal et al. 2017).

The standardization to 3.5% fat content was done using the formula

FCM (3.5%) = (0.35 × quantity of milk in kg) + (18.57 × fat in kg) (Parekh 1986). The unit of measurement is kg per animal per day.

Secondary outcomes

Our secondary outcomes are variable costs and net returns from dairying.

Variable costs of milk production (INR per animal per lactation)

To calculate the total variable cost, we add the feed and fodder costs; veterinary costs, like expenses on artificial insemination, vaccination, and deworming; hired labour costs; and the cost of treating milk fever (veterinarian's fee and the cost of medicine).

Income/net return from dairying (INR per animal per lactation)

To calculate the net return, we subtract the variable cost from the value of milk produced (the product of price of milk (INR per kg) and total lactation milk production (kg)).

$$\begin{aligned}\text{Lactation milk production (in kg)} &= \text{average daily milk yield (in kg/day)} \\ &\times \text{lactation length (in days)}\end{aligned}$$

Sample characteristics

Dairying is the principal source of income for the sample farmers (67%). The farmers in the treatment and control groups own 6–7 acres of land and 5–6 dairy animals (Table 1).

The milk yield averages 8 kg per buffalo per day and 10–11 kg per cow per day. The incidence of milk fever at the baseline is around 15% in cows and 27% in buffaloes. All the animals in the sample are in their third parity on average.

The net income, or net returns to variable costs, is around INR 52,888 (US$ 714) per buffalo per annum, higher than the INR 42,881 (US$ 579) per cow per annum. The average variable cost is a little higher for crossbred cows than for buffaloes.

We had selected higher parity animals, with a peak milk yield of at least 10 kg per day; our inclusion criteria are reflected in the summary of baseline characteristics. We used as control variables herd size and the green fodder, dry fodder, and concentrates fed; on average, per day, dairy animals are fed 20–21 kg of green fodder, 12 kg of green fodder, and 4 kg of

Table 1 Baseline characteristics of sampling units and mean difference by treatment status

Variables	Buffalo (n=100)					Cow (n=100)					Overall (n=200)				
	Control (n=50)		Treated (n=50)		Mean Diff	Control (n=50)		Treated (n=50)		Mean Diff	Control (n=100)		Treated (n=100)		Mean Diff
	Mean	SD	Mean	SD	(C-T)	Mean	SD	Mean	SD	(C-T)	Mean	SD	Mean	SD	(C-T)
Panel A. Dependent variables															
Average milk yield (kg/animal/day)	7.80	1.94	7.86	2.82	–0.06	10.19	3.84	10.72	4.57	–0.53	8.99	2.45	9.29	4.25	–0.30
Incidence of MF (1/0)	0.18	0.37	0.12	0.26	0.06	0.28	0.44	0.26	0.35	0.02	0.23	0.32	0.19	0.40	0.04
Net income (000’ ₹ /animal/lactation)	51.22	22.26	54.56	23.18	–3.34	40.85	33.72	44.91	39.23	–4.06	46.03	28.90	49.74	32.42	–3.70
Average variable cost (₹ /animal/ day)	195.32	40.79	188.20	45.22	7.12	178.54	45.65	190.20	56.29	–11.66	186.93	43.89	189.20	50.81	–2.27
Panel B. Household characteristics															
Experience in dairying (years)	13.22	9.55	14.20	10.96	–0.98	14.76	7.92	15.26	9.61	–0.50	13.99	10.26	14.73	8.79	–0.74
Education (1–7)+	4.36	1.42	4.22	1.89	0.14	4.10	1.74	4.06	1.58	0.04	4.23	1.59	4.14	1.74	0.09
Training in dairying (1/0)	0.26	0.44	0.24	0.43	0.02	0.32	0.47	0.38	0.49	–0.06	0.29	0.46	0.31	0.46	–0.02
Principal income from dairying (1/0)	0.66	0.48	0.52	0.50	0.14	0.68	0.47	0.82	0.38	–0.14	0.67	0.47	0.67	0.47	0.00
Land owned (acres)	6.39	6.61	6.41	5.63	–0.02	5.12	4.58	6.83	5.48	–1.71*	5.76	6.12	6.62	5.11	–0.86
Panel C. Animal characteristics															
Parity (nos.)	2.64	0.80	2.80	0.81	–0.16	2.80	1.03	2.80	0.90	0.00	2.72	0.81	2.80	0.97	–0.08
Peak milk yield in the previous lactation (kg/animal/ day)	11.89	2.95	11.98	4.30	–0.09	15.54	5.86	16.35	7.02	–0.81	13.72	3.74	14.17	6.51	–0.45
Herd size (nos.)	6.24	3.18	6.30	2.82	–0.06	4.60	2.95	5.10	2.56	–0.50	5.42	3.00	5.70	2.77	–0.28
Health score#	3.60	0.67	3.48	0.86	0.12	3.74	0.69	3.80	0.53	–0.06	3.67	0.77	3.64	0.62	0.03
Panel D. Feed and fodder fed															
Green fodder fed (kg/animal/ day)	21.65	6.58	20.49	6.30	1.16	20.27	6.17	17.68	4.59	2.59**	20.96	6.45	19.09	5.58	1.87**
Dry fodder fed (kg/animal/ day)	12.32	3.76	12.85	5.14	–0.53	10.71	4.11	12.03	4.90	–1.32	11.52	4.50	12.44	4.56	–0.93
Concentrate fed (kg/animal/ day)	3.90	1.52	3.47	1.36	0.42	3.56	1.64	3.59	1.54	–0.03	3.73	1.45	3.53	1.59	0.20
Milk price received (₹ /kg)	46.60	4.10	46.60	4.34	0.00	30.56	1.20	31.32	2.14	–0.76**	38.58	8.60	38.96	8.40	-0.38

Note ** and * indicates statistical significance at 5% and 10%, respectively.
+ 1 is illiterate, 2 is educated up to primary school (1–5), 3 middle school (6–8), 4 secondary school (9–10), 5 higher secondary (11–12), 6 diploma / certification, and 7 is graduate and above.
# Health score is an index computed by adding four dichotomous variables: artificial insemination (1/0), vaccination (1/0), deworming (1/0), and others (1/0).
Source Authors’ calculations

concentrate. Cows in the control group are fed significantly more green fodder than those in the treatment group. Note that the baseline characteristics of treatment and control group are similar except for 2-3 variables.

Balance test

Although statistical similarities in the individual variables are achieved, sometimes the differences in characteristics between the treatment and control group might be in the same direction, indicating the inability of the random assignment to generate two statistically similar groups. A solution is to complement Table 1 with a test for joint orthogonality (Table 2) (McKenzie 2015).

The treatment status has a non–significant relationship with the control and dependent variables—except for the net income and variable costs incurred (at 10% level)— shows the linear probability estimates of the correlates of the treatment status (Table 2). The random assignment to two groups has succeeded in generating balance (p = 0.91), indicated the joint test of orthogonality (F-test).

Under pure randomization, we can expect balance in unmeasured or unobserved variables if balance is achieved in the observed variables (Bruhn and McKenzie 2009); any difference between the treatment and control groups could then be attributed to the intervention and causally interpreted.

Estimation strategy

Following McKenzie (2012), we estimate an intent-to-treat (ITT) analysis using the randomized controlled design and the analysis of covariance (ANCOVA) specification. When evaluating the impact of interventions on outcomes that have less autocorrelations in the baseline and follow-up—such as household income, consumption expenditure, and profits—ANCOVA with lagged dependent variable achieves more power than difference-in-differences (DID) (McKenzie 2012). We estimate the multivariate model

$$Y_{it} = \beta_0 + \beta_1 \times Y_{it-1} + \beta_2 \times D_i + \varepsilon_i$$

where Y_{it} and Y_{it-1} is the outcome of interest (for instance farmer's income) for animal i at the follow-up and baseline, respectively.

Table 2 Balance test: linear probability estimates

Dependent variable: Treatment status (1/0)	(1) Buffalo	(2) Cow	(3) Overall
Incidence of MF (1/0)	–0.131	–0.008	–0.064
	(0.164)	(0.130)	(0.096)
Average daily milk yield (kg/animal)	0.008	–0.132	0.002
	(0.099)	(0.077)	(0.020)
Net income (000' ₹ /animal/lactation)	0.000	0.000*	0.000
	(0.000)	(0.000)	(0.000)
Years of education of dairy farmer	0.008	–0.032	–0.021
	(0.048)	(0.040)	(0.029)
Years of experience in dairying	0.003	0.000	0.001
	(0.007)	(0.006)	(0.004)
Land holding (acres)	–0.001	0.019	0.008
	(0.010)	(0.013)	(0.008)
Herd size (nos.)	0.014	0.008	0.008
	(0.023)	(0.021)	(0.014)
Variable costs incurred (₹ /animal/day)	–0.001	0.004*	0.000
	(0.002)	(0.002)	(0.001)
Training in dairying (1/0)	0.006	0.089	0.061
	(0.143)	(0.149)	(0.095)
Health index of the animal	–0.043	0.060	0.021
	(0.082)	(0.093)	(0.062)
Extension (contact) index	0.009	–0.117	–0.057
	(0.070)	(0.071)	(0.049)
Constant term	0.604	0.458	0.427
	(0.503)	(0.394)	(0.301)
N	100	100	200
R^2	0.03	0.11	0.03
Joint test of orthogonality (F test)	0.26	1.34	0.49
p-value	0.99	0.22	0.91

Note * $p < 0.1$. Standard errors in parentheses.
Source Authors' calculations

D indicates the treatment status of animal i (treatment=1 and control=0)

β_2 is the parameter of interest as it captures the impact of being in the treatment group.

We also use an extended model by simply adding baseline covariates (X_i) to the above equation as follows:

$$Y_{it} = \beta_0 + \beta_1 \times Y_{it-1} + \beta_2 \times D_i + \beta_3 \times X_i + \varepsilon_i$$

The baseline covariates (X_i) are added to increase the precision and to correct any baseline imbalances between treated and control animals.

Results and discussion

Impacts of AMM

Supplementing animal feeds with AMM reduced the incidence of milk fever, in absolute terms, in buffaloes from 15% at the baseline—the baseline value is the average of control animals and to-be-treated animals—to 2% at the follow-up (the follow-up value is from the treated animals) and, in cows, from 22% at the baseline to 2% at the follow-up (Figure 1). And the probability of milk fever incidence fell by 15 percentage points ($p < 0.01$) (Table 3, Panel A), implying that if AMM is supplemented, the incidence of milk fever will fall from 21% at the baseline to 6%.

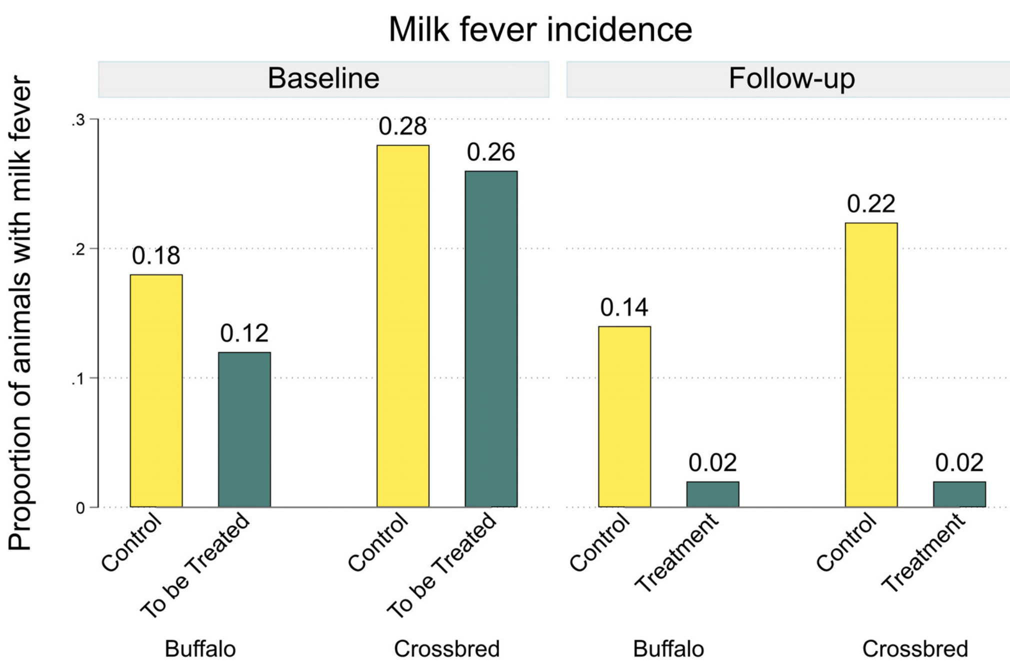
Supplementing animal feeds with AMM increases the FCM yield by 1.50 kg per animal per day ($p < 0.01$), a 14.3% increase over the baseline value, and it leads to a decline in the variable costs of milk production and an increase in farmer income. The variable costs fall by INR 1,626 (US$ 22) (2.83%, $p < 0.1$). Farmer income rises by INR 16,764 (US$ 226) (35%, $p < 0.01$).

Randomization is a process that generates two statistically identical groups by randomly assigning subjects to the treatment and comparison groups. A test of validity of randomization asks how the additions of control covariates affect the coefficient of interest (Ashraf, Berry, and Shapiro 2010). Adding covariates to the ANCOVA specification does not alter the impact estimates, we find, implying that our randomization is valid and successful in creating two identical groups. Our estimates are robust to alternative specifications, like DID, and to alternative functional forms, Appendix Tables 1 and 2.

The null hypothesis is that the distributions of the treated and control farmers are similar (Figures 2 and 3). The Kolmogorov–Smirnov test for the equality of milk yield and income distributions rejects the null hypothesis ($p < 0.01$), implying that all the farmers—not only some well-to-do farmers—contribute to the increase in the milk yield and net income, as the whole distribution of the treated group in the follow-up shifted to the right.

The incidence of milk fever decreased by 70% ($p < 0.01$) in treated cows and by 60% ($p > 0.1$) in treated buffaloes, as expected, because the incidence is higher in cows than in buffaloes (Table 3, Panel B).

The reduction in variable costs was not statistically significant, but it was higher for cows (INR 2,271, or ~ US$ 31) than for buffaloes (INR 937, or ~ US$ 13). Supplementing feeds with AMM increases the milk



Source Authors' calculations

Figure 1 Incidence of milk fever

Table 3 Impact of AMM supplementation

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent Variable	Probability of MF occurrence		Milk yield (kg/animal/d)		FCM yield (kg/animal/d)		Variable costs (₹ /animal/lactation)		Net returns (₹/animal/lactation)	
A. Overall sample										
AMM	–0.15***	–0.15***	1.24***	1.27***	1.51***	1.50***	–1623**	–1626*	16,775***	16,764***
	(0.04)	(0.04)	(0.25)	(0.22)	(0.25)	(0.25)	(683)	(681)	(2634)	(2616)
Baseline mean	0.21		9.14		10.47		57,360		47,891	
% change	–71.43		13.89		14.33		–2.83		35.00	
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	200	200	200	200	200	200	200	200	200	200
R^2	0.25	0.26	0.78	0.82	0.69	0.70	0.91	0.91	0.71	0.73
F	15.11	6.10	284.8	95.40	205.1	59.64	661.1	780.6	247.6	40.31
B. Stratified sample										
Strata	Cow	Buffalo	Cow	Buffalo	Cow	Buffalo	Cow	Buffalo	Cow	Buffalo
AMM	–0.19***	–0.09	1.22*	1.21**	1.10*	1.77**	–2270.6	–937	14694**	18857**
	(0.052)	(0.047)	(0.36)	(0.20)	(0.32)	(0.30)	(1097.9)	(846.2)	(3966.8)	(3348.7)
Baseline mean	0.27	0.15	10.46	7.82	9.48	11.46	56233	58487	42881	52888
% change	–70.37	–60.00	11.66	15.47	11.60	15.44	–4.04	–1.60	34.27	35.65
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	100	100	100	100	100	100	100	100	100	100
R^2	0.39	0.17	0.82	0.47	0.82	0.47	0.92	0.92	0.83	0.59
F	7.18	2.60	72.8	11.7	72.8	11.7	419.1	346.1	37.8	13.7

Note Standard errors in parentheses. Romano-Wolf step-down adjusted p-values are used to correct for multiple hypothesis testing.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Columns 1–2: Marginal effects are estimated at treated = 1 and period = 1 (i.e., treatment group at the follow-up), thus are average treatment effects on treated (ATT).

Controls used in stratified sample are milk yield and parity; in overall model, milk yield, parity, and type of animal (cow = 1 and buffalo = 0).

Columns 3–6: Control covariates in stratified sample: green fodder fed, dry fodder fed, and concentrates fed (all in kg per animal per day) and parity of animals; overall model included an additional variable, type of animal (1 for cow, 0 for buffalo).

Columns 7–10: Control covariates: parity and herd size (in numbers), green fodder fed, dry fodder fed, and concentrates fed (all in kg per animal per day in linear models and its log values in log transformed models), health score, training on dairying (1/0), experience, landholding, principal income from dairying (1/0) and extension score; and type of animal (1 for cow, 0 for buffalo) in the overall equation.

Source Authors' calculations

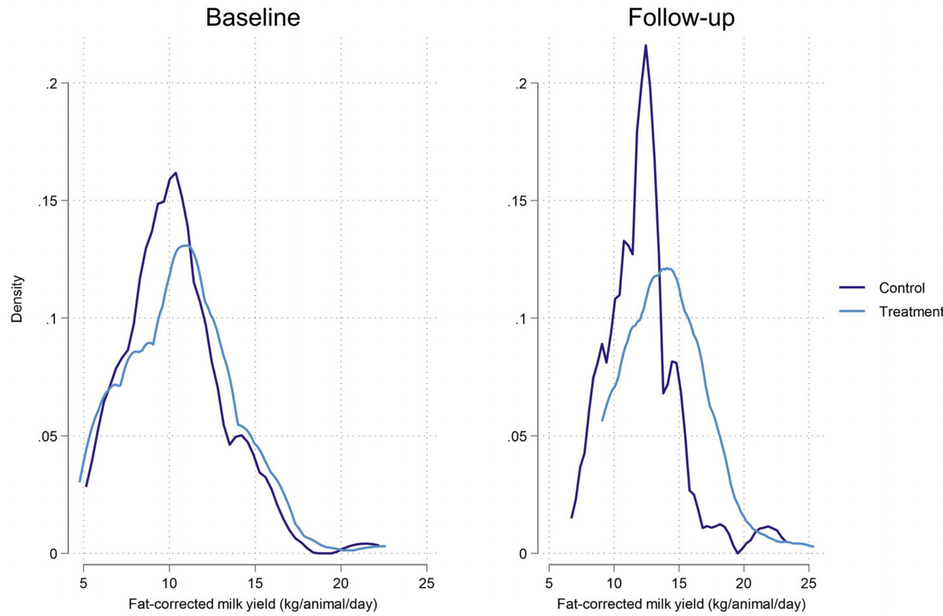
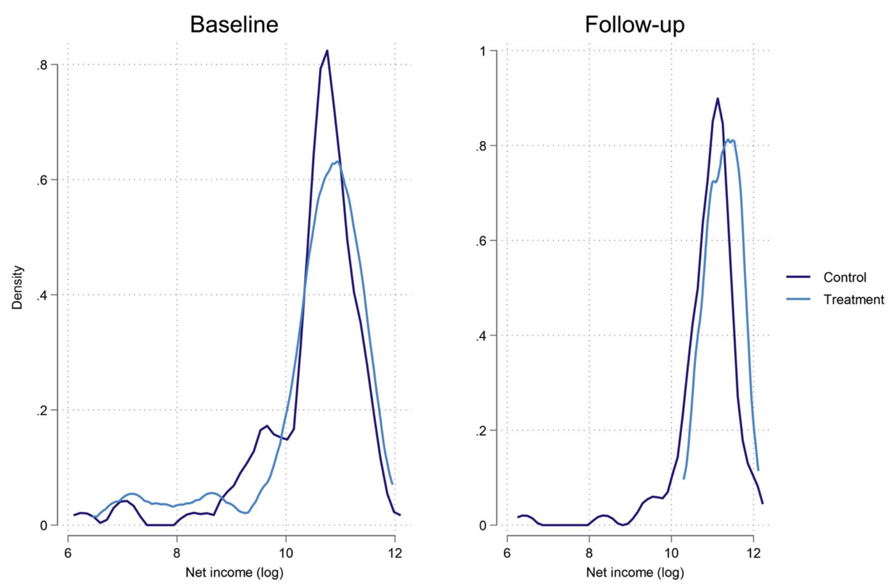


Figure 2 Distribution of 3.5% fat-corrected milk yield in control and treated groups by period



Source Authors' calculations

Figure 3 Distribution of farmer's net income from milk in control and treated groups by period

yield of cows by 12% ($p < 0.1$) and of buffaloes by 15% ($p < 0.05$); it also increases the returns to variable costs by 34% ($p < 0.05$) in cows and by 36% ($p < 0.05$) in buffaloes.

Our findings are in line with several experiments in foreign settings and in the results of meta-analyses (Lean et al. 2019; Santos et al. 2019; Melendez et al. 2019; Iwaniuk and Erdman 2015; Weich, Block, and Litherland 2013). Even the impact estimates from this study are comparable to the pooled impact estimates from meta-analysis; for instance, our estimate that milk yield increased by 1.5 kg per day, or 14%, is in line with the increase, 1.7 kg per day, reported by a meta-analysis (Lean et al. 2019).

We estimated the total economic loss (milk production loss + treatment cost + mortality loss) in the sample at INR 4,320 (USD 58.3) per animal. We simulated the total economic loss in Haryana to be around INR 873 crores (USD 137 million) (Cariappa et al. 2021a).

The finding that AMM supplementation reduces the incidence of milk fever is encouraging, and it has important implications for farmer welfare, because the population of exotic and crossbred cattle in India increased by 27% from 2012 to 2019 (PIB 2019), milk production increased around 47% (NDDB 2020), and the productivity of Indian dairy animals, too, has been increasing; therefore, the risk of milk fever is growing continually (Appendix Figure 3), and we recommend the use of AMM to prevent huge income loss due to milk fever.

Heterogeneous impact of anionic mineral mixture

The conventional wisdom is that older animals and animals at their peak of milk production are more susceptible to milk fever.

We had stratified our sample into a cow stratum and a buffalo stratum. We expect the impact to be homogeneous across the categories of animals and dairy farmers. Therefore, we test the impact on the parity of animals to check if it is homogeneous or differential.

We expect that compared to medium-size and large dairy farmers, small farmers would gain more from AMM supplementation because they were less likely to use preventive measures, like calcium solutions, against milk fever.

We expected that farmers who had undergone formal training in commercial dairying manage their herds better, and they have good breeds of animals with higher yields, and would therefore benefit from AMM supplementation more than would farmers who had not undergone formal training in commercial dairying.

Table 4 displays the coefficients of the interaction variable, treatment indicator (fed AMM or not) with covariates such as type of animal, parity, herd size, training in dairying, and the results of the F-test of equality of coefficients.

If the difference between the coefficients is statistically significant, we conclude that the impact is heterogeneous.

Table 3, Panel B displays the results of heterogeneous impacts of AMM on cows and buffaloes (see the subsection on the impact of AMM).

The F-test of equality coefficients of cows and buffaloes was not rejected ($p > 0.1$), implying that AMM is equally effective in reducing the incidence of milk fever in cows and buffaloes and in improving the welfare of dairy farmers.

Table 4, Panel B depicts the differential impact on animals of different parities. The results indicate that the effect of AMM on milk fever incidence is highest in the 5th parity (a 100% probability of reduction), and it is significantly different from the effects on the 2nd, 3rd, and 4th parity animals at $p < 0.01$ (Column 1). The increase in milk yield was highest in the 5th parity, and it was statistically higher ($p < 0.1$) than among animals in the 3rd parity. However, the effect of AMM on net returns was equal ($p > 0.1$) for animals of all parities (Column 6).

Table 4, Panel C presents the impact of AMM on small, medium-size, and large dairy farmers by herd size. Small dairy farmers experienced substantially higher positive effects in all the outcomes measured except for variable costs. Medium-size farmers experienced a higher milk yield and income gain than did large farmers ($p < 0.05$). Compared to farmers with no formal training, farmers formally trained in dairy farming had higher gains except for variable costs (Panel D).

Therefore, needy vulnerable farmers—farmers who own small herds (<6 animals) and older animals—who attend formal training programmes experience greater benefits than others from supplementing animal feeds with AMM. This finding has important implications for policy.

Conclusions

We use a randomized controlled design to evaluate the impact of AMM, a preventive health product, on milk fever in 200 dairy animals.

Supplementing animal feed with AMM prevents milk fever and improves animal health and productivity—the incidence of milk fever falls by 71%, and milk yield

Table 4 Heterogeneous impact of AMM

Model → Dependent variable	(1) Probability of MF occurrence	(2) Milk yield (kg/animal/d)	(3) FCM yield (kg/animal/d)	(5) Variable cost (₹/animal/lactation)	(6) Net returns (₹/animal/lactation)
A. Type of animal					
Cow	-0.19***	1.37***	1.28***	-2514.1**	15907.9***
	(0.052)	(0.38)	(0.36)	(1015.5)	(3613.7)
Buffalo	-0.10*	1.18***	1.73***	-742.4	17571.2***
	(0.05)	(0.247)	(0.34)	(829.38)	(3794.25)
F test of equality of coefficients					
Cow=Buffalo	1.57	0.18	0.82	1.95	0.10
B. Parity					
2nd parity	-0.11*	1.46***	1.67***	-680.9	17001.6***
	(0.057)	(0.39)	(0.35)	(503.7)	(3546.2)
3rd parity	-0.11**	0.95**	1.14***	-1468.3	13166.7***
	(0.050)	(0.39)	(0.38)	(1058.2)	(4116.1)
4th parity	-0.24**	0.60	1.40*	-5015.8*	19173.3**
	(0.11)	(0.71)	(0.81)	(2577.5)	(9257.0)
5th parity	-1.00***	3.41**	3.16***	8377.3	23560.5***
	(0.17)	(1.66)	(1.08)	(7503.5)	(8377.7)
F test of equality of coefficients					
T_2 = T_3	0.01	0.87	1.02	0.42	0.50
T_2 = T_4	1.16	1.13	0.09	2.66	0.05
T_2 = T_5	24.55***	1.30	1.73	1.45	0.52
T_3 = T_4	1.05	0.20	0.09	1.74	0.36
T_3 = T_5	24.66***	2.09	3.12*	1.71	1.23
T_4 = T_5	13.54***	2.43	1.71	2.90*	0.12
C. Herd size (number of animals)					
Small (<6)	-0.15***	1.48***	1.69***	-2234.9**	19142.0***
	(0.045)	(0.36)	(0.34)	(1089.1)	(3552.5)
Medium (6-10)	0.00	-0.53	-0.36	1092.7	-4891.2
	(0.06)	(0.45)	(0.45)	(1221.8)	(4806.3)
Large (>10)	-0.05	1.10**	0.96*	1498.1*	10619.1*
	(0.07)	(0.55)	(0.56)	(772.0)	(5665.5)
F test of equality of coefficients					
Small=Medium	2.85*	7.16***	7.99***	2.26	10.02***
Small=Large	1.31	0.31	1.14	5.69**	1.56
Medium=Large	0.94	7.05***	4.34**	0.15	5.95**
D. Training in dairying					
Training	-0.34***	2.01***	2.16***	-2100.8	24070.6***
	(0.090)	(0.50)	(0.47)	(1361.0)	(4866.7)
No training	-0.068**	0.91***	1.22***	-1440.4*	13669.4***
	(0.032)	(0.29)	(0.29)	(789.7)	(3094.7)
F test of equality of coefficients					
Training=No training	7.90***	3.73**	2.95*	0.17	3.30*

Note: Columns display OLS regressions for six outcome variables as dependent variables. Variable in each row is interacted with the treatment variable. Each cell displays the coefficient of the interaction term of control covariate (row) and the treatment indicator.

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

rises by 14%—and reduces variable costs by 3% and improves farmer profit by 35%.

The total economic loss due to milk fever is INR 4,320 per animal (Cariappa et al. 2021a). If farmers supplement animal feed with AMM, milk yield increases by 1.5 kg per day and farmer income by INR 16,000 (USD 216) per animal per annum. Even if the market price of AMM (a maximum of INR 900 (USD 12) per animal) is subtracted, the net gain is INR 15,000 (USD 202).

The effect of AMM supplementation varies by farmer type: it is higher on small farmers (herd size < 6 animals), older animals, and who had attended formal training in dairying.

Preventing milk fever reduces economic loss and increases productivity and profit; therefore, the prevention of milk fever (+ INR 15,000, or ~ US$ 202) is better than the cure (INR 4,320, or ~US$ 58).

Farmer adoption of technology is constrained by demand-side, supply-side, and mediating factors: insufficient managerial skills; behavioural traits, such as procrastination; credit constraints; high transaction costs; non-existence of technology; lack of understanding; and unavailability (De Janvry et al. 2016).

If animal feeds are supplemented with AMM, the potential of improving farmer welfare is huge, but more farmers must adopt AMM supplementation, and there is potential for rapid adoption.

First, the demand-side constraint for technology adoption will relax in the future as the risk of milk fever rises. Farmers will adopt AMM supplementation because it reduces the incidence of milk fever and the production cost by INR 1,600 per animal, much more than the market price of AMM (maximum INR 900 per animal). Supplementing animal feeds with AMM saves on cost, and farmers rapidly adopt technologies that improve productivity and income (Ogutu et al. 2018).

Second, preventing milk fever can save the state of Haryana INR 873 crore (USD 1.5 billion) (Cariappa et al. 2021a). The government and public sector could subsidize AMM and distribute it, as the fertilizer policy does, and remove the supply-side constraints by using modern extension tools to explain to farmers that AMM is easy to use. The private sector, too, can use the evidence that AMM is a cost-saving, productivity-enhancing technology to market it.

Finally, the income gain from AMM use can overpower the influence of mediating factors.

Further research building on this successful pilot is required to corroborate the results in different settings to draw generalizable conclusions. Therefore, promoting the use of prevention strategies and training of dairy farmers is recommended by the study.

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Ethics approval

The experiment involving dairy animals were conducted under the guidelines of ICAR-NDRI Animal Ethical Committee. The research proposal was discussed and approved in the Inter Disciplinary Seminar of the Institute (a seminar of the Institutional Review Board chaired by the Joint Director (Research)). Also, farmer's consent was taken prior to the interview after explaining the length of the study and especially, the need to contact repeatedly.

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Appendix

Table 1 Robustness to alternative specification

Strata	Cow		Buffalo		Overall	
Panel A Dependent variable: milk yield						
Estimator	Difference-in-Differences (DID)					
Dependent variable in#	kg/animal/ day	Natural logarithm	kg/animal/ day	Natural logarithm	kg/animal/ day	Natural logarithm
Treatment	1.319	0.106	1.173***	0.123***	1.457**	0.115**
	(1.100)	(0.086)	(0.364)	(0.044)	(0.563)	(0.048)
Mean of milk yield in baseline	10.456	2.292	7.823	2.039	10.472	2.307
Controls?	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.19	0.22	0.40	0.38	0.30	0.33
Panel B Dependent variable: net returns from dairying						
Estimator	Difference-in-differences (DID)					
Dependent variable in	₹/animal/ lactation	Natural Logarithm	₹/animal/ lactation	Natural logarithm	₹/animal/ lactation	Natural logarithm
Treatment	14666	0.523**	17727***	0.245**	16196***	0.380**
	(9192)	(0.262)	(5732)	(0.119)	(5657)	(0.149)
Mean of income in baseline	42881	10.219	52888	10.758	47885	10.496
Controls?	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.42	0.37	0.48	0.43	0.37	0.33
Number of observations	200	200	200	200	400	400

Note Panel A: # Dependent variable in overall sample is 3.5% fat corrected milk (FCM). FCM = (0.35 x milk in kg) + (18.57 x fat in kg)

Control covariates: green fodder fed, dry fodder fed and concentrates fed (all in kg/animal/day) and parity of animals; and of FCM included an additional variable, type of animal (1 – cow, 0 – buffalo)

Panel B: Net income = gross income – variable cost. Variable costs included are a sum total of expenses on green fodder, dry fodder, concentrates, hired labor including veterinary costs (artificial insemination, vaccination and deworming) and MF treatment costs

Control covariates: parity and herd size (in nos.), green fodder fed, dry fodder fed and concentrates fed (all in kg/animal/day in linear models and its log values in log transformed models), health score, training on dairying (1/0), experience, land holding, principal income from dairying (1/0) and extension score; and type of animal (1 – cow, 0 – buffalo) in overall equation

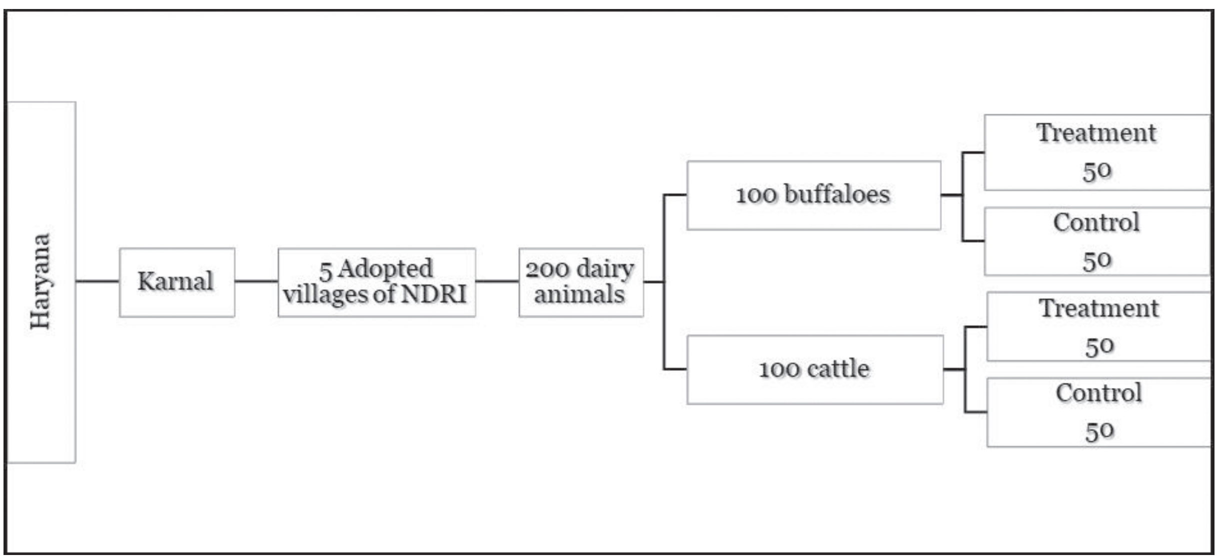
Figures in parenthesis are standard errors

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

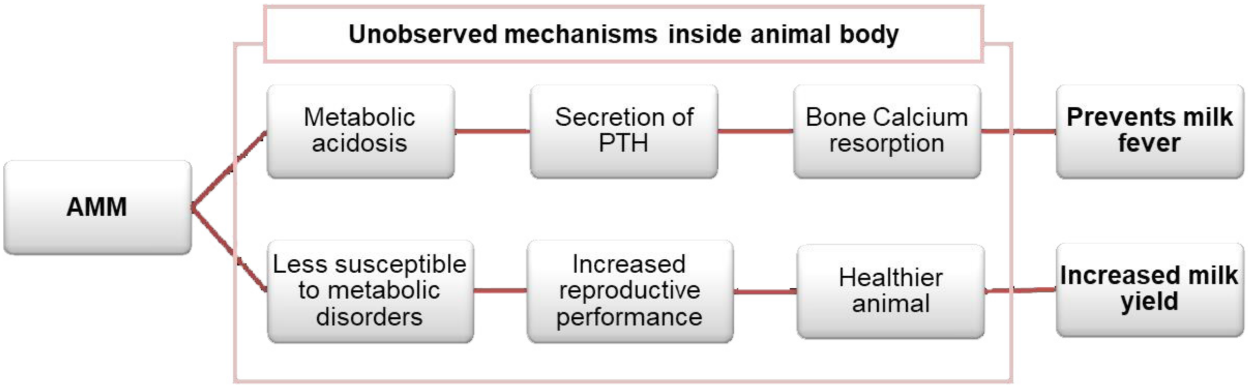
Table 2 Robustness to alternative functional forms

Dependent variable: FCM	(1)	(2)	(3)	(4)
Estimator	ANCOVA (Lagged dependent variable)			
Specification	Lin-lin	Log-lin	Lin-log	Log-log
Treated (1/0)	1.50***	0.11***	1.68***	0.13***
	(0.25)	(0.02)	(0.25)	(0.02)
Controls	Yes	Yes	Yes	Yes
N	200	200	200	200
R^2	0.699	0.702	0.673	0.698
adj. R^2	0.688	0.691	0.661	0.688
AIC	798.290	-241.540	814.580	-239.039
BIC	824.676	-215.153	840.967	-212.653
F	59.64	66.64	51.19	64.25

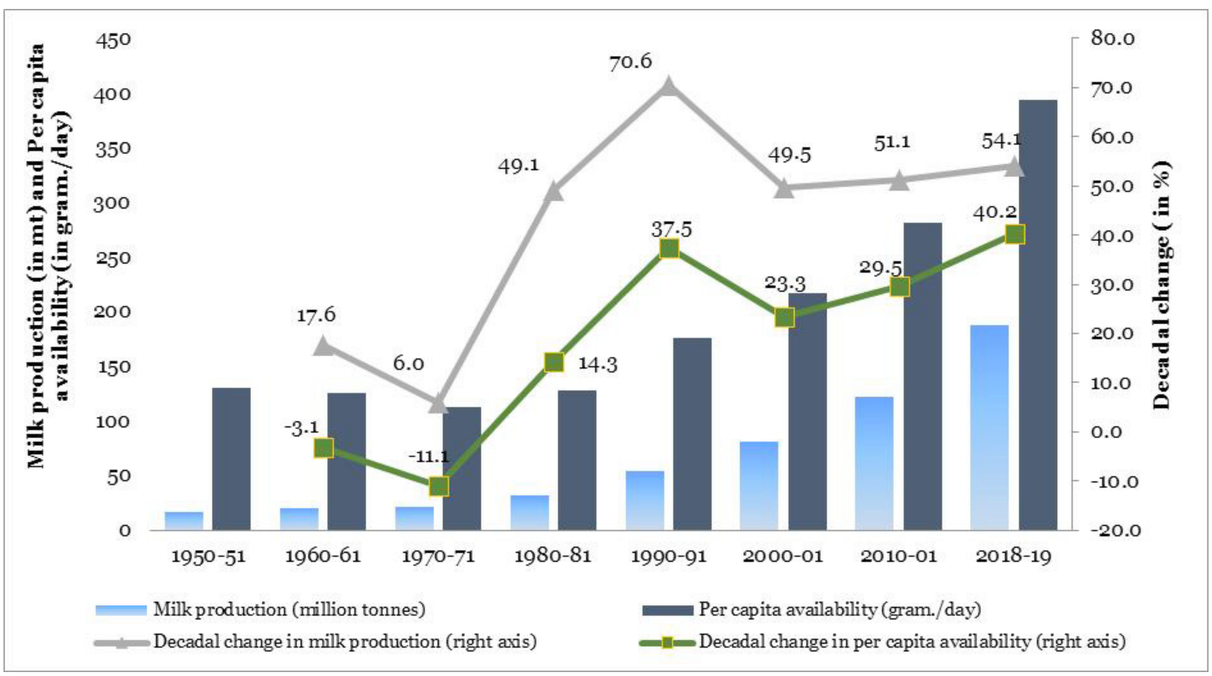
Note: Figures in parenthesis are standard errors
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.



Appendix Figure 1 Sampling plan of the study



Appendix Figure 2 Causal pathway of AMM



Appendix Figure 3 Milk production in India (1950-2018)