



Genetic improvement of cattle and buffaloes in smallholder production systems in India

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ABSTRACT

Cattle and buffaloes have been supporting livelihoods of a large number of poor farmers in India. Eighty-five percent of 63 million dairy households are smallholder having less than three animals. The country has 191 million cattle and 105 million buffaloes and 37 distinct cattle and 13 buffalo breeds. During 2017–18, the country produced 115 million semen doses and carried out 100 million inseminations, but efforts towards genetic improvement were negligible prior to the launching of National Dairy Plan (NDP) by National Dairy Development Board in 2012. Under NDP, 13 progeny testing (PT) and 10 two-tier nucleus schemes (referred to as Pedigree Selection (PS)) have been initiated. This paper describes the experiences of implementing these programs. During the period between 2012 and 2018, the PT programs together have completed test mating of about 2,000 bulls and built the infrastructure to test annually more than 400 bulls and evaluate them for various traits with 70–100 daughter records per bull. Breeding values are estimated every six months. The PT and PS programs together have supplied 1,720 young bulls, replacing about 40% of the AI bulls in the country. The key learning of implementing PT and PS includes: implementing a classical PT program is not feasible under Indian conditions; producing young males using progeny tested semen and selecting them based on their breeding value is feasible; introduction of genomic selection is very relevant; unravelling environmental effects from genetics under the smallholder production system is the key challenge; developing an appropriate information system is the key to success; evolving right institutional arrangement is very important, and genetic improvement has to be treated as a public good and programs need to be publicly funded at least for the initial 15 years.

Keywords: Developing countries, Genetic evaluation, Genetic improvement programs, Smallholder production systems

Cattle and buffaloes have been an integral part of Indian rural households from time immemorial and playing a critical role in supporting and sustaining livelihoods of a large number of poor farmers. Of the total 156 million rural households, some 63 million households own at least one cow or buffalo and dairying provides them a major source of livelihood (NSSO, 2013). About 85% of the dairy farmers are small and marginal owning one to three animals. Milk is an important part of food and nutrition security for a largely vegetarian society of 1.3 billion people.

India has a huge population of cattle and buffaloes with vast biodiversity. According to the Livestock Census 2012, the country had 191 million cattle and 105 million buffaloes (19th Livestock Census, 2012). There are 37 well-defined breeds of cattle and 13 of buffaloes (Breed Survey, 2013). The country has a very large infrastructure for semen production and artificial insemination (AI) services. There are 54 semen stations, which produced 115 million frozen semen doses during 2017–18, and more than 120 thousand AI service centres carrying out some 100 million inseminations.

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However, there had been a few isolated efforts to implement systematic genetic improvement programs in cattle and buffaloes prior to the launching of its National Dairy Plan (NDP) by National Dairy Development Board (NDDB) in 2012. NDDB, under its NDP, has initiated genetic improvement programs for 14 breeds—9 cattle breeds, viz. Gir, Sahiwal, Rathi, Kankrej, Tharparkar, Hariana, pure Holstein Friesian (HF), HF crossbred (HFCB) and Jersey crossbred (JCB) and five buffalo breeds namely Murrah, Mehsana, Nili Ravi, Jaffarabadi, and Pandharpuri. If the native tract had a good infrastructure for artificial insemination, a progeny testing program (PT) was developed for that breed and in case the infrastructure for AI was poor a pedigree selection (PS) program was developed for the breed. The programs under NDP were supported through an IDA loan from the World Bank to GoI. GoI made available the funds as grant-in-aid to NDDB to be passed on to the project implementing agencies. This paper describes the experiences and learnings of implementing the PT and PS programs under NDP.

MATERIALS AND METHODS

The components considered in putting in place both the

progeny testing and pedigree selection programs include: defining a breeding goal; designing an appropriate breeding scheme; evolving an effective institutional arrangement; building an infrastructure for performance recording; developing and putting in place an information system; estimating breeding values; building an infrastructure for dissemination of genetics; and establishing monitoring and evaluation systems.

Breeding goal: As the breeds selected were dairy or dual-purpose breeds, the primary breeding goal set for all PT and PS programs was to increase milk production and milk components without compromising on functional traits related to fertility and health.

Breeding design: For certain breeds such as pure HF, HFCB, JCB, Murrah buffalo, and Mehsana buffalo, a large population of respective breeds having good infrastructure for artificial insemination was available in a few pockets in the country and, therefore, it was possible to initiate a structured PT program for these breeds. For other important native cattle breeds such as Gir, Sahiwal, Kankrej, Rathi, Hariana, and Tharparkar and that of buffalo breeds, viz. Jaffarabadi, Nili Ravi and Pandharpuri having a large population but limited AI infrastructure in their respective native tract, a two-tier nucleus breeding program referred to as PS was established. Having developed a good infrastructure for AI and performance recording in the native tract of Gir breed, the Gir PS program has been converted into a PT program recently.

Breeding design for progeny testing programs: Putting a very large number of bulls under test and using a small proportion of very best progeny tested bulls for AI to produce replacement heifers is not practical in India. Due to harsh environmental conditions and poor feed and fodder resources, the average age at first calving in Indian cows and buffaloes is very high between 3 to 4 years. So, by the time progeny test results of bulls put to test are available, the bulls either no more exist or are too old (8–10 years) to be useful for semen production. The focus is therefore given on enhancing efficiency on the sire-sire and dam-sire paths to produce better quality bulls and using selected best among them (sire-dam path) based on pedigree information for AI to produce replacement heifers.

The minimum standards set for each progeny testing program include: putting minimum of 20 bulls under test annually; carrying out about 2,000 test inseminations per bull spread over as many villages as possible in the project area to produce minimum of 70 complete first lactation daughter records per bull; to store minimum of 3,000 doses per test bull till progeny test results of the bulls put to test are available; identify dams with ear tags having unique number and record all events of AI, pregnancy diagnosis (PD) and calving; register all daughters born applying ear tags and follow up for growth; record all events of AI, PD, and calving of daughters; record milk yield and milk components of all daughters once a month for a complete lactation; score all daughters once in their first lactation for dairy type conformation traits; estimate breeding values

of bulls and recorded females for all traits; select top 5% or less of recorded cows; use the stored semen doses of top 10% progeny tested bulls or less for nominated mating of elite cows to produce the next generation of young bull calves; to procure selected required young male calves after finding them and their dams negative for all disease testing, and finally induct these bulls into semen stations after their clearance through disease testing in quarantine and rearing stations. If more than one PT program is being implemented for a breed in different locations, it is ensured that a minimum number of daughters of some bulls are produced under each of these programs.

Breeding design for pedigree selection programs: A two-tier breeding structure with top-tier referred to as multiplier villages and another tier as a base population was set up under each PS program in the native tract of the breed. Multiplier villages included some 50–150 villages having relatively better-producing animals. An infrastructure for artificial insemination was established in multiplier villages to provide AI services to farmers at their doorstep. All better-producing animals in the multiplier villages were put under a systematic milk recording program. Elite recorded animals were inseminated with selected high-pedigreed bulls. Farmers having top recorded animals were encouraged to rear male calves born to their top recorded females. On weaning, male calves born to top elite cows were purchased from farmers after parentage testing and disease screening.

Institutional structure: Having selected the breeds for genetic improvement, an institution that can implement the specified PT or PS program in the native tract of the breed was identified. The main criteria kept in selecting an institution were: the institution should have an experience of implementing a field-based cattle and buffalo development program preferably a genetic improvement program or AI service delivery; it should have a semen station graded “A” or “B” by the Central Monitoring Unit (CMU) of GoI or an arrangement with such a semen station, and a team of competent professionals with the necessary knowledge and experience of implementing large field-based development programs. Three types of institutions namely Milk Cooperative Unions/Federations, State Livestock Development Boards (LDB, State Govt.), and Non-Governmental Organisations (NGO) were entrusted to implement PT or PS program at different places. These institutions were referred to as End Implementing Agencies (EIAs). These institutions were supported for establishing infrastructure for performance recording.

Each EIA signed a Memorandum of Understanding (MoU) with NDDB agreeing to follow the Standard Operating Procedures (SOP) and achieve the Minimum Standards (MS), get evaluated annually by an independent expert team, use the Information Network for Animal Productivity and Health (INAPH) application for monitoring and reporting, and set up a dedicated project team governed by an independent Management Committee represented by all stakeholders. Each project team was headed by a project coordinator and the other necessary

staff was employed by each EIA. Each EIA also engaged AI technicians for providing AI services and milk recorders for milk recording services. Some supervisors were trained as “typers” for recording conformation traits. To provide technical assistance to EIAs in preparing, implementing and monitoring the projects a Project Management Unit (PMU) was set up with subject matter specialists at NDDb. The functioning of each EIA was supervised by a Project Steering Committee (PSC) chaired by the Mission Director, NDP. Apart from overseeing the implementation of projects, the role of PSC was to approve the proposals received from EIAs and sanction funds for disbursement. Besides, a National Steering Committee (NSC) chaired by Secretary of the Department of Animal Husbandry, Dairy and Fisheries (DADF) was set up to provide policy and strategic support, approve annual action plans, and oversee implementation of all programs.

Infrastructure for performance recording: The infrastructure for the measurement of traits given in Table 1 was created under each PT and PS program. All animals included under the programs were identified by applying a plastic ear tag having nation-wide 12 digits unique number on a single ear. Appropriate instruments such as Smart Weighing Machine (SWM), small milk component analyzers, retractable measuring tapes with levellers, etc. that suit the conditions of smallholder dairy producers were developed and used.

AI technicians while providing AI services in their assigned villages recorded data such as AI date, bull number, date of pregnancy diagnosis (PD), result of PD, calving date, calving ease, sex of calf born, and weight of newborn female calf (measuring heart girth and body length) using a handheld device running the INAPH application. The application internally calculated all reproduction traits mentioned in Table 1.

Milk recorders in their assigned villages visited the participating dairy farmers once a month in morning and evening for the entire lactation of the animal and recorded milk yields using a calibrated plastic jar or SWM and collected a milk sample for component analysis.

Information System–INAPH: NDDb has developed an integrated IT application referred to as “Information Network for Animal Productivity and Health (INAPH)”. At present, INAPH is being used on all platforms—

smartphones, tablets, netbooks, laptops, and desktops – across the country. NDDb has two teams now: one INAPH development team which is responsible for incorporating all required modifications in the application and for maintenance of the central server and the other INAPH implementation team which is responsible for capacity building and troubleshooting. Many productivity enhancement service providers in the country use this application. The INAPH application produces a variety of reports for field and supervisory staff of service providers as well as for policymakers. These reports can be grouped into seven classes: Operational reports, Performance review reports, Analytical reports, Graphs, Alerts, SMS Messages, and Data extraction tools.

Breeding value estimation: A Breeding Value Estimation Committee has been constituted by GoI to decide on the model to be used for estimating breeding values, oversee the estimation of breeding values by a subcommittee of this committee, and publish breeding values of all bulls used under PT programs every six months on NDDb’s web page. Currently, the following Random Regression Test-day Model is used for estimating breeding values:

$$Y_{thijklm} = A_i + YS_j + O_m + HYMR_h + \sum_{l=0}^{nf} \phi_{kl} \beta_l + \sum_{l=0}^{nr} \phi_{kl} u_{kl} + \sum_{l=0}^{nf} \phi_{kl} pe_{kl} + e_{thijklm}$$

where, $Y_{thijklm}$, test-day milk/fat yield of cow k made on day t within fixed A (age at calving groups) subclass i , fixed YS (year of calving $\times$ season of calving (3)) subclass j , random owner (O) subclass m , and random HYMR (herd $\times$ year of recording $\times$ month of recording) subclass h ; β_l are fixed regression coefficients; u_{kl} and pe_{kl} are the l^{th} random regression for animal additive genetic and permanent environmental effects respectively for animal k ; ϕ_{kl} is the l^{th} Legendre polynomial for the test day record of cow k made on t^{th} day in milk; nf is the order of polynomials fitted as fixed regressions (0 to 3); nr is the order of polynomials for u and pe effects (0 to 3); $e_{thijklm}$, random residual effect, and $var(u) = A \otimes G$, $var(pe) = I \otimes P$ and $var(e) = I \sigma_e^2 = R$ where, A is the numerator relationship matrix; $\otimes$ is the Kronecker product, and G and P are of the order of polynomial for u and pe effects respectively.

Recently, NDDb developed a genotyping chip for indigenous breeds and their crosses named as INDUSCHIP.

Table 1. Traits measured under PT and PS programs

Production Trait	Reproduction Trait	Type Trait	
Test day yield	Age at first AI	Stature	Fore Udder Attachment
305-day yield	Age at first calving	Heart Girth	Rear Udder Height
Test day fat%	Als per conception	Body Length	Central Ligament
Test day fat yield	Bull conception rate	Body Depth	Udder Depth
305-day fat%	Service period	Angularity	Front Teat Placement
305-day fat yield	Inter-calving period	Rump Angle	Teat Length
Protein and SNF%	Calving ease	Rump Width	Rear Teat Placement
Protein test day yield		Rear Leg Set	Rear Udder Width
Protein 305-day yield		Rear Leg Rear View	Teat Thickness
SNF test day yield		Foot Angle	
SNF 305-day yield			

Some HFCB bulls and HFCB recorded daughters were genotyped and genomic breeding values were estimated incorporating both genotyped and non-genotyped animals using Single Step GBLUP procedure employing the same model as given above with the difference of using a combined relationship matrix of genotyped and non-genotyped animals “H” instead of usual relationship matrix “A”.

Dissemination of genetics: Not more than 10% of available proven bulls’ semen doses were used every year for nominated mating on the top 5% of selected females to produce the next generation of young bulls under each PT program. It was also ensured that at least five bulls are used every year for each breed for producing the next generation of young bulls. All bull calves identified for procurement were confirmed for correct parentage through a DNA test and both the bull calves and their dams were tested negative for various diseases. These bull calves were used by semen stations for semen production and the semen doses thus produced were sold by semen stations to AI service providers, who in turn provided AI services to farmers in their area of operations.

Monitoring and evaluation: For evolving an effective

monitoring system all AI technicians, milk recorders, supervisors, and managers of each program were trained in using the INAPH application both for entering data and generating the required information. All monitoring activities and awarding incentives to field workers were done only through data generated from the INAPH database. Each supervisor was assigned 10–15 villages depending on the workload and the distance between villages for monitoring all activities of AI, milk recording, milk component testing, and typing in his assigned villages. The supervisors were required to follow the SOP of supervision both for routine and surprise checking of all activities. Besides supervisors, district coordinators and project coordinators were also required to carry out their routine and surprise checking and organize regular review meetings. NDDB allotted a specified number of programs to its officers, who routinely visited the programs. NDDB also conducted an annual independent evaluation of each PT and PS programs and provided recommendations for improvement.

RESULTS AND DISCUSSION

The details of institutions selected along with their area

Table 2. Details of institutions implementing PT and PS programs

Breed	EIA	Type of institution	State of operation	Year of initiation
<i>Progeny testing programs</i>				
HF	KMF	Cooperative	Karnataka	2012
HFCB	SAG	NGO	Gujarat	2012
	ULDB	LDB, State Govt.	Uttarakhand	2013
	BAIF	NGO	Uttar Pradesh	2014
	KLDB	LDB, State Govt.	Kerala	2014
JCB	TCMPF	Cooperative	Tamil Nadu	2012
	APLDA	LDB, State Govt.	Andhra Pradesh	2013
Murrah	HLDB	LDB, State Govt.	Haryana	2013
	PLDB	LDB, State Govt.	Punjab	2013
	ABRO	NGO	Uttar Pradesh	2013
	SAG	NGO	Gujarat	2012
Mehsana	Mehsana	Cooperative	Gujarat	2012
	Banas	Cooperative	Gujarat	2012
<i>Pedigree selection programs</i>				
Gir	SAG	NGO	Gujarat	2012
Sahiwal	PLDB	LDB, State Govt.	Punjab	
	GANGMUL	Cooperative	Rajasthan	
Rathi	URMUL	Cooperative	Rajasthan	2013
Kankrej	Banas	Cooperative	Gujarat	2012
Haryana	HLDB	LDB, State Govt.	Haryana	2013
Tharparkar	RLDB	LDB, State Govt.	Rajasthan	2014
Jaffarabadi	SAG	NGO	Gujarat	2012
Nili Ravi	PLDB	LDB, State Govt.	Punjab	2014
Pandharpuri	MLDB	LDB, State Govt.	Maharashtra	2014

KMF, Karnataka Milk Federation; SAG, Sabarmati Ashram Gaushala; ULDB, Uttarakhand Livestock Development Board; BAIF, Bharatiya Agro Industries Foundation; KLDB, Kerala Livestock Development Board; TCMPF, Tamil Nadu Cooperative Milk Producers’ Federation; APLDA, Andhra Pradesh Livestock Development Agency; HLDB, Haryana Livestock Development Board; PLDB, Punjab Livestock Development Board; ABRO, Animal Breeding Research Organisation; Mehiana, Mehiana Milk Union; Banas, Banas Milk Union; GANGMUL, Sri Ganganagar Cooperative Milk Union Ltd.; URMUL, Urmul Trust; RLDB, Rajasthan Livestock Development Board; MLDB, Maharashtra Livestock Development Board; NGO, Non-Governmental Organization; HF, Holstein Friesian; HFCB, HF Crossbred; JCB, Jersey Crossbred.

of operation for all PT and PS programs are given in Table 2. Initially, PMU of NDDDB helped each EIA to prepare a detailed project proposal for PT or PS program. PMU then appraised the proposal and recommended it to the Project Steering Committee (PSC) for approval. PMU also prepared SOP for implementing PT and PS programs. The approved proposal and SOP, in fact, became the guiding documents for EIA to implement PT and PS programs. Thus, in the first two years of initiating NDP, all 13 PT and 10 PS programs were prepared, appraised and approved by PSC.

Progeny Testing Programs

Building infrastructure and human capacity: In first six years of implementing the PT programs, a large infrastructure for testing of bulls and the performance recording of animals for various traits has been created, and a large number of AI technicians, milk recorders and supervisors has been trained to implement these programs following the laid down SOP. In all PT programs, a very high emphasis was placed on building an infrastructure for the measurement of traits, which greatly helped in improving the quality of data collected.

In the first six years, the PT programs together completed test mating of 1,684 number of bulls and built the required infrastructure and capacity to test annually more than 400 bulls and evaluate them for production, reproduction and type traits (listed in Table 1) with 70–100 daughter records per bull. The progress made in implementing the PT programs is summarized in Table 3. At present 1,591 AI technicians and 1,374 milk recorders are engaged in implementing PT programs.

Building a database on phenotypic records: A big database is being built on the traits listed in Table 1. The average performance of daughters born under the PT

programs for three important parameters, viz. age at first calving, conception rate, and 305-day standardized first lactation yield including fat and protein percentage is given in Table 4.

Breeding values estimation: Currently, breeding values are estimated every six months using a Random Regression Test-day Model for six old projects that have a reasonable number of daughter records namely SAG for HF and Murrah, TCMF for Jersey CB, KMF for HF, ABRO for Murrah buffalo, Banas Union for Mehsana buffalo and Mehsana Union for Mehsana buffalo, and the results are published on the NDDDB website (<https://www.nddb.coop/services/animalbreeding/geneticimprovement/sireproofs>). The variance components and heritability estimated during the last run in September 2018 using the data of three old PT programs, which had sufficient daughter records, namely SAG-HF, SAG-Murrah, and Mehsana Union for Mehsana buffaloes are given in Table 5.

The other eight PT programs are expected to have sufficient daughter records in other one or two years. This means in another two years' time, breeding values of bulls and recorded females will be estimated for all 13 programs routinely every six months and their results will be published on the NDDDB website.

Pedigree Selection Programs

The progress made in building the infrastructure of AI and performance recording in the PS programs is given in Table 6. The inseminations carried out in the multiplier villages significantly increased.

The high conception rates achieved in the PS programs, comparable to those achieved in the PT programs, further boosted the AI expansion process in the project areas (Table 7). First time in the history of these breeds, a large

Table 3. Details of infrastructure for testing of bulls and performance recording under PT programs

Breed	EIA	Bulls put to test	Bulls completed test	Test AI done	Daughters registered	Daughters calved	Dams milk recorded	Dams' test day records	Daughters milk recorded	Daughters test day records
Pure HF	KMF	275	199	501,378	48,166	8,158	12,739	119,560	6,175	49,019
HFCB	SAG	294	264	638,869	87,332	14,595	13,955	136,872	12,555	113,170
	ULDB	70	51	126,311	12,246	449	5,881	52,131	252	1,688
	BAIF	80	32	127,520	13,428	1,071	10,902	97,259	842	6,152
	KLDB	63	16	84,056	9,288	585	10,572	85,050	454	2,383
HFCB	Total	507	363	976,756	122,294	16,700	41,310	371,312	14,103	123,393
JCB	TCMPF	349	300	669,433	83,173	11,818	43,344	408,059	11,073	94,015
	APDA	148	105	259,909	29,167	1,919	10,093	91,022	1,637	11,757
JCB	Total	497	405	929,342	112,340	13,737	53,437	499,081	12,710	105,772
Murrah	HLDB	181	132	324,724	21,488	258	30,131	256,922	147	546
	PLDB	147	123	248,864	24,582	708	17,818	152,869	469	2,644
	ABRO	134	101	230,219	15,367	500	9,004	65,362	414	2,204
	SAG	209	170	395,147	56,807	6,008	10,009	93,099	5,191	41,891
Murrah	Total	671	526	1,198,954	118,244	7,474	66,962	568,252	6,221	47,285
Mehsana	Mehsana	138	114	305,137	23,512	4,216	8,776	84,633	3,619	31,283
	Banas	100	77	192,558	22,582	2,230	7,240	62,921	1,565	11,651
Mehsana	Total	238	191	497,695	46,094	6,446	16,016	147,554	5,184	42,934
Overall	Total	2,188	1,684	4,104,125	447,138	52,515	190,464	1,705,759	44,393	368,403

Table 4. Performance of daughters in their first lactation on a few key parameters under PT programs

Breed	PT Program	Sire conception rate		Daughters' age at first calving (days)		Daughters' 305-day first lactation yield					
						Milk yield		Fat %		Protein %	
		No. Obs.	CR %	No. Obs.	Mean/SD	No. Obs.	Mean/SD	No. Obs.	Mean/SD	No. Obs.	Mean/SD
HF	KMF	463,908	41.5	6,731	1,061/236	4,999	3,828/834	3,534	4.06/0.52	3,109	3.29/0.43
HFCB	SAG	590,029	40.5	16,850	1,195/253	12,254	2,734/799	12,189	4.15/0.68	11,422	3.38/0.46
	ULDB	114,944	39.9	383	1,012/156	195	2,611/947	180	4.16/1.45	180	2.92/0.58
	BAIF	114,334	45.4	764	929/134	690	2,508/1005	687	3.90/1.23	687	2.82/0.54
	KLDB	74,133	40.3	499	875/102	255	3,069/916	250	2.98/0.79	243	3.13/0.45
	Total	893,440	41.0	18,496	1,172/256	13,394	2,727/817	13,306	4.12/0.74	12,532	3.34/0.48
JCB	TCMPF	629,626	42.3	10,893	1,082/224	10,910	2,153/596	10,903	4.45/0.62	10,832	3.09/0.46
	APLDA	232,483	42.2	1,780	1,020/161	1,179	2,332/556	1,179	4.48/0.77	1,179	3.47/0.46
	Total	862,109	42.3	12,673	1,073/217	12,089	2,170/594	12,082	4.45/0.64	12,011	3.13/0.48
Murrah	HLDB	288,934	39.2	119	1,103/87	30	2,734/481	14	7.53/2.15	14	4.06/0.66
	PLDB	223,425	39.0	451	1,251/161	263	2,367/453	249	8.16/1.28	250	3.95/0.55
	ABRO	211,379	33.3	480	1,279/187	241	2,463/475	216	6.91/1.14	215	3.63/0.59
	SAG	362,757	42.6	7,350	1,523/283	4,626	1,750/425	4,583	7.26/1.24	4,331	3.69/0.48
	Total	1,086,495	39.1	8,400	1,489/286	5,160	1,820/477	5,062	7.29/1.00	4,810	3.70/0.49
Mehsana	Mehsana	280,918	29.8	4,453	1,407/252	3,281	1,981/415	3,281	7.31/1.35	3,165	3.94/0.62
	Banas	172,154	40.8	2,145	1,406/274	1,514	2,272/484	1,514	6.75/0.96	1,318	3.75/0.53
	Total	453,072	34.0	6,598	1,407/259	4,795	2,073/455	4,795	7.13/0.90	4,483	3.88/0.61

Table 5. Estimates of variance components and heritability for three PT programs

Component	Milk	Fat	Protein	SNF
<i>SAG HFCB PT</i>				
No. of Observations	99,210	93,980	84,170	84,159
Genetic varinace-Vg	1,01,011	159	102	745
Phenotypic varinace-Vp	5,45,094	1082	684	4278
Heritability-h ²	0.185	0.147	0.149	0.174
<i>SAG Murrah PT</i>				
No. of observations	42,280	39,303	36,362	36,361
Genetic varinace-Vg	22,385	84	31	192
Phenotypic varinace-Vp	1,70,689	1,111	279	1498
Heritability-h ²	0.131	0.076	0.112	0.128
<i>Mehsana PT</i>				
No. of observations.	1,09,448	1,09,084	24,138	24,132
Genetic varinace-Vg	40,093	132	36	200
Phenotypic varinace-Vp	1,78,455	1,010	338	1,687
Heritability-h ²	0.225	0.131	0.108	0.119

number of better-producing animals of farmers were put under monthly milk recording.

High averages of estimated 305-day yield of selected better-producing animals showed that these were very promising breeds capable of sustaining the livelihood of farmers in prevailing harsh environments and poor-resource conditions.

Dissemination of genetics: The EIAs of PT and PS programs procured 2,566 and 273 young males calves (produced through nominated mating) respectively. By the end of 2018, 1,566 bull calves were distributed to different semen stations for semen production from the PT programs

and 154 bulls from PS programs. By the end of 2018, the bulls supplied under NDP constituted about 35% of the total bulls under collection. In the next two years, it is expected that the PT and PS programs would meet more than 90% of the total bull replacement needs of all semen stations in the country.

INAPH: INAPH is a multi-purpose integrated system catering to the needs of all productivity enhancement service providers including animal breeding, nutrition, and veterinary healthcare. After its launch in 2008, the use of INAPH has grown exponentially. As on 1st January 2019, INAPH had 10.05 million registered farmers and 17.03 million registered animals spread over 125 thousand villages

Table 6. Details of infrastructure and performance recording under PS programs

Breed	EIA	No. of AI centres	AI done	Calving recorded	Animals recorded	Test day records
<i>Cattle</i>						
Gir	SAG	101	78,563	21,353	9,284	73,134
Sahiwal	PLDB	29	11,963	2,314	1,272	10,464
	GANGMUL	28	30,162	8,620	2,946	25,817
Rathi	URMUL	54	78,223	23,565	4,649	40,912
Kankrej	Banas	86	62,659	20,450	3,042	27,933
Haryana	HLDB	41	13,250	4,657	4,830	41,988
Tharparkar	RLDB	70	22,210	4,353	1,726	13,651
<i>Buffalo</i>						
Jaffarabadi	SAG	101	71,336	15,841	3,142	28,634
Nili Ravi	PLDB	50	20,928	4,682	2,467	22,780
Pandharpuri	MLDB	30	24,522	5,091	2,862	26,525
Total		590	413,816	110,926	36,220	311,838

Table 7. Performance of female animals on a few key parameters under PS programs

Breed	EIA	Conception rate (CR)		305-day yield of all lactations			
		No. of obs.	CR (%)	Milk yield		Fat%	
				No. of obs.	Mean/SD*	No. of obs.	Mean/SD*
<i>Cattle</i>							
Gir	SAG	71,162	42.9	7,532	2190/760	7,080	4.84/1.00
Sahiwal	PLDB	10,638	38.4	1,108	2587/641	1,107	4.38/0.74
	GANGMUL	27,033	48.0	2,509	2544/480	2,479	4.20/0.50
Rathi	URMUL	73,236	40.2	4,042	2728/518	2,286	3.92/0.50
Kankrej	Banas	52,578	44.7	3,557	2493/576	3,557	4.41/0.64
Haryana	HLDB	12,536	50.7	4,419	2155/419	3,884	4.87/0.89
Tharparkar	RLDB	19,647	42.9	1,367	2105/442	–	–
<i>Buffalo</i>							
Jaffarabadi	SAG	62,799	37.7	2,791	2823/804	2,411	7.37/1.40
Nili Ravi	PLDB	19,552	35.3	2,271	2424/544	2,269	6.43/0.88
Pandharpuri	MLDB	22,741	40.3	2,699	1597/340	2,689	7.13/0.80

*These are averages of elite recorded dams and not of randomly selected dams.

covering 464 districts in 28 states. The system was used by about 44 thousand active users. The INAPH database had records on 11.99 million AIs, 2.32 million calvings, 3.17 million test-day yields, 24.2 million ration balancing advices, 0.28 million vaccinations, etc. GoI has made it mandatory the use of INAPH application for all its animal husbandry related projects. NDDDB has also been managing centrally the unique animal identification system for the country.

Unlike in a classical progeny testing program, where only the proven bulls are used for AI to produce herd replacements, in the PT programs under NDP, the bulls used for AI were the selected bulls produced using top proven sires and top recorded females. Genetic gain that can be achieved under the latter strategy might work out to be as good as that achieved under the former. Chacko *et al.* (1985) while studying the different options of breeding design to implement a progeny testing program in the crossbred population under smallholder dairy production systems in the state of Kerala in India showed that if less than 50% of young bulls produced using proven bulls and top selected dams are used for AI, the genetic gain achieved could possibly be as good as that achieved when only selected proven bulls are used for AI. In a situation where a very small number of bulls are put to test, often bulls produced using semen of top progeny tested bulls and elite recorded dams may turn out to be genetically better than progeny tested bulls produced six or seven years back. As young bulls are from a younger generation of elite parents than the generation from which the proven bulls are selected, the young bulls often could be competitive to proven bulls (Van der Werf J 1999). It is obvious therefore that if young bulls produced are further selected on the basis of their genomic breeding values, it would enhance significantly the genetic gains under Indian conditions. NDDDB, in collaboration with Aarhus University, Denmark, has developed a genotyping chip specifically for indigenous

and crossbred cattle referred to as INDUSCHIP. This chip was used recently for genotyping of crossbred bulls and recorded females and genomic breeding values were estimated using a single step GBLUP procedure with very encouraging results (Nayee *et al.* 2018).

The other problem that one faces in a genetic evaluation under the smallholder production system in implementing progeny testing programs is to identify contemporary groups in a situation where dairy producers have less than 5 dairy animals and in the majority of cases just two to three animals. One way to solve this problem is to treat a village as a herd and daughters of as many bulls as possible are produced within each village across all villages. Farmers within a village learn from each other and often follow common management practices (Trivedi K 1998). But still, we find a large variation in production within a village due to varying economic conditions and resource use by farmers. To capture this variability, the owner was added as a random effect in the model, which did help in explaining the variability within a village, but the challenge always remains to identify the relevant factors that help in unraveling environmental effects from genetics under the smallholder production system.

All the breeds selected for PS programs have been supporting and sustaining the livelihood of a large number of poor farmers in the marginal areas in the country where alternative opportunities of earning are scarce. If such breeds are lost, they would take away the main means of their survival. Our recording of elite animals in the respective native tract of the breeds has shown that all these breeds can be very competitive to any other global breed or their crosses under environmental and resource constraints. Animals of these breeds are also found in many parts outside their native tract, particularly Gir and Sahiwal (Breed Survey, 2013). Gir and Kankrej cows and Jaffarabadi buffaloes have been successfully used in Brazil and Sahiwal cows in Kenya (Philipsson *et al.* 2006, Rege *et al.* 2011).

Apart from providing a livelihood, maintaining the genetic diversity is equally important for the country as under looming climate changes and uncertain future, it provides an opportunity to farmers to choose breeds in response to changes in the environment, a threat to diseases, changes in feed and water supplies, etc.

Besides deciding on the breeding design, putting in place a performance recording system (PRS), developing a computer application for collecting and processing of data and dissemination of information, and evolving a right institutional structure for implementation, monitoring and evaluation of all components are equally important.

Developing an effective performance recording system involves identifying the traits to be measured, defining the data to be collected for each trait, establishing a procedure and developing appropriate measuring instruments for collecting data, and deciding on by whom the data to be collected, how the data to be processed and what information to be disseminated to stakeholders including farmers. The International Committee for Animal Recording (ICAR) has been setting rules, standards and guidelines for the measurement of different traits in various species (ICAR, 2012). The ICAR guidelines could be used as a base document for developing procedures for the measurement of various traits suiting to the needs and existing constraints in developing countries. Our experience and learning of developing performance recording systems for PT and PS programs include: (i) In most of the cases in smallholder production systems producers will not be able to collect data; the job of collecting data will have to be entrusted to service providers; (ii) Identifying an individual animal with an ear tag on one or both ears with a unique number is a prerequisite for any PRS; (iii) Simple equipment need to be developed for measurement of different traits, viz. for a smallholder dairy farmer having one or two animals sophisticated milking machine may not be required, a simple calibrated milk jar or an electronic weighing machine would be adequate to measure milk yields; (iv) Software developed for providing herd information to an individual dairy farmer having a large herd may not be that relevant to farmers having one or two animals, as they know everything about their one or two animals, however, sending SMS messages as alerts to carry out certain activities for an individual animal could be very relevant; (v) Often producers will not be in position to use the information provided for decision making; they would need to be helped to interpret and apply results; (vi) Promoting producers involvement and regular training of producers and technicians would be vital in sustaining PRSs in developing countries; (vii) Documenting benefits should be an integral part of any PRS; and (viii) Public support is absolutely necessary to establish a PRS in smallholder production systems; one should not expect producers to pay for the recording services, at least in the beginning. Trivedi K (2016), FAO (1998) and FAO (2016) provide detailed guidelines on establishing performance recording systems in smallholder production systems.

The development of a software application is a key component in implementing any genetic improvement program. The software application enables users to capture and validate data, process and store data, and generate and transmit information to all stakeholders. A recent publication of FAO (2016) provides excellent guidelines for developing an integrated multipurpose animal recording system for mid- and low-income countries.

Evolving an appropriate institutional structure that enables the implementation of many complex activities required for genetic improvement programs and that sustains them for a long period of time is very crucial. The PT and PS programs were implemented through cooperative, government and non-government institutions. NDDB through its PMU and PSC provided the necessary help to EIAs for preparation and appraisal of projects, monitoring, and evaluation of projects, and employing INAPH. It also set up a group for estimating breeding values. The Steering Committee provided the necessary policy support. It is recognized that an organization like NDDB having the necessary technical know-how is important for effective implementation of genetic improvement programs in developing countries where the availability of trained manpower is limited. For continuing these programs, it is realized now that the current institutional structure needs to be strengthened at all levels. At the EIA level, the semen stations need to take over the ownership of genetic improvement programs and implement them largely through their own internally generated resources over a period of time. To make this happen, the semen stations need to be empowered and encouraged to assume higher responsibility and over a period of time need to be made independent operating units like a private breeding company running their own genetic improvement programs and meeting the cost of running them through the revenue generated from the sale of their semen doses.

One of the biggest factors that have contributed to the failure of many genetic improvement programs under smallholder production systems in mid- and low-income countries is not planning for the long-term financial sustainability of such programs (FAO 1998, Trivedi K 1998). Many genetic improvement programs have been initiated in mid- and low-income countries but they are continued so long as donor agencies fund such programs. Once the donor agency stops funding, many of such genetic improvement programs get closed. It is pertinent to mention here that the investment on performance recording and genetic improvement not just benefits dairy farmers in terms of increasing production and income and breeding organizations in terms of enhancing the value of their products, but also benefits consumers in terms of reducing price and enhancing the quality of products. In these respects, performance recording and genetic improvement are partly public goods and need to be supported partially through public funding particularly so under smallholder production systems in mid- and low-income countries.

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