Animal Genetic Resources, 2016, 59, 81–95. © Food and Agriculture Organization of the United Nations, 2016
doi:10.1017/S2078633616000096

Dairy production systems and the adoption of genetic and breeding technologies in Tanzania, Kenya, India and Nicaragua

J.M.K. Ojango[1], C.B. Wasike[2], D.K. Enahoro[1] and A.M. Okeyo[1]
[1]*International Livestock Research Institute, Nairobi, Kenya;* [2]*Maseno University, Maseno, Kenya*

Summary
Development of the livestock industry and its role in poverty alleviation in developing countries depends on how adaptive the production systems are to changing global environmental and economic trends. This paper characterizes dairy production systems in India, Tanzania, Kenya and Nicaragua, and describes the genetic and breeding technologies that hold promise for the advancement of global development goals. The dairy value chain has been prioritized for development under the CGIAR research programme on Livestock and Fish in Tanzania (East Africa), India (South Asia) and Nicaragua (Latin America), while ILRI is involved in research on dairy development in Kenya. In all the countries, a large number of smallholder farmers operating mixed crop–livestock production systems play a significant role in dairy production. In Tanzania, Kenya and Nicaragua, milk is predominantly produced by cattle of genotypes that differ both across countries and among production systems within the same country. In India, buffaloes contribute to a larger proportion of the national milk than cattle. Information on productivity per animal and on optimal genotypes to utilize within the smallholder production systems of all the countries is however limited. Crossbreeding and artificial insemination were identified as the most widely utilized breeding and reproductive technologies. Only in Kenya is there a national organization conducting livestock recording and monitoring productivity, however, the proportion of the dairy cattle population enrolled in the recording system is small (<2.5 percent). In all the countries, enhanced and adequately planned use of breeding and reproductive technologies, complemented with the relevant infrastructure, is needed to sustainably increase dairy productivity. The capacities of actors in the dairy value chain need to be developed in order to properly implement and manage improvements.

Keywords: *breeding technologies, dairy production, developing countries*

Résumé
Le développement du secteur de l'élevage et son rôle dans la réduction de la pauvreté dans les pays en développement dépendent de l'adaptabilité des systèmes de production à l'évolution des contextes environnementaux et économiques. Cet article caractérise les systèmes de production laitière en Inde, Tanzanie, Kenya et Nicaragua et décrit la génétique et les méthodes de sélection avec lesquelles l'on cherche à atteindre les objectifs mondiaux de développement. La chaîne de valeur du lait a été une priorité pour le développement dans le cadre du programme de recherche du CGIAR sur l'Élevage et la Pêche en Tanzanie (Afrique Orientale), Inde (Asie du Sud) et Nicaragua (Amérique Latine), alors qu'au Kenya c'est l'ILRI qui a pris en charge la recherche sur le développement du secteur laitier. Dans tous les pays, un grand nombre de petits éleveurs exploitant des systèmes agropastoraux mixtes jouent un rôle important dans la production de lait. En Tanzanie, Kenya et Nicaragua, le lait est principalement produit par des bovins de génotypes qui diffèrent à la fois entre les pays et entre les systèmes de production dans le même pays. En Inde, les bufflonnes contribuent plus que les bovins à la production nationale de lait. Cependant, il existe un manque d'information sur la productivité par animal et sur les génotypes optimaux à utiliser dans les systèmes de production des petits exploitants de ces pays. Les croisements et l'insémination artificielle ont été identifiés comme les stratégies reproductives et de sélection les plus amplement utilisées. Seulement au Kenya il existe une organisation nationale qui procède à l'enregistrement des animaux et qui fait le suivi de la productivité, bien que le pourcentage de bovins laitiers inscrits dans ce registre est faible (<2.5 pour cent). Dans tous les pays, il s'avère nécessaire d'améliorer et de planifier adéquatement l'utilisation des techniques de reproduction et de sélection, ceci complété par l'infrastructure pertinente, afin d'accroître de façon durable la productivité laitière. Les capacités des acteurs de la chaîne de valeur du lait doivent être renforcées afin que les progrès soient convenablement mis en œuvre et gérés.

Mots-clés: *production laitière, méthodes de sélection, pays en développement*

Resumen
El desarrollo del sector ganadero y su papel en la mitigación de la pobreza en países en desarrollo dependen de la capacidad de adaptación de los sistemas de producción a contextos ambientales y económicos cambiantes. Este artículo caracteriza los sistemas de producción lechera en India, Tanzania, Kenya y Nicaragua y describe la genética y las técnicas de selección con las que se pretende alcanzar los objetivos mundiales de desarrollo. Con vistas al desarrollo, se ha dado prioridad a la cadena de valor de la leche en el marco del programa de investigación CGIAR sobre Ganadería y Pesca en Tanzania (África Oriental), India (Asia Meridional) y

Correspondence to: J.M.K. Ojango, International Livestock Research Institute (ILRI). email: j.ojango@cgiar.org

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

Nicaragua (América Latina), mientras que en Kenya ha sido el ILRI quien ha asumido la investigación sobre el desarrollo del sector lechero. En todos los países, un gran número de pequeños ganaderos, que operan sistemas agropecuarios mixtos, juegan un papel destacado en la producción lechera. En Tanzania, Kenya y Nicaragua, la leche es producida principalmente por ganado bovino de genotipos que difieren entre países y de unos sistemas de producción a otros dentro del mismo país. En India, las búfalas contribuyen en mayor proporción que el ganado bovino a la producción nacional de leche. Sin embargo, es escasa la información sobre la productividad por animal y sobre los genotipos óptimos a utilizar en los sistemas de producción de los pequeños ganaderos de estos países. Los cruzamientos y la inseminación artificial fueron identificados como las estrategias reproductivas y de selección más ampliamente utilizadas. Únicamente en Kenya existe una organización nacional que lleva a cabo el registro del ganado y el seguimiento de la productividad, si bien el porcentaje de ganado bovino lechero inscrito en este registro es bajo (<2.5 por ciento). En todos los países, se necesita mejorar y planificar adecuadamente el uso de las tecnologías reproductivas y de selección, todo ello complementado por la infraestructura pertinente, para incrementar de manera sostenible la productividad lechera. Las capacidades de los actores en la cadena de valor de la leche deben ser desarrolladas con el fin de que las mejoras se implementen y se gestionen convenientemente.

Palabras clave: *producción lechera, técnicas de selección, países en desarrollo*

Submitted 22 July 2015; accepted 4 April 2016

Introduction

Rapid changes are taking place in the livestock sector of developing countries in response to globalization and an increasing demand for animal-product based diets, owing primarily to the combination of population growth, increasing consumer affluence and urbanization (Seré *et al.*, 2008; Robinson *et al.*, 2011; Mpofu, 2014). In these countries, the increasing consumption of livestock products is projected to continue beyond the year 2050 (Thornton, 2010; Table 1). However, livestock development faces increased threats from the growing competition for natural resources (such as land, water and fossil fuels), human conflicts and socio-political instability, weak institutions and market failures, and environmental effects of climate change. Changing climates are foreseen to have the greatest effect on food insecure areas in Africa and South Asia where hunger is a persistent problem and these changes in climate will present new challenges that may stifle rural development and livestock production (Thornton *et al.*, 2007; Global Harvest Initiative, 2013).

At a national level, livestock is a major contributor to the gross domestic product (GDP) of many developing country economies, both directly and indirectly. A large proportion of the rural households in developing countries own livestock, which are quite valuable financially and play significant social and economic roles in the communities (World Bank, 2008; Herrero *et al.*, 2013; Mpofu, 2014). Development of the livestock industry and its future role in alleviation of household poverty largely depends on how adaptive the livestock production systems will be to the changing global environment (Thornton *et al.*, 2007). According to the 2013 GAP report (Global Harvest Initiative, 2013), adoption of advanced agricultural technologies and better production practices are critical for realizing significant productivity gains in both industrialized and developing countries. In order to catalyse livestock producers in developing countries to be more efficient, take advantage of the rising demand for animal products, adapt to a changing climate, minimize disease risk and spread, and mitigate undesirable environmental impacts of livestock, a good understanding of the differences across livestock production systems is necessary (Robinson *et al.*, 2011). Characterization studies that elucidate the differences in the way livestock are produced in different places with regard to use of locally available production resources are critical for planning and targeting interventions.

Table 1. Consumption of meat and milk in developing countries and projected trends.

Year	Annual per capita consumption		Total consumption	
	Meat (kg)	Milk (kg)	Meat (MT)	Milk (MT)
1980	14	34	47	114
1990	18	38	73	152
2002	28	44	137	222
2015	32	55	184	323
2030	38	67	252	452
2050	44	78	326	585

Source: Thornton (2010).

In 2012, the Consultative Group on International Agricultural Research (CGIAR) implemented a number of collaborative research programmes to tackle cross-cutting issues in agricultural development (CGIAR, 2012). One of the programmes aimed to increase the productivity of small-scale livestock and fish systems in sustainable ways, thereby making meat, milk and fish more available and affordable to poor consumers across the developing world (ILRI *et al.*, 2011). The first phase of this Livestock and Fish Programme (L&F) had a focus on a small number of carefully selected animal source food value chains in multiple developing countries building on pre-existing work by ILRI in other countries. Inclusion of countries in multiple regions was to allow

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

comparisons and cross-system learning that would support development of lessons, methodologies and technologies of wide applicability (ILRI *et al.*, 2011). The dairy value chain, focusing on a commodity produced by small-scale farmers across Africa, Asia and Latin America was one area identified to have a high potential for transformational improvement. Analysis of this value chain, however, showed significant productivity gaps, and supply constraints that needed addressing (ILRI *et al.*, 2011). This paper presents information on dairy production systems and requisite genetic and breeding technologies that hold promise for the advancement of global development goals in countries prioritized for dairy improvement under the L&F programme, namely Tanzania (East Africa), India (South Asia), and Nicaragua (Latin America), in addition to Kenya (East Africa) where ILRI is involved in research on dairy development through other projects. Information compiled in this paper has more general application in the prioritization of long-term investments in scientific research for the development of appropriate genetic and breeding technologies to improve dairy livestock production in developing countries.

Materials and methods

A desk study was conducted to collate information on the dairy production systems of Kenya, Tanzania, India and Nicaragua. Information from published literature comprised papers spanning both field and experimental studies. Additional information on the current status of dairy production and utilization of breeding and genetic improvement technologies was obtained from other literature, including government reports, conference and symposia presentations, and from responses to a structured questionnaire administered to managers of the dairy and livestock sectors in the selected countries (listed in Acknowledgement section). The questionnaire was developed by the authors for the current context and included both closed and open-ended questions.

Data obtained from the literature and questionnaires was organized to fit into general classifications of dairy production systems in developing countries (following Robinson *et al.*, 2011), taking into consideration specific classifications used by the ministries responsible for livestock development in the respective countries. Production and related parameters were compared for dairy production systems found within a country, and, to the extent possible, for "similar" systems from one country to the other. The data assessed in this regard included the breeds and numbers of dairy animals raised within production systems, animal breeding technologies utilized in dairy production, and levels of milk productivity. Country-level information on the production and populations of milk-producing animals over the years was obtained from the statistical database of the Food and Agriculture Organization of the United Nations (FAOSTAT). To understand the context in which dairy genetic and breed improvement is occurring; information was also gathered on key organizations and institutions involved in providing support in the application and use of animal breeding technologies in the countries.

Results and discussion

Trends in animal populations and milk production

In all four countries, livestock play a significant role in people's lives, and positively contribute to the respective countries' GDP. Livestock contribute to the livelihoods of at least 70 percent of Eastern Africa's rural farmers in terms of income and diet (Cecchi *et al.*, 2010). In Tanzania, the livestock sector is estimated to provide livelihood support to 37 percent of households engaged in agricultural production. In 2013, the sector contributed 4.4 percent to the national GDP and accounted for 18 percent the agricultural GDP (National Bureau of Statistics Tanzania, 2014). From the 2014 national statistics of Kenya, agriculture is reported to have accounted for 27.3 percent of the GDP, while livestock accounted for 4.9 percent of the GDP (KNBS, 2014). Studies on the livestock sector in Kenya however indicate that livestock production is underestimated in the national GDP estimates and actually accounts for between 10 and 12 percent of the national GDP (IGAD, 2013; KEVEVAPI, 2014; KALRO, 2015). Kenya has the most developed dairy industry in East and Central Africa.

India's livestock sector accounts for 28 percent of the agriculture GDP and 3.9 percent of the national GDP (NDDB, 2013). India is the world's largest milk producing country in terms of volume, with a large proportion of the milk coming from buffaloes relative to cattle (Ahlawat and Singh, 2005; Gandhi and Sharma, 2005; Rao *et al.*, 2014). The dairy sector in India demonstrated steady growth during the different phases of "Operation Flood," a major initiative in dairy development first launched in 1970 by the National Dairy Development Board (NDDB). These initiatives over time have resulted in an increased per capita availability of milk. For example between 2010 and 2011, per capita availability of milk in the country increased from 128 to 267 g/day (Rao *et al.*, 2014). The average milk productivity per animal is however reported to be low (Gautam, Dalal and Pathak, 2010; Rao *et al.*, 2014).

Agriculture contributes 20 percent of the GDP of Nicaragua, with livestock accounting for 45 percent of the agriculture GDP (IFAD, 2014). The Ministry of Agriculture and Livestock (MAGFOR, 2012) in Nicaragua estimates that up to 75 percent of the income for cattle keepers comes from the sale of milk. Table 2 gives a summary of the number of bovine dairy animals in 2013, and the milk produced within the four countries in 2012.

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

Table 2. Bovine population and milk production statistics within four developing countries[1].

Country	Bovine species	Number of animals (1 000)	Milk production (tonnes)
Tanzania	Cattle	21 500	1 853
Kenya	Cattle	19 500	3 733
India	Cattle	214 350	54 000
	Buffaloes	115 420	66 000
Nicaragua	Cattle	3 740	765

Source: FAOSTAT (2014).
[1]The animal population estimates are for the year 2013; milk production estimates are for the year 2012.

A general overview of the dairy sectors and the key existing challenges with an economic focus is presented for Tanzania, India and Nicaragua at http://livestock-fish.wikispaces.com/Situational+Analysis+Report.

Cattle and domestic Buffalo population trends in the target countries

Statistics on animal populations and related parameters as reported by public sector departments responsible for livestock production in the various countries were generated from the Food and Agriculture Organization (FAO) of the United Nations' database (FAOSTAT, 2014). Trends in dairy cattle and buffalo populations are presented for India, Tanzania, Kenya and Nicaragua in Figures 1 and 2. India is home to the world's second largest population of cattle and half of the world's buffalo population, while Nicaragua has the largest cattle population in Central America (FAOSTAT, 2014). Tanzania has the second largest cattle population in Eastern Africa (behind Ethiopia), followed by Kenya (FAOSTAT, 2014). Kenya has the largest number of dairy animals in East Africa, estimated at 3.58 million (Muriuki, 2011).

Over the last decade, animal numbers have increased in all the countries, but at different rates. The slowest increase occurred in Nicaragua (Figure 2). Tanzania has experienced a fairly constant increase in its livestock population over the years, while the population of cattle in Kenya drastically increased between 2006 and 2008 then slowed down thereafter.

Milk production trends in the target countries

Trends in milk production from 2000 to 2013 are presented for the four countries in Figures 3 and 4. India recorded the largest volume of milk in all the years, with the milk

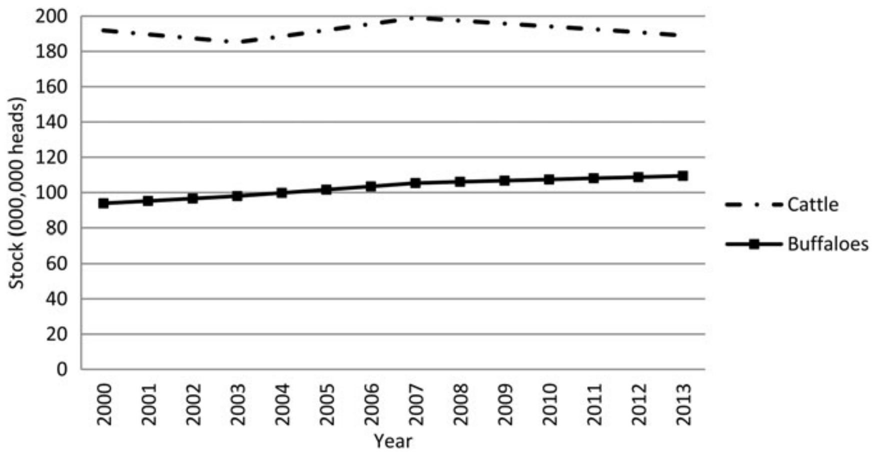


Figure 1. Trends in cattle and buffalo population in India (Source: FAOSTAT, 2014).

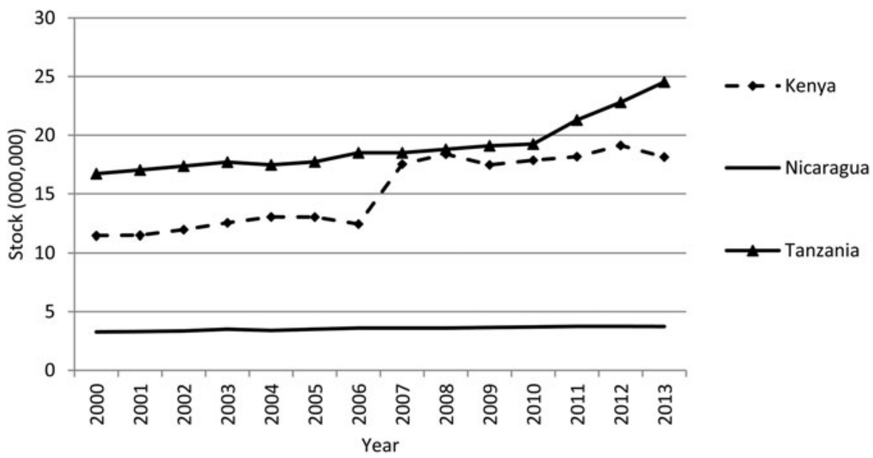


Figure 2. Trend in the cattle populations of Tanzania, Kenya and Nicaragua (Source: FAOSTAT, 2014).

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

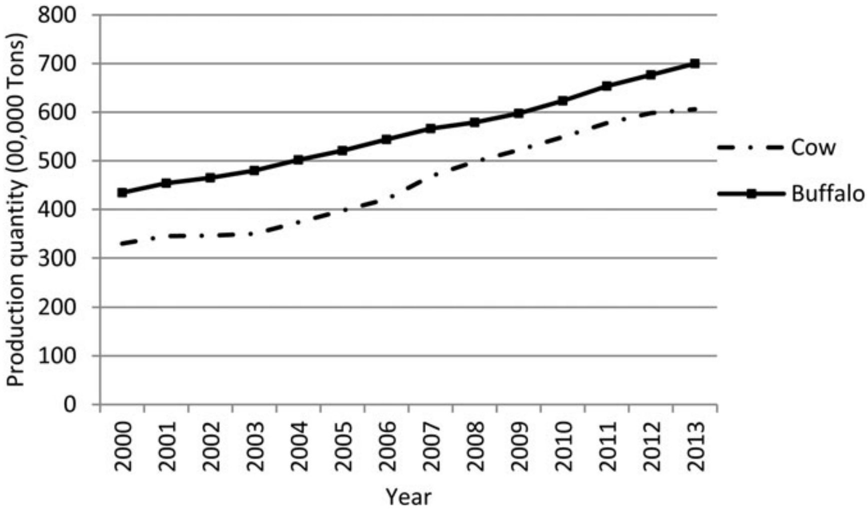


Figure 3. Amount of milk produced annually in India from 2000 to 2012 (Source: FAOSTAT, 2014).

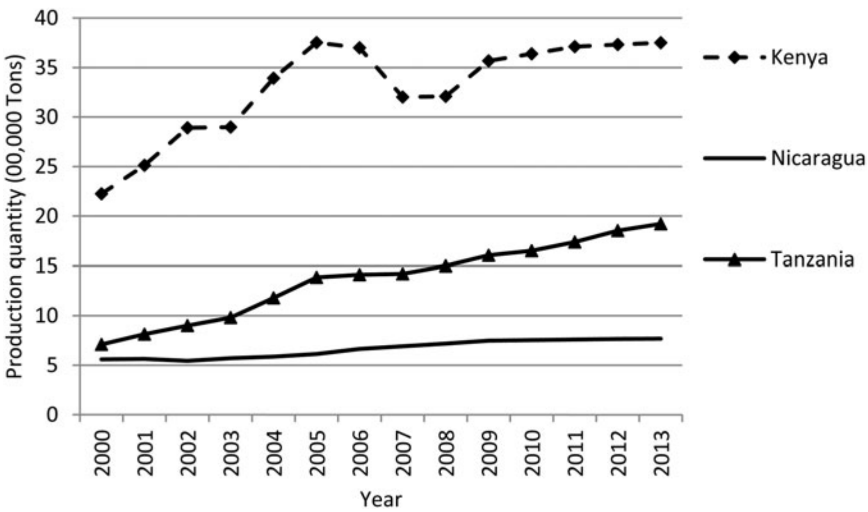


Figure 4. Annual milk production trends from cattle in Tanzania, Kenya and Nicaragua (Source: FAOSTAT, 2014).

produced from cows increasing from 35 million tonnes in 2001 to 55 million tonnes in 2010 (Figure 3), and that from buffalos increasing from 45 million tonnes in 2001 to 65 million tonnes in 2010. Total milk production from cows increased at a greater rate than the increase in the number of cattle, suggesting an increase in dairy cattle productivity in the country.

The quantity of milk produced in Nicaragua gradually increased from 2005 (614 000 tonnes) to 2010 (753 000 tonnes) then remained at the same level to 2013 (Figure 4). Over the same period, the cattle population increased, but by a smaller proportion – from 3.5 million animals in 2005 to 3.7 million animals in 2010, implying a slight increase in milk production per animal.

Figure 4 presents a scenario of increased milk production in Tanzania. This increase largely resulted from growth in the livestock population (Figure 2), rather than from an increase in production per dairy animal. In Kenya, milk production increased from 2000 to 2005, while the cattle population size remained practically the same (Figures 2 and 4). There was however a marked increase in the cattle population after 2006 (Figure 2), which did not result in increased milk production (Figure 4).

Systems of dairy production and the main dairy genotypes

Systems of livestock production vary with climates, availability of production resources, the economic ability and market orientation of producers, and consumer demands (Peeler and Omore, 1997; Thornton *et al.*, 2007). Attempts have been made to define more unified criteria for production systems classification, including providing spatial mapping of the systems (Robinson *et al.*, 2011). Table 3 presents dairy production systems found in the four countries of this study, and the types of dairy animals reared within the systems.

The main genotype reared in each system depends on the scale of operation and the level of economic investment. In the large-scale commercial dairy systems, the exotic dairy breeds are the main breed types reared due to their

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

Table 3. Dairy production systems reported in literature and breeds and genotypes of livestock used in the various systems of the four countries.

Country	Production system	Genotype	Breed	Reference
Tanzania	Mixed crop–livestock system	Crossbreed, purebred exotic, purebred indigenous, synthetic	50–75% Holstein crosses, unspecified exotics, Zebu, Mpwapwa	Msanga *et al.* (2000)
	Medium scale and Smallholder systems	Crossbreed/purebred	*B. indicus* × *B. taurus*, Ayrshire, Friesian	Chenyambuga and Mseleko (2009), Gillah, Kifaro and Madsen (2013), Ogutu, Kurwijila and Omore (2014)
	Extensive grass/rangeland-based (Traditional pastoral system)	Purebred/crossbreed	Tanzania Shorthorn Zebu (TSZ), Boran, Ankole, Tanzania shorthorn zebu × Exotic crosses	Kanuya *et al.* (2006), Msanga and Bee (2006)
	Intensive urban/peri-urban dairy production system	Purebred/crossbreed	Friesian, Ayrshire, Jersey and crosses indigenous × Exotics (Tanzania shorthorn zebu × exotic crosses)	Gillah, Kifaro and Madsen (2013)
Kenya	Mixed crop–livestock systems	Crossbreds:	Ayrshire x Sahiwal/Holstein × Zebu	Kahi (2000), Mwacharo *et al.* (2009), Muasya (2013)
	Large-scale commercial dairy	Purebred	Holstein/Jersey/Guernsey/Ayrshire/Brown Swiss/ Sahiwal	Ojango and Pollott (2001), Muasya (2013)
	Intensive smallholder farms (urban/ peri-urban systems)	Purebred/crossbreed	exotic breeds/zebu × exotic crosses	Mwacharo *et al.* (2009), Muriuki (2011)
India	Mixed crop–livestock systems (semi-intensive)	Purebred Cows/Buffaloes Crossbreds-among indigenous	*Buffalo*: Murrah, Nili Ravi, Surti and Jaffarabadi Buffalo *Cattle*: Local breeds (42 indigenous breeds)	Rao *et al.* (2014), Valsalan *et al.* (2014)
	Extensive grass/rangeland-based system	Purebred indigenous	Local breeds (both Buffalo and cattle)	Gandhi and Sharma (2005), Hegde (2006a), NDDB (2014)
	Small-holder low-input (traditional housed)	Purebred and crossbred indigenous cattle and buffalo	Local breeds and their crosses	Kumaresan *et al.* (2009)
	Intensive urban/peri-urban system	Cows and buffaloes : Purebred/crossbred (cattle-indigenous × exotic)	*Buffalo*: Nili Ravi, Surti and Jaffarabadi Murrah *Cattle*: Crossbreds of Jersey and Holstein Friesians with local indigenous breeds Sahiwal	Shekhar, Thakur and Shelke (2010), Rao *et al.* (2014)
Nicaragua	Extensive grass/rangeland-based dual-purpose system	Crossbreed	Crosses between *B. taurus* (Holstein and Brown Swiss) and *B. indicus* (Brahman)	Corrales (2011), Galetto and Berra (2011)
	Mixed crop–livestock dual-purpose system (medium and small scale)	Crossbreed/purebred	Crosses between *B. taurus* (Holstein and Brown Swiss) and *B. indicus* (Brahman), Reyna Creole Cattle	Holmann *et al.* (2014)

Downloaded from https://www.cambridge.org/core. Maseno University, Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

high milk production potential. In the mixed crop–livestock systems, either pure indigenous breeds or their crosses with the exotic milk breeds tend to be reared (Table 4). The differences among countries are outlined below.

Tanzania: In Tanzania, both traditional pastoral and urban dairy production systems exist (Msanga and Bee, 2006; Gillah, Kifaro and Madsen, 2013; Ogutu, Kurwijila and Omore, 2014). Although typically associated with meat production elsewhere, the traditional pastoral system is included as a dairy production system in the country because more than 75 percent of the milk in Tanzania, is produced by indigenous cattle in these systems (Msanga and Bee, 2006; National Bureau of Statistics Tanzania, 2014). The main breed-type reared within these systems is the indigenous Zebu (Musanga, Questionnaire response). Mixed crop–livestock systems are mainly found in the highland, sub-humid and less-humid areas (Kaijage, 2011). Within the intensive urban and peri-urban systems, crossbreds of the exotic (*Bos taurus*) breeds and the indigenous (*Bos indicus*) breeds, with some limited numbers of pure bred exotic breeds are reared.

Kenya: Mixed crop–livestock systems are common in Kenya. These systems are found in highlands, sub-humid and less-humid areas with good potential for agricultural production (Kahi, 2000). The systems are highly varied in terms of level of inputs. Animals reared in the smallholder mixed crop and livestock production systems comprise a mixture of exotic (*B. taurus*) and indigenous (*B. indicus*) breed-types. These account for more than 70 percent of milk consumed in areas not classified as milk shed areas (Staal *et al.*, 2001; Muriuki, 2011). Smallholder systems of dairy production in Kenya have been extensively characterized under the Smallholder Dairy Development Programme (ILRI, 2004). Large-scale commercial farms operating in the country as either dairy or dual-purpose units have also been described (Kahi, 2000; Ojango and Pollott, 2001). These systems are highly mechanized, tend to raise pure-bred exotic (*B. taurus*) breeds, and produce large quantities of dairy products to which they add value. They produce diverse products that are mainly targeted for urban consumers. The large-scale commercial dairy systems also serve as a source of replacement animals for smallholder farmers, and carry out the bulk of the selection and improvement of dairy cattle in the country (Kahi, Nitter and Gall, 2004; Makoni *et al.*, 2013).

There have been concerted efforts over the past two decades to improve dairy production in Eastern Africa.

Table 4. Milk production performance of animals used for dairy production in, India, Kenya, Nicaragua and Tanzania.

Country	Production system	Genotype	Ave. DMY[1]	Ave. LMY[2]	Ave. LL[3]	Reference
Tanzania	Mixed crop–Livestock	Crossbred cattle, Mpwapwa	5.42	1 626	300	Msanga *et al.* (2000)
	Extensive grass/rangeland based (traditional pastoral)	Tanzania shorthorn zebu × Exotic crosses	3.0	600	200	Mwambene *et al.* (2014)
	Medium-scale system	Exotic × indigenous crosses	7.0	–	–	Gillah, Kifaro and Madsen (2014)
	Smallholder system	Exotic × indigenous crosses, purebred exotic	5.6	–	–	Gillah, Kifaro and Madsen (2013, 2014)
				1 381	288	Chenyambuga and Mseleko (2009)
Kenya	Mixed crop–livestock (semi-arid lowland)	Crossbred (Ayrshire, Sahiwal, Friesian, Brown Swiss)	5.2	1 485	286	Kahi (2000)
	Mixed crop–livestock (sub-humid tropics)	Crossbred (Ayrshire, Sahiwal, Friesian, Brown Swiss)	11.5	4 065	354	Kahi *et al.* (2000)
	Large-scale commercial dairy	Exotic (Holstein Friesian)	15.1	4 540	301	Ojango and Pollott (2001)
	Small-holder dairy	Crossbred	6.5	2 021	365	Muraguri, McLeod and Taylor (2004)
			5.4		365	Ojango *et al.* (2014)
India	Mixed crop–livestock system (Semi-Intensive)	Nili Ravi	–	1 941	286	Sethi and Kala (2005)
		Murrah Bufallo	9.0	2 080	–	Sethi and Kala (2005)
	Smallholder low-input (Traditional housed)	Crossbred cows, Sahiwal	7.0	2 064	285	Joshi and Singh (2005), Kumaresan *et al.* (2009)
		Crossbred (Holstein × indigenous		2 932	305	Duclos *et al.* (2008)
Nicaragua	Extensive grass dual-purpose system	Reyna Creole Cattle	4.8	1 321	274	Corrales (2011)
	Mixed crop–livestock dual-purpose medium scale	Brahman × Exotic dairy	3.7			Holmann *et al.* (2014)

[1]DMY, Daily Milk Yield.
[2]LMY, Lactation Milk Yield.
[3]LL, Lactation Length.

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

These include the Smallholder Dairy Development Programme in Kenya (ILRI, 2004), the East Africa Dairy Development Programme in Kenya, Uganda, Rwanda and Tanzania (ILRI, 2008) and the Livestock Sector Development Policy in 2011 by the government of Tanzania (MLFD, 2011a). Ogutu, Kurwijila and Omore (2014) summarized the impacts of ten projects implemented for dairy improvement in Tanzania starting in the 1980s. Though each of the projects impacted dairy production in a specific region of the country, the level of impact was greatly variable. In general, it was considered that improvement in infrastructure would be required for long-term sustainability of the interventions.

India: Most of dairy production in India is by a large number of livestock producers on small land holdings, typically organized into three main systems of production (Table 3). Dairying is also practiced by landless farmers (NDDB, 2014). More than 70 percent of the cattle reared in India are indigenous (*B. indicus*) breeds (Rao *et al.*, 2014). The dairy cattle among these comprise both pure and crossbred animals (Hegde, 2006a). An increased level of cross breeding between indigenous (*B. indicus*) and exotic (*B. taurus*) cattle has been encouraged in the country through various projects (Hegde, 2006a; NDDB, 2014; NPBBDD, 2014).

Among the 13 buffalo breeds used for milk production in the country, the Murrah breed is the most important for dairy (Valsalan *et al.*, 2014) and is the breed of choice for upgrading buffaloes for milk production (Rao *et al.*, 2014). A National dairy plan implemented since 2011 aims to develop more productive animals (both cattle and buffaloes) and to develop and expand production systems to increase milk supply in India over a 15 year horizon (NDDB, 2014).

Nicaragua: In Nicaragua, more than 95 percent of the milk is produced by dual-purpose (dairy and beef) cattle (MAGFOR, 2012). A large proportion of the farmers producing milk in the country are medium and small scale (CENAGRO, 2012). In addition to producing milk, these farmers raise male calves for sale at weaning to larger-scale farmers/feedlots where they are grown for beef production (Holmann *et al.*, 2014). Up to half of the milk produced in the country is processed and sold as cheese either for local consumption or for export to neighbouring countries. Dairy production in Nicaragua received a major boost from 2001 to 2010 following the creation of a network of dairy cooperatives through a joint project between the Ministry of Agriculture and Forestry and the Swedish Agency for agricultural development (FondeAgro). By providing milk cooling and storage facilities and other essential services, the cooperatives enabled more stable farm gate prices for milk and supported an expanded market for milk products and livestock production (Galetto and Berra, 2011).

In all the countries, farmer cooperative groups formed through an aggregation of smallholder farmers serve to promote services to farmers, and also organize the collection, handling and sale of milk from the farms. Cooperatives enable small holder farmers to improve their competitive edge in the open market economies (Devendra, 2001).

Milk production and the reproductive performance of dairy animals

Milk production performance

Most of the studies reviewed on the performance of dairy animals in the target countries addressed milk production, reproductive performance, and to a lesser extent survival ability of the animals (Muasya, 2005; Zambrano *et al.*, 2006; Chenyambuga and Mseleko, 2009; Kumaresan *et al.*, 2009; Corrales, 2011; Holmann *et al.*, 2014). Table 4 presents reported milk production performance of dairy animals in the countries.

The average daily milk yield (DMY) was slightly more than 5 kg in mixed crop–livestock systems in semi-arid areas, and in the smallholder systems in Kenya and Tanzania. Large-scale commercial dairy systems in Kenya had the highest recorded production in the literature for systems in developing countries, with an average DMY per animal of 15 kg (Table 4). This high level of production could be attributed to the high genetic potential of the animals for milk production as well as good nutritional management. Crop–livestock systems in the semi-arid lands of Kenya, and Tanzania had the lowest milk yield, understandably due to the breeds and types of cattle kept in such systems.

In India, indigenous cattle, which comprise more than 75 percent of the total cattle population, are reported to produce on average 1.83 kg milk/day, crossbred cattle produce on average 6.36 kg/day, while buffaloes on average produce 3.83 kg/day (Gandhi and Sharma, 2005; Joshi and Singh, 2005). Higher yields are reported for animals raised under more intensive management systems (Table 4). It should be noted that a large amount of published information on productivity of different breed-types in India is based on animals reared in research stations rather than on the small holder farms (Gaur, Garg and Singh, 2005; Joshi and Singh, 2005; Birthal, Taneja and Thorpe, 2006; Mwacharo *et al.*, 2009).

The quantity of milk produced by animals in the dual-purpose production systems of Nicaragua is reported to be greatly variable depending on the season, and ranges from 3 to 5 kg/animal/day (Holmann *et al.*, 2014). Information on individual animal productivity within the country is, however, limited; reports from the country tended to present data on bulk milk production only.

Lactation length in dairy cattle is usually standardized to 305 days for purposes of performance comparison. Animals in the mixed crop–livestock systems, however, were not reported to have lactation lengths of 305 days. The longest lactation was 365 days in Kenya, and the

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

Table 5. Age at first calving (AFC, in months) and calving interval (CI, in days) of animals used for dairy production in India, Kenya, Nicaragua and Tanzania.

Country	Production system	Genotype	Ave. AFC (Months)	Ave. CI (days)	Source
Tanzania	Mixed crop–livestock	Crossbred	33	498	Msanga *et al.* (2000), Kaijage (2011)
	Extensive grass/rangeland based (traditional pastoral)	Tanzania shorthorn zebu × Exotic crosses, purebreds	51	476	Swai, Kyakaisho and Ole-Kawanara (2007)
	Medium-scale systems	Crossbred		412	Gillah, Kifaro and Madsen (2013)
	Smallholder dairy systems	Exotic × Indigenous crosses		432	Kanuya *et al.* (2000)
	Intensive urban/peri-urban dairy production	Crossbred/purebred	33	506	Gillah, Kifaro and Madsen (2013)
Kenya	Mixed crop–livestock (semi-arid lowland)	Crossbred	33	454	Thorpe *et al.* (1993)
	Mixed crop–livestock (sub-humid tropics)	Crossbred		412	Kahi (2000)
	Large-scale commercial dairy	Crossbred/purebred exotic	30	409	Ojango and Pollott (2004)
			36	412	Kahi (2000)
	Smallholder dairy	Crossbred		451	Mujibi *et al.* (2014)
India	Smallholder low input (traditional housed)	Crossbred cows	41	538	Kumaresan *et al.* (2009)
		Sahiwal	36	420	Joshi and Singh (2005)
Nicaragua	Extensive grass dual-purpose system	Reyna Creole	37	424	Corrales (2011)

shortest was reported in Tanzania (200 days). Tanzania relies mostly on indigenous *B. indicus* breeds that are associated with short lactation length (Katjiuongua and Nelgen, 2014).

Reproductive performance

Reproductive traits reported in the literature were age at first calving (AFC) and calving interval (CI). These traits are easily recorded as they occur following major events in an animal's life. Information is more difficult to obtain on other reproductive traits like conception rates and services per conception. These two indicators may only be accurately captured in systems where artificial insemination (AI) or hand mating is practiced and followed by pregnancy diagnosis. Pregnancy diagnosis generally requires more specialized personnel who may not be readily available; consequently, producers carry out insemination/mating of their animals and wait to see the progress of pregnancy hoping that their animals have conceived. This leads to poor capturing and reporting of information on animal conception in the low-input production systems. Table 5 presents AFC and CI for dairy animals in the countries.

In India, AFC was greater in more traditional low-input smallholder systems than in the mixed crop–livestock semi-intensive smallholder systems. The Kenyan large-scale dairy systems had the earliest AFC (30 months), while the extensive grazing systems in Tanzania reported the latest AFC (51 months) (Table 5). Large variations in AFC have been reported between production systems in the different countries (Table 5). These differences could be due to variation in breeds used within systems, differences in management practices across systems, and differences in climatic conditions. In systems where exotic breeds were reared, the AFC was generally younger than observed in systems utilizing mostly indigenous *B. indicus* breeds.

The average CI across the systems was 449 days. The longest CIs (more than 500 days) were reported in the traditional small holder systems of India, and in the urban dairy systems of Tanzania (Table 5). The large-scale commercial systems in Kenya had the shortest CIs. Improved and better informed management of dairy animals can greatly reduce the CIs and improve the overall herd productivity.

Reproductive and genetic technologies

Reproductive technologies

Dairy systems have experienced drastic transformation in the past few decades due to intensification and more extensive use of a wide range of technologies. Reproductive and genetic technologies (biotechnologies) are major avenues through which herd improvement has been achieved. The biotechnologies used in dairy production systems in India, Kenya, Nicaragua and Tanzania are presented in Table 6.

The most widely used reproductive technology in all four countries under review is AI, where it serves to introduce and disseminate desired dairy characteristics in populations. Large-scale commercial dairy systems in particular tend to use AI extensively, and opt for semen from commercial dairy *B. taurus* sires that is imported from more developed countries. Although available since the 1930s

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

Table 6. Biotechnologies used in dairy production in the target countries.

Country	Genetic technology	Reproductive technology	Source
Tanzania	Crossbreeding, upgrading	Artificial insemination (AI)	Msangi, Bryant and Thorne (2005), MLFD (2011b), Gillah, Kifaro and Madsen (2013), Katjiuongua and Nelgen (2014)
Kenya	Pedigree and milk recording, phenotypic and BLUP selection, progeny testing, pure breeding, crossbreeding and upgrading	AI, sexed semen, MOET (small extent) Cryopreservation	Ilatsia *et al.* (2007), Kosgey *et al.* (2011), Muriuki (2011), KALRO (2015)
	SNP assays to optimize choice of different crossbred dairy cattle genotypes		Ojango *et al.* (2014)
India	Crossbreeding, milk recording, progeny testing, genetic parameter and breeding value estimation, milk-based selection criteria, crossbreeding, pedigree selection	AI pregnancy diagnosis MOET, cryopreservation	Hegde (2006a), Kumaresan *et al.* (2009), NDDB (2014)
Nicaragua	Crossbreeding	AI, sexed semen, MOET (small extent)	Galetto and Berra (2011), Holmann *et al.* (2014)

and relatively cheap and easy to use, AI has been difficult to administer successfully in smallholder cattle production systems in developing countries. This difficulty is due mostly to logistical and institutional challenges (Okeyo *et al.*, 2000; Kosgey *et al.*, 2011; NDDB, 2014).

In India, the use of AI has risen since 2008 (Gautam, Dalal and Pathak, 2010; NDDB, 2014; Rao *et al.*, 2014) and has been applied to animal breeding in both cattle and buffalo. Although national coverage was low until 2005 (Ahlawat and Singh, 2005); India currently has the world's largest AI infrastructure, consisting of 49 semen stations producing 66.8 million doses of frozen semen annually (NDDB, 2014). Transformations have been induced in the dairy sector through new interests in the organization of services and markets such that dairy farming in India is rapidly evolving to a more professionally managed industry (NDDB, 2014).

Use of sexed semen and MOET has also been reported in India with an increasing demand for sexed semen (Hegde, 2006b). More extensive use of sexed semen alongside the ongoing expansion of AI infrastructure and adoption in the country could prove useful for improving the productivity of India's dairy sector by helping to reduce the number of male animals born into dairy herds that are not needed for reproduction.

Within East Africa, use of AI is most widespread in Kenya. However, national coverage in Kenya is quite low when compared with current AI use in India (Figure 5). Sexed semen and MOET are also reported to have been used by large-scale commercial farms in Kenya (Muriuki, 2011), although details are scanty on their adoption and use.

AI use in Tanzania is very low, as are conception rates following use of AI in the country (Ogutu, Kurwijila and Omore, 2014). Tanzania has a single national AI centre that produces about 150 000 doses annually, and also relies on limited amounts of semen imported through private companies (MLFD, 2011b; Katjiuongua and Nelgen, 2014; Ogutu, Kurwijila and Omore, 2014). Plans are now underway for substantial investment through public–private partnership arrangements between the government and its development partners to enhance the existing

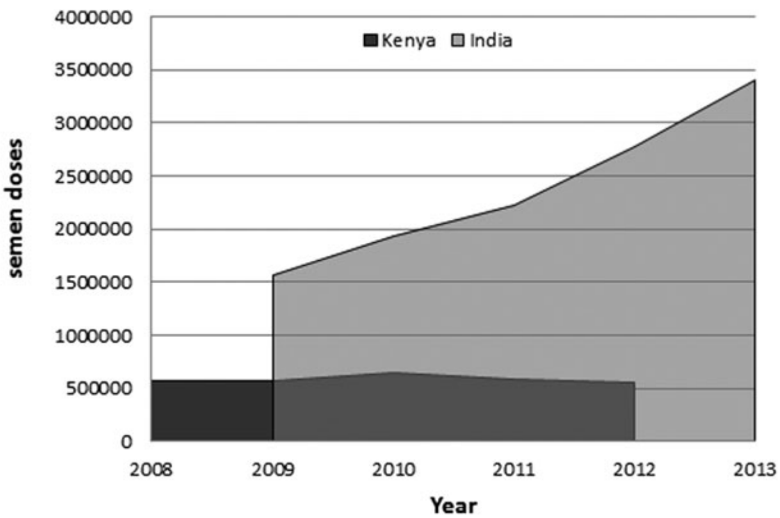


Figure 5. Number of semen doses used for AI annually between 2008 and 2013 (Source: BAIF reports 2008–2013; KAGRC website (http://www.kagrc.co.ke).

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

semen production and to implement an increasingly private sector-driven delivery system (Ogutu, Kurwijila and Omore, 2014).

In more extensive systems of Eastern Africa, the use of bulls, mostly of the local *B. indicus* breeds, remains common practice (Kaimba, Njehia and Guliye, 2011).

Although promoted through projects and organizations supported by the government, AI is not widespread in the smallholder cattle systems in Nicaragua (Holmann *et al.*, 2014). Many of the smallholder farmers have a strong cultural attachment to having a bull (Toro) in their herds. Where adopted, AI is mainly carried out by private companies that import semen of various breed-types. Smallholder and mixed crop–livestock farmers with interest in upgrading their dairy animals for higher productivity do so using both AI and hand mating, with the semen typically coming from *B. taurus* bulls (MAGFOR, 2012). The government recently introduced an animal traceability system that allows for monitoring of the movement of animals. This system is applied mainly to animals for export and its adoption remains limited across the country (Holmann *et al.*, 2014).

Use of other reproductive technologies such as in-vitro fertilization and embryo sexing is limited in all the countries, as these technologies tend to be more expensive, are logistically more demanding and require administration by more technically skilled manpower. Statistics are generally not available on the use of these technologies in dairy production in the study countries.

Genetic improvement technologies

The use of genetic improvement technologies (Table 6) is not widespread in the target countries. However, crossbreeding and upgrading are commonly used in all the countries with the objective of improving the local stock (Hegde, 2006a; Mwacharo *et al.*, 2009; Holmann *et al.*, 2014; Katjiuongua and Nelgen, 2014; NDDB, 2014). Livestock keepers in the countries practice some form of selection of their heifers and bulls for breeding. This is usually based on either physical appraisal of the animals, or records on phenotypic performance available for the animals and their relatives. Use of molecular information and genomic selection technologies is limited. However, studies are ongoing on utilization of genomic information for selection and parentage determination (Ahlawat and Singh, 2005; Kios, van Marle-Köster and Visser, 2012; Mujibi *et al.*, 2014).

In India, structures are in place to facilitate milk recording and genetic evaluation (Hegde, 2006b; Duclos *et al.*, 2008; NDDB, 2013). A milk-based selection criteria has been adopted for the selection of breeding bulls using pedigree information as well as progeny testing.

In East Africa, Kenya is the only country that has a national animal recording system where pedigree and performance recording is carried out. Kenya also has a national contract mating scheme through which sire selection is done (Mukisira, 2002; Kosgey *et al.*, 2011). These schemes, though open to all producers, are primarily used by the large-scale dairy producers in high-input systems where pure-breeding is common (Kosgey *et al.*, 2011). To date, only an estimated 2.5 percent of the national dairy herd is accounted for in the national animal recording program (Kenya Livestock Breeders Organization, (http://www.klbo.co.ke/) personal communication). Given that the larger-scale producers are the major source of improved dairy animals for other production systems, the benefits of the animal recording infrastructure would be greatly improved if more of the smallholder farmers provided information on the performance of their animals. Crossbreeding and upgrading of local stock are more common practice within the smaller-scale livestock production enterprises in Kenya.

In Tanzania, many livestock keepers in the pastoral systems practice selection within their own herds, and use natural mating (Ogutu, Kurwijila and Omore, 2014). In the smaller-scale systems, crossbreeding of various breed-types is common, resulting in a broad mix of breeds (Msangi, Bryant and Thorne, 2005). Few farmers have a well-developed breeding strategy and many rely on inseminators marketing semen from different countries to inform them about available bulls, characteristics of those bulls and about AI. Use of genomic selection technologies is still in an experimental stage (ILRI, personal communication).

Many livestock keepers in Nicaragua practice crossbreeding using natural mating, and strive to maintain animals with no more than 50 percent exotic breed-types (Corrales, 2011; Holmann *et al.*, 2014).

Table 7. Average costs of artificial insemination (AI) offered by various service providers in the four countries.

Country	AI service providers	Country currency[1]	Average costs of AI in US$	
			Local semen	Imported Semen
Tanzania	Government	TzS	11.2	67.04
Kenya[2]	Government	KES	3.0 (at source)	
	Private sector	KES	16.64	33.3
India	Government/private farms, NGO	INR	0.80	79.80
Nicaragua	Government/private	USD	10	15

Source: Ouma *et al.* (2014).

[1]Currency exchange rates used: 1 US$ = 62.65 INR; 90.12 KES; 1790.15 TzS; 597 CFA.

[2]See an example AI supply chain in Box 1.

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

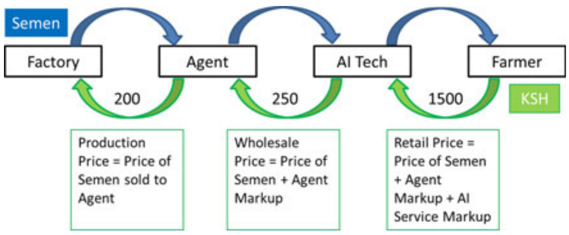
Costs of genetic and reproductive technologies and their influence on extent of usage

Compared with other reproductive technologies, AI has lower costs. The average costs vary greatly across the countries and are influenced by the population from which the sires were selected. This is illustrated in Table 7. In all the countries, semen imported from other countries is generally priced higher than that produced locally from the *B. taurus* breeds. It should however be noted that semen costs will also differ between countries based on national policies governing the use of imported semen, and depending on the prevailing exchange rates. The price of MOET was reported to be very high with no specific values given, and its use limited to high-input production systems (Questionnaire responses). In Nicaragua, the price per unit of sexed semen was reported to be US$30–40, while costs of embryos were reported to be higher than US$100 (Martin Mena Urbina, Questionnaire response).

The farm gate price of AI may vary greatly depending on the number of actors involved in the distribution chain (Ouma *et al.*, 2014). An example of variation pricing along one AI distribution chain in Kenya is presented in Box 1. Data were generally hard to find on current and projected costs of technology adoption, particularly at the level of dairy producer.

Box 1. Illustration of one AI Distribution chain in Kenya (adapted from (Ouma *et al*., 2014)).

Semen is sold from the producer for Ksh 200 to the agent (price may vary depending on the bull and its breed), this represents 13 percent of the end price. The Agent sells to the AI service provider at 250, retaining 50 shillings representing 3 percent of the end price. The AI technician then sells the semen to a farmer at 1500 Shillings, retaining 1250 Shillings gross profit which represents 83 percent of the end price.



Conclusion and recommendations

The information collated in this study indicates that data on genetic characteristics and performance of the dairy populations in developing countries is becoming more readily available although still limited in scope. The countries presented are at different stages of developing national genetic improvement strategies that have clearly defined objectives, and are implementing genetic technologies that already exist, notably AI, to effect change. However, limited evidence on the current state and costs of the technologies in the different livestock populations makes it difficult to estimate the benefits to obtain from their adoption.

Crossbreeding and upgrading are common practices across the systems and countries but there is limited information on animal genetics and performance to guide selection towards the desired change. Changing a population without evidence of which animals to retain in the existing population could yield negative rather than positive results.

To bring about change in production practices that will lead to improved productivity of dairy systems within the countries, investments will be needed: to improve measurement and documentation of animal performance; to build technical capacity at different levels to better design and manage genetic improvement; for research to improve the uptake of genetic technologies in key production systems; and in the infrastructure and processes that will deliver appropriate technologies to target populations.

While there seems to be a case for public and private sector providers to offer services like AI that are already popular in some countries, in combination with other technologies currently adopted to a lesser extent, there is still much to understand about technology combinations that will bring about optimum benefits under the different management and agro-ecological systems. There also remains the larger questions on what models of policy, market and institution interventions and arrangements are needed to improve the adoption of animal genetic and reproductive technologies in the mostly smallholder dairy systems found in developing countries.

Acknowledgements

We wish to acknowledge the support of the Global Futures and Strategic Foresight Project (GFSF). This work was undertaken at the International Livestock Research Institute (ILRI) as part of the CGIAR Research Programme on Policies, Institutions and Markets (PIM), led by the International Food Policy Research Institute (IFPRI), and the CGIAR Research Programme on Livestock and Fish (L&F). Colleagues from various institutions in the countries studied shared documents and information on breeding technologies used in their countries. This information was provided by:

1. Dr. Y.N. Msanga National Coordinator AnGRs, Tanzania
2. Dr. H.A. Mruttu Principal Livestock Research Officer, Tanzania
3. Martin Mena Urbina Research Assistant on forages, CIAT, Nicaragua
4. Dr. Albert Soudre Scientist/Lecturer University of Koudougou, Burkina faso
5. Dr. S.K. Singh Principal Scientist, Head Genetics and Breeding Division, India

We gratefully acknowledge the support received from these institutions and individuals. However, the opinions expressed here are the full responsibility of the authors, as are the errors and omissions.

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

Statement of interest

No.

References

Ahlawat, S.P.S. & Singh, P.K. 2005. Conservation and improvement of Indian cattle breeds. In *Proc. VIII National Conf. on Animal Genetics and Breeding in India*, pp. 1–12.

Birthal, P.S., Taneja, V.K. & Thorpe, W. 2006. Smallholder livestock production in India: opportunities and challenges. In *Proc. an ICAR–ILRI Int. Workshop held at National Agricultural Science Complex*, DPS Marg, Pusa, New Delhi-110 012, India, 31 January–1 February 2006.

Cecchi, G., Wint, W., Shaw, A., Marletta, A., Mattioli, R. & Robinson, T. 2010. Geographic distribution and environmental characterization of livestock production systems in Eastern Africa. *Agric. Ecosyst. Environ*. 135: 98–110.

CENAGRO (Censo Nacional Agropecuario). 2012. *Informe final. IV Censo Nacional Agropecuario*. Managua, Nicaragua, Instituto Nacional de Información de Desarrollo (INIDE).

CGIAR. 2012. CGIAR Research Programs (available at http://www.cgiar.org/our-strategy/cgiar-research-programs/).

Chenyambuga, S.W. & Mseleko, K.F. 2009. Reproductive and lactation performances of Ayrshire and Boran crossbred cattle kept in smallholder farms in Mufindi district, Tanzania. *Livest. Res. Rural Dev*. 21 (available at http://www.lrrd.org/lrrd21/7/chen21100.htm).

Corrales, R. 2011. *Population structure and phenotypic characterization as a basis for conservation and sustainable use of Reyna Creole cattle in Nicaragua*. Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden. (PhD thesis).

Devendra, C. 2001. Smallholder dairy production systems in developing countries : characteristics, potential and opportunities for improvement – review. *Asian-Austr. J. Anim. Sci*. 14: 104–113.

Duclos, D., Gokhale, S., Bacilieri, R. & Ducrocq, D. 2008. Simplified milk-recording protocols adapted to low-input environments with very small herd size. *Animal* 2: 160–166.

FAOSTAT. 2014. FAO Statistical database (available at http://faostatfaoorg).

Galetto, A. & Berra, C. 2011. Dairy development in Nicaragua and farmer cooperatives in the Matagalpa region. Contact author. In *21st Annu. World Symp. on Int. Food & Agribusiness Management Association*, Franckfurt, Germany, pp. 1–17.

Gandhi, R.S. & Sharma, A. 2005. Breeding strategies for self sustainance of Indian Cattle. In *Proc. VIII National Conf. on Animal Genetics and Breeding in India*, pp. 29–37.

Gaur, G.K., Garg, R.C. & Singh, K. 2005. Experiences of crossbreeding in cattle in India. In *Proc. VIII National Conf. on Animal Genetics and Breeding in India*, Mathura, India, pp. 38–49.

Gautam,, Dalal, R.S. & Pathak, V. 2010. Indian dairy sector: time to revisit operation flood. *Livest. Sci*. 127: 164–175 (available at http://dx.doi.org/10.1016/j.livsci.2009.09.010).

Gillah, K.A., Kifaro, G.C. & Madsen, J. 2013. Management and production levels of cross-bred dairy cattle in Dar es Salaam and Morogoro urban and peri urban areas. *Livest. Res. Rural Dev*. 25 (available at http://www.lrrd.org/lrrd25/9/gill251.htm).

Gillah, K.A., Kifaro, G.C. & Madsen, J. 2014. Effects of pre partum supplementation on milk yield, reproduction and milk quality of crossbred dairy cows raised in a peri urban farm of Morogoro town Tanzania. *Livest. Res. Rural Dev*. 26 (available at http://www.lrrd.org/lrrd26/1/gill260.htm).

Global Harvest Initiative. 2013. *The 2013 Global Agricultural Productivity (GAP) Report*. The Global Harvest Initiative, Washington, DC (available at http://globalharvestinitiative.org/GAP/2013_GAP_Report_BOOK_ONLINE.pdf).

Hegde, N.G. (BAIF). 2006a. Dairy Development for poverty alleviation and environmental protection (available at http://www.baif.org.in/Scientific_Papers_livestock_development.asp).

Hegde, N.G. (BAIF). 2006b. Livestock Devt for Sustainable Livelihood of Small Farmers. In *Souvenir of the 39th Annu. General Meeting and 48th National Symp. on Energising Rural India – A Challenge to Livestock Industry. Compound Livestock Feed Manufactures Association of India (CLFMA)*, Manesar, Haryana, pp. 50–63 (available at http://www.google.co.id/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCIQFjAA&url=http://www.baif.org.in/doc/Livestock_Devt/Livestock%20Devt%20for%20Sustainable%20Livelihood%20of%20Small%20Farmers.doc&ei=ovYgVNHZF).

Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S. & Rufino, M.C. 2013. The roles of livestock in developing countries. *Animal* 7: 3–18.

Holmann, F., Mtimet, N., Mora, M.A. & van der Hoek, R. 2014. *Dual-purpose milk and beef value chain development in Nicaragua : past trends, current status and likely future directions*. Nairobi, Kenya (available at https://cgspace.cgiar.org/bitstream/handle/10568/66467/PR_situation_analysis_nicaragua_web.pdf?sequence=4).

IFAD. 2014. Investing in rural people in Nicaragua (available at http://www.ruralpovertyportal.org).

IGAD. 2013. *Centre for pastoral areas and livestock development: the contribution of livestock to the Kenyan economy ICPALD*. Nairobi, Kenya (available from: 4/CLE/8/2013. http://igad.int/attachments/714_TheContributionofLivestocktotheKenyanEconomy.pdf).

Ilatsia, E.D., Muasya, T.K., Muhuyi, W.B. & Kahi, A.K. 2007. Milk production and reproductive performance of Sahiwal cattle in semi arid Kenya. *Trop. Sci*. 47: 120–127.

ILRI. 2004. The Kenya Smallholder Dairy Project (available at http://www.smallholderdairy.org/).

ILRI. 2008. The East Africa Dairy Development (EADD) project (available at http://www.ilri.org/EADD).

ILRI, CIAT, ICARDA & Worldfish Centre. 2011. CGIAR Research Program 3.7; More Meat, Milk, and Fish by and for the Poor (CGIAR Research Program 3.7): A proposal submitted to the CGIAR Consortium Board by ILRI on behalf of CIAT, ICARDA and WorldFish Centre. Nairobi, Kenya (available at https://cgspace.cgiar.org/handle/10568/3248).

Joshi, B.K. & Singh, A. 2005. Indigenous cattle Milch breeds – their potential and improvement programs. In *Proc. VIII National Conf. on Animal Genetics and Breeding in India*, India, pp. 21–28.

Kahi, A.K. 2000. *Genetic and economic aspects of breeding for dairy production in Kenya*. Bueren, Stuttgart, Germany, Verlag Grauer.

Kahi, A.K., Thorpe, W., Nitter, G., Van Arendonk, J.A.M. & Gall, C. F. 2000. Economic evaluation of crossbreeding for dairy production in a pasture based production system in Kenya. *Livest. Prod. Sci*. 65: 167–184.

Kahi, A.K., Nitter, G. & Gall, C.F. 2004. Developing of breeding schemes for pasture based dairy production systems in Kenya. II. Evaluation of alternative objectives and schemes using a two- tier open nucleus and young bull system. *Livest. Prod. Sci*. 88: 179–192.

Kaijage, J.T. 2011. Small scale dairy production and marketing in the Southern highlands of Tanzania. In *The 5th National Dairy Development Conf.*, Mwanza, Tanzania, p. 139.

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

Kaimba, G.K., Njehia, B.K. & Guliye, A.Y. 2011. Effects of cattle rustling and household characteristics on migration decisions and herd size amongst pastoralists in Baringo District, Kenya. *Pastoralism: Res. Policy Pract*. 1: 18.

KALRO. 2015. The Kenya Agricultural and Livestock Research Organization (available at http://www.kalro.org/livestock_more).

Kanuya, N.L., Kessy, B.M., Bittegeko, S.B.P., Mdoe, N.S. & Aboud, A.A. 2000. Suboptimal reproductive performance of dairy cattle kept in smallholder herds in a rural highland area of northern Tanzania. *Prev. Vet. Med*. 45: 183–192.

Kanuya, N.L., Matiko, M.K., Kessy, B.M., Mgongo, F.O., Ropstad, E. & Reksen, O. 2006. A study on reproductive performance and related factors of zebu cows in pastoral herds in a semiarid area of Tanzania. *Theriogenology* 65: 1859–1874.

Katjiuongua, H. & Nelgen, S. 2014. *Tanzania smallholder dairy value chain development: situation analysis and trends*. Nairobi, Kenya (available at https://cgspace.cgiar.org/bitstream/handle/10568/68513/PR_Tanzania.pdf?sequence=1).

KEVEVAPI. 2014. Kenya Veterinary Vaccines Production Institute, Nairobi, Kenya (available at http://www.kevevapi.org/index.php/about-us/item/4-livestock-sector-contribution).

Kios, D., van Marle-Köster, E. & Visser, C. 2012. Application of DNA markers in parentage verification of Boran cattle in Kenya. *Trop. Anim. Health Prod*. 44: 471–476.

KNBS, K. N. B. of Statistics. 2014. *Kenya National Bureau of Statistics Kenya Facts and Figures, 2014*. Nairobi, Kenya, Kenya National Bureau of Statistics.

Kosgey, I.S., Mbuku, S.M., Okeyo, A.M., Amimo, J., Philipsson, J. & Ojango, J.M.K. 2011. Institutional and organizational frameworks for dairy and beef cattle recording in Kenya: a review and opportunities for improvement. *Anim. Genet. Resour. Food Agric. Org. U.N.* 48: 1–11.

Kumaresan, A., Prabhakaran, P.P., Bujarbaruah, K.M., Pathak, K. A., Chhetri, B. & Ahmed, S.K. 2009. Reproductive performance of crossbred dairy cows reared under traditional low input production system in the eastern Himalayas. *Trop. Anim. Health Prod*. 41: 71–78.

MAGFOR (Ministerio Agropecuario y Forestal). 2012. *Informe final. Cuarto Censo Nacional Agropecuario*. Managua, Nicaragua, MAGFOR.

Makoni, N., Mwai, R., Redda, T., van der Zijpp, A. & van der Lee, J. 2013. *White gold: opportunities for dairy sector development collaboration in East Africa*. Wageningen (available at http://library.wur.nl/WebQuery/wurpubs/454917).

MLFD. 2011a. Livestock sector development programme. Dar Es Salaam, Tanzania (available at http://www.tanzania.go.tz/egov_uploads/documents/Livestock_Programe_sw.pdf).

MLFD. 2011b. The Tanzania Dairy Industry: status, opportunities and prospects. In *7th African Dairy Conf. and Exhibition held at MovenPick Palm Hotel. Ministry of Livestock and Fisheries development Tanzania*, Dar Es Salaam, Tanzania, 25–27 May 2011.

Mpofu, N. 2014. Livestock production and development: challenges and opportunities for smallholder farmers in Africa. In *State of the African Farmer. Heifer International*, pp. 42–50 (available at http://www.heifer.org/join-the-conversation/blog/2014/October/state-of-the-african-farmer.html).

Msanga, N.Y. & Bee, J.K.A. 2006. The performance of Friesian x Boran bulls managed extensively under agro-pastoralism with indigenous Tanzanian zebu. *Livest. Res. Rural Dev*. 18 (available at http://www.lrrd.org/lrrd18/2/msan180).

Msanga, Y.N., Bryant, M.J., Rutam, I.B., Minja, F.N. & Zylstra, L. 2000. Effect of environmental factors and of the proportion of Holstein blood on the milk yield and lactation length of crossbred dairy cattle on smallholder farms in north-east Tanzania. *Trop. Anim. Health Prod*. 32: 23–31.

Msangi, B.S.J., Bryant, M.J. & Thorne, P.J. 2005. Some factors affecting variation in milk yield in crossbred dairy cows on smallholder farms in north-east Tanzania. *Trop. Anim. Health Prod*. 37: 403–412.

Muasya, T.K. 2005. *Genetic evaluation of the dairy cattle herd at the University of Nairobi Vetrinary Farm*. Kenya, University of Nairobi.

Muasya, T.K. 2013. *Genetic improvement of dairy cattle under different herd environments in Kenya*. Berlin, Humboldt-University of Berlin, Verlag Dr. Köster.

Mujibi, F.D.N., Ojango, J., Rao, J.E.O., Karanka, T., Kihara, A., Marete, A., Baltenweck, I., Poole, J., Rege, J.E.O., Gondro, C., Weerasinghe, W.M.S.P., Gibson, J.P. & Okeyo, A.M. 2014. Use of high density SNP genotypes to determine the breed composition of cross bred dairy cattle in smallholder farms: assessment of reproductive and health performance. In *Proc. 10th World Congress on Genetics Applied to Livestock Production*, pp. 4–6.

Mukisira, E.A. 2002. Dairy recording in Kenya. *In* K.R. Trivedi, ed. *Int. Workshop on Animal Recording for Smallholders in Developing Countries*, 20–23 October 1997, pp. 147–153. Anand, India, ICAR Technical Series 1.

Muraguri, G.R., McLeod, A. & Taylor, N. 2004. Estimation of milk production from smallholder dairy cattle in the coastal lowlands of Kenya. *Trop. Anim. Health Prod*. 36: 673–684.

Muriuki, H.G. 2011. *Dairy development in Kenya*. FAO, Rome, Italy.

Mwacharo, J.M., Ojango, J.M.K., Baltenweck, I., Wright, I., Staal, S., Rege, J.E.O. & Okeyo, A.M. 2009. *Livestock productivity constraints and opportunities for investment in science and technology*. Nairobi, Kenya, ILRI.

Mwambene, P.L., Chawala, A., Illatsia, E., Das, S.M., Tungu, B. & Loina, R. 2014. Selecting indigenous cattle populations for improving dairy production in the Southern Highlands and Eastern Tanzania. *Livest. Res. Rural Dev*. 26: Article 6 (available at http://www.lrrd.org/lrrd26/3/mwam26046.html).

National Bureau of Statistics Tanzania. 2014. Statistical Abstract 2013. Dar Es Salaam, Tanzania (available at http://www.nbs.go.tz/nbs/StasticalAbstract/StatisticalAbstractReport2013.pdf).

NDDB, N. D. D. B. I. 2013. National Accounts Statistics (available at http://www.nddb.org/information/stats/GDPcontrib).

NDDB, N. D. D. B. I. 2014. National Dairy Plan, India (available at http://www.nddb.coop/sites/default/files/pdfs/NDPBrochure-Eng-singlepage%29.pdf).

NPBBDD. 2014. National Programme for Bovine Breeding and Dairy Development, India (available at http://www.dairyknowledge.in/content/01-national-programme-bovine-breeding-and-dairy-development-npbbdd-0).

Ogutu, C., Kurwijila, L. & Omore, A. 2014. *Review of successes and failures of dairy value chain development interventions in Tanzania*. International Livestock Research Institute (ILRI), Nairobi, Kenya.

Ojango, J.M.K. & Pollott, G.E. 2001. Genetics of milk yield and fertility traits in Holstein-Friesian cattle on large-scale Kenyan farms. *J. Anim. Sci*. 79: 1742–1750.

Ojango, J.M.K. & Pollott, G.E. 2004. The productivity of Holstein–Friesian dairy cattle in different farming systems of Kenya. *Int. J. Agric. Rural Dev*. 5: 145–155.

Ojango, J.M.K., Marete, A., Mujibi, D., Rao, J., Pool, J., Rege, J.E. O., Gondro, C., Weerasinghe, W.M.S.P., Gibson, J.P. & Okeyo, A.M. 2014. A novel use of high density SNP assays to optimize choice of different crossbred dairy cattle genotypes in small-holder

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096

systems in East Africa. In *Proc. 10th World Congress of Genetics Applied to Livestock Production*, pp. 2–4.

Okeyo, A.M., Kajume, J.K., Mosi, R.O., Okila, E.V.A., Gathuma, J. M., Kiere, S.M.N., Agumbah, G., Kuria, J.N. & Chema, S. 2000. Artificial Insemination a bio-technological tool for genetic improvement of Kenyan dairy cattle herds: historical perspective, current status, challenges and way forward in the next millenium. A Kenya Country Paper. In *Symp. on Dairy Cattle Breeding in East Africa: Sustainable Artificial Insemination Service. Kenya Agricultural Research Institute (KARI), Headquarters, Kaptagat Road*, Nairobi, 20–21 March 2000.

Ouma, R., Jakinda, D., Magati, P. & Rege, J.E.O. 2014. *Benchmarking the Kenyan Artificial Insemination service sub-industry. A study for the Kenya Markets Trust and the Competition Authority of Kenya*. Kenya Markets Trust, Nairobi, Kenya.

Peeler, E.J. & Omore, A.O. 1997. *Manual of livestock production systems in Kenya*. Nairobi, Kenya, KARI/DFID National Agricultural Research Project II.

Rao, C.K., Bachhman, F., Sharma, V., Venkataramaiah, P., Panda, J. & Rathinam, R. 2014. *Smallholder dairy value chain development in India and select States (Assam and Bihar): past situation analysis and trends*. International Livestock Research Institute (ILRI), Nairobi, Kenya.

Robinson, T.P., Thornton, P.K., Franceschini, G., Kruska, R.L., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., Fritz, S., You, L., Conchedda, G. & See, L. 2011. *Global livestock production systems*. Food and Agriculture Organization of the United Nations (FAO) and International Livestock Research Institute (ILRI). FAO, Rome, Italy.

Seré, C., van der Zijpp, A., Persley, G. & Rege, E. 2008. Dynamics of livestock production systems, drivers of change and prospects for animal genetic resources. *Anim. Genet. Resour. Inf. Bull*. 4: 1–27.

Sethi, R.K. & Kala, S.N. 2005. Buffalo wealth and genetic improvement programmes in India. In *Proc. of the VIII National Conf. on Animal Genetics and Breeding in India*.

Shekhar, C., Thakur, S.S. & Shelke, S.K. 2010. Effect of exogenous fibrolytic enzymes supplementation on milk production and nutrient utilization in Murrah buffaloes. *Trop. Anim. Health Prod*. 42: 1465–1470.

Staal, S., Owango, M., Muriuki, H., Kenyanjui, M., Lukuyu, B., Njoroge, L., Njubi, D., Baltenweck, I., Musembi, F., Bwana, O., Muriuki, K., Gichungu, G., Omore, A. & Thorpe, W. 2001. *Dairy systems characterisation of the greater Nairobi milk shed*. Nairobi, Kenya, ILRI.

Swai, E.S., Kyakaisho, P. & Ole-Kawanara, M.S. 2007. Studies on the reproductive performance of crossbred dairy cows raised on smallholder farms in eastern Usambaramountains, Tanzania. *Livest. Res. Rural Dev*. 19: Article 61 (available at http://www.lrrd.org/lrrd19/5/swai19061.htm).

Thornton, P., Herrero, M., Freeman, A., Mwai, O., Rege, E., Jones, P. & Mcdermott, J. 2007. Vulnerability, climate change and livestock – research opportunities and challenges for poverty alleviation. *Open Access J*. published by ICRISAT 4: 1–23.

Thornton, P.K. 2010. Livestock production: recent trends, future prospects. *Philos. Trans. R. Soc.: Biol. Sci*. 365: 2853–2867.

Thorpe, W., Kang'ethe, P., Rege, J.E.O., Mosi, R.O., Mwandotto, B. A.J. & Njuguna, P. 1993. Crossbreeding Ayrshire, Friesian and Sahiwal cattle for milk yield and preweaning traits of progeny in the semiarid tropics of Kenya. *J. Dairy Sci*. 76: 2001–2012.

Valsalan, J., Chakravarty, A.K., Patil, C.S., Dash, S.K., Mahajan, A. C., Kumar, V. & Vohra, V. 2014. Enhancing milk and fertility performances using selection index developed for Indian Murrah buffaloes. *Trop. Anim. Health Prod*. 46: 967–974.

World Bank. 2008. *World development report. Agriculture for development*. The World Bank, Washington, DC.

Zambrano, S., Contreras, G., Pirela, M., Cañas, H., Olson, T. & Landaeta-Hernández, A. 2006. Milk yield and reproductive performance of crossbred Holstein × Criollo Limonero cows. *Revista Científica* 16: 155–164.

Downloaded from https://www.cambridge.org/core. Maseno University. Library, on 31 Jan 2018 at 10:18:41, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S2078633616000096