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Invited review: Learning from the future—A vision for dairy farms and cows in 2067

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ABSTRACT

The worldwide population in 2067 will reach 10.4 billion with 81% residing in Africa or Asia. Arable land available for food production will decrease to 0.15 ha per person. Temperature will increase in tropical and temperate zones, especially in the Northern Hemisphere, and this will push growing seasons and dairy farming away from arid areas and into more northern latitudes. Dairy consumption will increase because it provides essential nutrients more efficiently than many other agricultural systems. Dairy farming will become modernized in developing countries and milk production per cow will increase, doubling in countries with advanced dairying systems. Profitability of dairy farms will be the key to their sustainability. Genetic improvements will include emphasis on the coding genome and associated noncoding epigenome of cattle, and on microbiomes of dairy cattle and farmsteads. Farm sizes will increase and there will be greater lateral integration of housing and management of dairy cattle of different ages and production stages. Integrated sensors, robotics, and automation will replace much of the manual labor on farms. Managing the epigenome and microbiome will become part of routine herd management. Innovations in dairy facilities will improve the health of cows and permit expression of natural behaviors. Herds will be viewed as superorganisms, and studies of herds as observational units will lead to improvements in productivity, health, and well-being of dairy cattle, and improve the agroecology and sustainability of dairy farms. Dairy farmers in 2067 will meet the world's needs for essential nutrients by adopting technologies and practices that provide improved cow health and longevity, profitable dairy farms, and sustainable agriculture.

Key words: dairy, future, technology, management

INTRODUCTION

Demand for dairy products and technologies will grow during the next 50 yr for 2 reasons. First, increased per capita income worldwide will boost demand for dairy and other food products from animals, and these products increasingly will provide essential nutrients in developing countries. The Food and Agriculture Organization (**FAO**) of the United Nations states: "Even small amounts of animal source foods can improve the nutritional status of low-income households. Meat, milk and eggs provide proteins with a wide range of amino acids as well as micronutrients such as iron, zinc, vitamin A, vitamin B_{12}, and calcium, in which many malnourished people are deficient" (Kourous, 2011). Second, dairy products efficiently meet nutritional requirements of humans from the standpoint of farming practices. Production of milk uses less land to produce 1 g of readily edible protein than production of other livestock or poultry products and some plant products (Figure 1; Clark and Tillman, 2017; Roser and Ritchie, 2017). Dairy-based diets are superior to vegan-, egg- and omnivore-based diets for maximizing capacity of croplands to feed the greatest number of people while adhering to recommended agronomic practices for various classes of lands (Peters et al., 2016). The advantage of dairy- and egg-based diets over vegan-based diets is attributable to the essential amino acids and micronu-

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trients from dairy- and egg-based diets that are missing in appropriate ratios in typical plant-based foods.

To supply increased demand for dairy products in the decades ahead, there must be a sustainable balance between products produced within country and imports. This provides opportunities for developed and developing exporting countries to provide dairy products as well as dairy equipment and technologies to expand dairy farming in countries where suitable land resources exist (Gerosa and Skoet, 2012).

As demand for dairy products increases, it is important to understand global dairy production today and how it may change during the decades ahead. We have been engaged informally for more than 2 yr with a specific focus on dairy cows and farms in 2067—primarily in developed countries with advanced dairy farm industries and technologies. In this forward-looking commentary, we first focus on global projections for population, arable land, and climate change, and on current dairy production in developed and developing countries. Then, we transition to describing changes that will occur in dairy cows, farms, technologies, and practices by 2067.

GLOBAL CHANGES THAT WILL AFFECT DAIRY PRODUCTION BY 2067

Population

The United Nations estimates that our world's population will grow from 7.6 to 10.5 billion between 2017 and 2067 (United Nations, 2017). This projection represents the median variant, between high (12.6 billion) and low (8.6 billion) variants. Asia and Africa will account for 93% of this growth (Figure 2). Latin America and the Caribbean, North America, and Oceania will grow modestly, whereas Europe will decline in population. Half of the world's population in 2067 will live in 10 countries, ranked by population: India, China, Nigeria, United States, Pakistan, Indonesia, Democratic Republic of the Congo, Ethiopia, Brazil, and Bangladesh. Population density will increase by 162% in Africa and by between 16 and 46% in most other regions and decline 7% in Europe by 2067 (inset, Figure 2), resulting in greater disparities in amount of arable land per capita among regions.

Arable Land

Growth in populations in Asia and Africa will put additional limits on amount of arable land per capita for food and feed production (World Bank, 2017). Currently, there is a 6-fold difference in amount of arable land (ha per person) among regions of the world (North America, 0.59; Europe and Central Asia, 0.38; Latin America and Caribbean, 0.28; Sub-Saharan Africa, 0.22; World, 0.20; Middle East and North Africa, 0.13, and East Asia and Pacific, 0.10. By 2067, there will be an estimated 0.15 ha of arable land per person worldwide (Alexandratos and Bruinsma, 2012).

Increased use of permanent grasslands and byproduct feeds for milk production will decrease pressure on arable land (Gill et al., 2010; Wilkinson, 2011) and improve food security in countries that have lands for permanent grazing. Countries with less arable land per capita will increasingly use their available land to produce human food rather than livestock feed. Some existing permanent grasslands will be converted to arable land in developing countries, which will reduce land for grazing by dairy cattle.

Some countries, such as China, are pursuing strategies in which investments in dairy production are focused on acquisition of dairy farms and processing facilities offshore in countries with more arable land per capita. Dairy farming and processing facilities in these countries will produce dairy products for import into China (Australia Plus, 2017).

Climate Change

Changes in climate during the next 50 yr will affect where dairy farms and cattle are located and focus

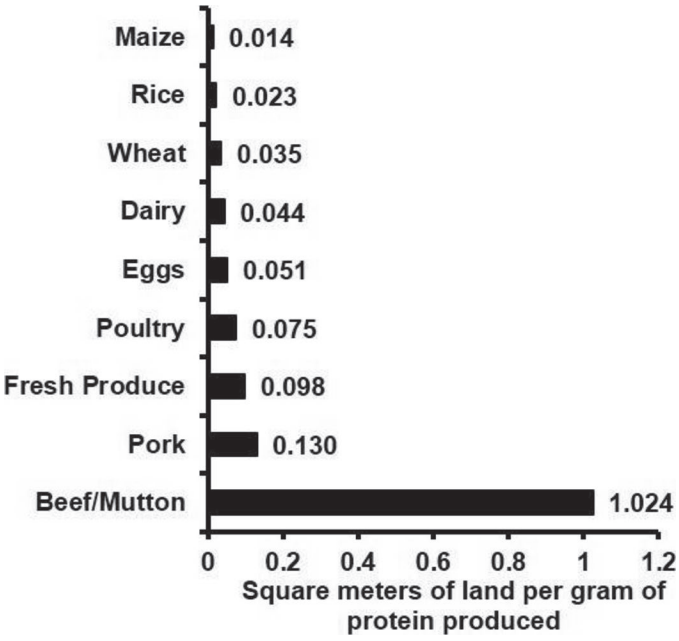

Figure 1. Square meters of land required to produce 1 g of edible protein from various crops or production systems. Data from Clark and Tillman (2017) and graph modified from Roser and Ritchie (2017) under a Creative Commons CC BY-SA 2.0 license (https://creativecommons.org/licenses/by-sa/2.0/).