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REVIEW

HARNESSING BIODIVERSITY FOR HEALTHY DAIRY FARMS

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KEYWORDS

biodiversity, dairy farm, one health concept, soil health

HIGHLIGHTS

- Plant and soil biodiversity underline healthy dairy farms with less agrochemical inputs.
- Biodiversity-driven integrative approaches support healthy soils and high-quality milk products.
- Biodiversity-based modern farms can achieve high profitability with less environmental impacts.

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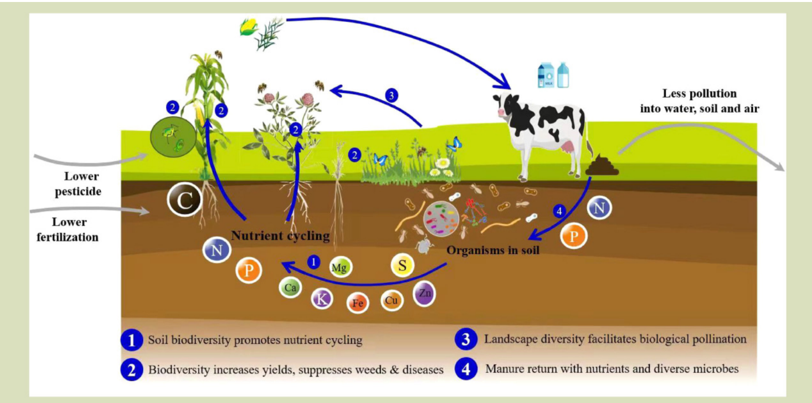
GRAPHICAL ABSTRACT



ABSTRACT

Producing sufficient high-quality forage to meet the increasing domestic demand for safe and nutritious milk products is one of the critical challenges that Chinese dairy farms are facing. The increased forage biomass production, mainly contributed by agrochemicals inputs in China, is accompanied by tremendous impacts on the ecology of dairy farms and soil quality. This paper presents a framework for healthy dairy farms in which targeted management practices are applied for quality milk products with minimal adverse environmental impacts. The paper also summarizes biodiversity management practices at the field and landscape scales toward lessening inputs of water, fertilizers, pesticides and mitigating soil compaction. Dairy farming with biodiversity-driven technologies and solutions will be more productive in producing quality milk and minimizing environmental damage.

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1 BACKGROUND

China’s dairy industry has developed dramatically and fresh milk production is presently around 35 Mt in 2020, while domestic demand for milk has grown at a faster rate than production, both in general-quality and high-quality levels[1,2]. Milk production in China now supplies less than 70% of this domestic demand[3]. One of the key challenges is the shortage of high-quality forage produced in China. For example, the two most important forage crops for protein intake of dairy cows are alfalfa (*Medicago sativa*) and oats (*Avena sativa*), but the self-sufficiency rate of the two crops in 2020 was only 76% and 78%, respectively. Also, less than 30% of alfalfa is high-quality, while 25% of oats are low-protein oats in China[4]. The low production of high-quality forage is attributed to, for example, continuous cropping obstacles and severe soil quality problems caused by excessive application of water, fertilizers and pesticides as well as soil compaction due to heavy machinery[5,6]. Excessive application of agrochemicals will mean that dairy farms cause severe environmental problems, such as water and soil pollution, with negative off-site impacts on ecosystems. For example, beneficial insects, for example, pollinators are declining or disappearing due to the use of herbicides and insecticides[7,8].

Confronting the low production of milk, low feeding values and overuse of inputs in dairy farms, the Chinese government has undertaken a series of measures. For example on 17 February 2015, the Ministry of Agriculture regulated the use of mineral fertilizers by in an action plan for zero growth of fertilizer use by 2020. The Regulation on the Administration of Pesticides was approved to reduce and standardize the use of pesticides in 2017. These measures will facilitate intensively managed dairy farms toward green transformation. Here we present a framework for healthy dairy farms with biodiversity management practices, include measures for improving soil quality, diversification of crop sequences to address yield constraints caused by continuous monocultures, and enhancing ecological services for pollination of forage grass, to obtain high production of quality milk with less environment damaging.

2 BIODIVERSITY OF DAIRY FARM IN SUPPORT OF ONE HEALTH CONCEPT

Increasing the biodiversity of dairy farm production systems helps improve soil quality and forage production, and further milk quality and production, and human health. The health of humans, animals, plants, microorganisms and ecosystems are closely related. This leads to the occurrence and spread of detrimental elements (e.g., pathogens, antibiotics and heavy metals) or inefficient elements (e.g., manure and plant residues) affecting all their health. To address these issues, the One Health concept was developed to prevent and control these disadvantages by multidisciplinary cooperation to achieve good health for people and environment[9–11]. Soil, one of the sources of nutrients for plants and microorganisms, and its quality and biodiversity can affect the growth of plants and microorganisms. The Soil-Food-Environment-Health Nexus framework highlights that soil properties and processes are essential in influencing food quality, environmental quality and human health through biogeochemical nutrient cycles among soil, food, environment and human populations[12,13].

Based on the Soil-Food-Environment-Health Nexus framework, it is clear that improving the soil quality in dairy farms is crucial in milk quality and production. The nutrient cycles from soil, to crops and human populations, links soil quality to environmental and human health from a systems perspective, within which management practices, especially those that effect biodiversity, matter (Fig. 1). In detail, soil biodiversity assists regulating nutrient cycling, in support of forage growth aboveground. Also, the interaction of diverse soil communities with forage plants may influence floral characteristics[14]. Mixtures of appropriate forage crops may improve herbage yield, reduce disease and suppress weeds[15]. Plant and soil biodiversity in dairy farms, is helpful for reducing the inputs of mineral fertilizers and synthetic pesticides, reducing environmental pollution of soil, water and air, consequently contributes to achieving high-quality soil, pastures and milk products, and in support of One Health[15,16].

3 MANAGEMENT MEASURES FOR HEALTHY FARMS

A range of solutions such as organic manures, crop diversification and wild species mixtures have been applied to enhance soil quality, reduce pest and weed pressure, improve quality of dairy products (Fig. 2). More detailed solutions are illustrated below.

3.1 Measures for improving soil quality

Organic fertilizer, crop diversification and soil fauna are beneficial for soil quality. Replacing mineral fertilizers with organic fertilizer can be helpful for reducing the overuse of mineral fertilizers[17–19] as well as provide a more diversified and balanced diet to fuel soil microorganisms and enhance multiple soil functions[20]. Substitution of mineral fertilizers with organic fertilizers requires matching the nutrient composition of organic fertilizers and the nutrient deficiency profile of the soil. In addition, treating manure to achieve a range of functional microbial fermentations, can promote nutrient cycling and reduce environmental pollution[21]. Intercropping or crop rotations can enhance soil quality through increasing soil organic matter and soil aggregate formation[15,22,23], which requires an understanding of relevant

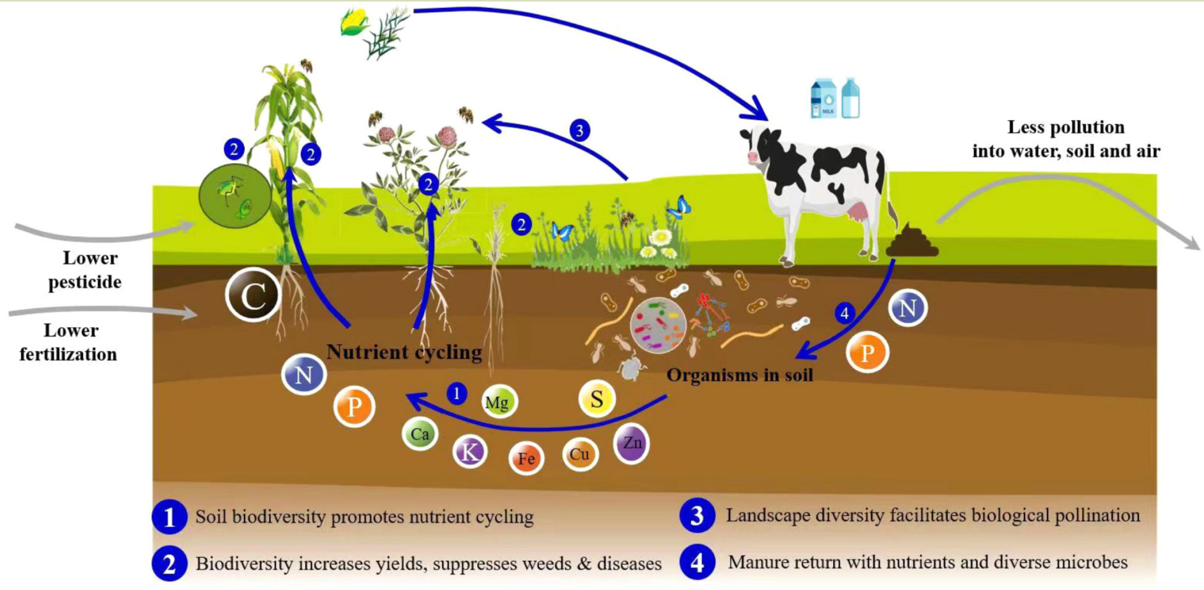

Fig. 1 Biodiversity-based principles applied in dairy farms in support of One Health concept.

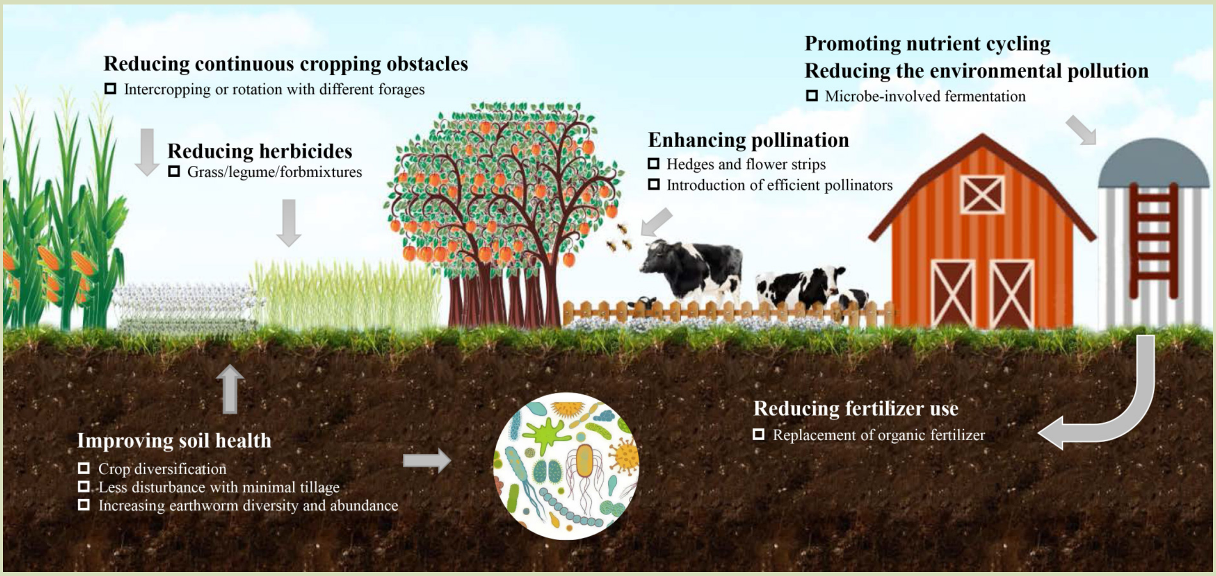

Fig. 2 Biodiversity-based measures for constructing a healthy farm.

disease cycles, crops combinations, and both productive and financially sustainable crop sequences.

To overcome soil compaction caused by frequent mechanical operations, soil macrofauna, such as earthworms, can be introduced to increase soil porosity and soil water storage, and mitigate the negative effects of machinery use[24]. Earthworms are regulated by the level of primary production and in this regulation process, the release of soil nutrients is promoted by earthworms, which helps reduce the input of nitrogen fertilizer[25]; in addition, earthworms can feed on seeds and seedlings of a wide range of weeds, facilitating reduction of the negative impacts of weeds on major crops as well as the use of herbicides[26]. To monitor soil quality, one measure is to establish an evaluation system with quantitative indicators for soil quality on dairy farms, such as the richness of soil microorganisms and animals, providing positive feedback to aboveground ecosystems[27]. Currently, the commonly used evaluation method is the Cornell Soil Health Assessment system, which includes physical, chemical and biological indicators[28]. The abundance, diversity, activity, physiology and behavior of soil organisms can reflect soil quality with adequate sensitivity, so the diversity of soil organisms is gaining more attention for evaluating the soil quality[29,30]. In recent studies, in addition to indicators related to microorganisms, some indicator animals (e.g., nematodes and earthworms) have been increasingly used[28,31,32].

3.2 Diversification of crop sequences to address yield constraints caused by continuous monoculture

The continuous cropping of legume forages may lead to a significant loss of crop yield; however, intercropping or rotating legume forages, can significantly relieve the autotoxicity or reduce the abundance of soil pathogenic fungi and inhibit soilborne pathogens under continuous cropping of legumes[23]. For example, the rotation of alfalfa and wheat or corn is effective in alleviating the soilborne pathogens of alfalfa caused by fungi and the autotoxicity in monoculture[33,34].

From statistical comparisons of field experiments, it found was that crop yields can be increased by 20% in rotations, and by 16%–29% in continuous monoculture[35,36]. Several studies have shown that replacing continuous cropping with intercropping or rotation can improve nutrient uptake efficiency of crops[37], while regulating the structure, diversity and stability of soil microbial communities and the food web thereby reducing populations soilborne pathogens, including bacteria, fungi and nematodes[38–40].

Forage grass mixtures can suppress weeds and thus reduce the need for herbicides. For example, including competitive forbs into grass-clover mixtures can significantly suppress weed growth[41,42]. The mixture of deep-rooting plantain with ryegrass/clover increases forage production, while suppressing weed growth. In addition, weed suppression was also observed when corn was mix-planted with mung bean at a one to three ratio[43]. This helps reduce the demand of herbicides and costs in forage cultivation.

3.3 Enhancing ecological services for pollination of forage crops

Increasing biodiversity and enhancing ecosystem services of pollinators can enhance crop yield[44]. The production of many forage crops such as *Melilotus officinalis* largely depends on pollinators[45]. In return, pollinator abundance can be influenced by forage species. Combined planting of leguminous crops and non-legumes forage crops, such as maize and ryegrass, can be an effective practice for improved crop nutrient and forage crop yield[46,47].

By planting flowering plants with different flowering periods, the source of nectar for pollinators such as bees can be extended throughout the biological period, thus increasing pollination[48,49]. Designing multispecies forage grass and adopting suitable cutting frequency management practices also can increase flower resources, support high populations of pollinator and enhance pollination services[48]. In addition, the integration of legumes into pastures may enhance pollination services and the development of legume-grass system or legume-grass-tree system has been demonstrated to improve livestock production and soil fertility[50,51].

4 CASE STUDIES

Based upon the solutions described above, the following three examples illustrate the integration of biodiversity measures in farming systems.

4.1 Ossekampen Grassland Experiment in the Netherlands

Nutrient application had a strong effect on productivity and species-richness. The Ossekampen Grassland was a species-rich pasture on heavy clay soil in Netherlands. Aiming at tracking productivity and plant species shifts, experiments with long-term application of fertilizers were conducted[52]. Liming had a positive effect on species-richness and yield, while N application resulted in a serious reduction in species numbers and yield. Species-richness in all fertilizer applications initially declined but started to recover after about 25 years of continued fertilization[53]. This exemplifies how optimal fertilization could be adopted to promote species diversity and yield in farming systems in China.

4.2 De Marke Farm in the Netherlands

The De Marke Farm is characterized by a rational allocation of land use driven by the nutritional needs of the cows; this means 60% of the land is used for long-term pastures and 40% for short-term pastures. The short-term pastures are rotated through a 20% ryegrass/clover mixture and 20% maize, with reversed cropping every 3 years. This helps to reduce feeding costs, improve soil quality and decrease leaching of N to groundwater, thus reducing pollution from N fertilizers. Also, grasses sown between rows of maize in the third year with suitable machinery and ryegrass grown as cover crop during maize harvest can markedly reduce nitrate leaching and soil erosion[54].

4.3 Salle Farm in the UK

In the Salle Farm, a 7-year rotation system has been adopted, with winter barley, winter rape, winter wheat, sugar beet, spring barley, snap beans and winter wheat grown each year. This long-term spatial-temporal rotation can be beneficial for controlling soilborne pathogens of grasses with by growing broadleaf crops. Combined with optimized nutrient management practices using manure and cover crops, the 7-year rotation reduced nitrate leaching and N loss, and increased soil organic C and stabilized the income of farmers. Machinery used according to crop characteristics, such as minimum and shallow plowing, and fast and precise sowing, is necessary to reduce economic costs. Also, flower strips at the margins of the field, and flower fields and hedgerows on the whole farm are included for improving crop yield and arable flora, and for better pollination and pest control[55,56].

5 CONCLUSIONS AND PERSPECTIVE

To achieve sustainable development goals, the synergistic effects of multiple management practices of soil, forage, livestock, environment and humans is critical. The problems in implementing these practices can be alleviated to some extent by adopting gradual and progressive management practices, which target their respective problems. The lack of multidisciplinary cooperation at current dairy farms in China limits dairy industry development and quality of dairy products, and causes severe environmental problems. The development of biodiversity-driven integrative approaches inspired by the One Health concept should be promoted to accelerate soil quality and contribute to high-quality milk, environmental sustainability and human health.

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Compliance with ethics guidelines

Ruqiang Zhang, Zixi Han, Qiaofang Lu, Kang Wang, Yanjie Chen, Wen-Feng Cong, and Fusuo Zhang declare that they have no conflict of interest or financial conflicts to disclose. All applicable institutional and national guidelines for the care and use of animals were followed.

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