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Literature Review: A Comparison of Dairy Production Systems

SUMMARY

This literature review focused on studies comparing the effects of dairy production systems (pasture-based, conventional/confinement[1], and mixed) on (i) environmental issues, (ii) social issues, (iii) economic issues, (iv) human health issues, and (v) animal welfare issues. The review was based on peer-reviewed research papers identified by experts at MSU, as well as (where specifically suggested) non peer-reviewed university and government reports. Additional studies were identified from the reference section of recommended papers, as well as via their citation index (primarily Google Scholar). A synopsis of each section is available below, as well as at the end of each section.

There is a great deal of research –much of it based in the United States- on the environmental effects of all types of dairy farming, including intensive/confinement, mixed, pasture-based, and management-intensive rotational grazing (MIRG) operations. The vast majority of studies identified for this review focused on the fate and management of excess nitrogen and phosphorous, their effects on terrestrial and aquatic ecosystems, and contributions to air quality and climate change. Many environmental mitigation efforts were suggested, including balancing nutrient inputs/outputs at the level of the farm, the watershed, and regionally; taking greater care in the timing of fertilizer and manure applications; increased testing for phosphorus and nitrogen in soil; and the use of riparian buffer strips and fencing to protect water bodies. In addition, many studies suggested that cattle stocking rates be calibrated to ensure that nitrogen and phosphorus levels do not exceed the absorptive capacity of the surrounding land, and/or that cattle be confined for part of the year to avoid heavy rainfall events. There was also some evidence that the adoption of pasture-based livestock production and/or the production of perennial forages (as compared with conventional livestock production practices and/or row crop production) can reduce nutrient losses, as long as proper manure and pasture management practices are followed. However, there are an increasing number of studies linking dairy farming practices, e.g., feed formulations, stocking density, and pasture and manure management, with greenhouse gas emissions. Almost all of these climate-change focused studies were based in New Zealand, Australia and the European Union.

Much of the literature examining the social impacts of dairy farming has focused on the structural changes that have occurred in this industry since WWII. This particular literature does not concentrate so much on the type of dairy operation, e.g., confinement,

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[1] Note that 'conventional' dairy production and 'confinement' dairy production are used interchangeably in this review, depending on which term was used in the original paper.

mixed, or grazing-based, but instead focuses on the size and number of dairy operations, their use of non-family labor, and degree of vertical integration. These structural changes and their effect on communities and individual farmers were reviewed, as well as the role of management intensive rotational grazing (MIRG or IRG) practices in ameliorating these structural changes. Fewer than 10 studies examining the structural, community, and individual changes associated with pasture-based dairying or MIRG were identified, and of these approximately ½ were based in Wisconsin. Overall, these studies concluded that the adoption of a managed grass or pasture-based dairy technique is essential for the survival of small and medium sized dairy farms in the face of increased competition from large, confinement dairies. The benefits to farmers in adopting rotational grazing techniques included improved quality of life, economic performance, e.g. greater net farm income, a closer relationship with the cows, the surrounding community, and the land, as well as greater focus on individual knowledge and innovation.

While many of the social issues touched on in the previous section could be considered economic issues as well, e.g., structural change, the economic section is based on articles that specifically examined such economic performance measures as net farm income, debt, or return on assets. Papers that were based on a comparative study of grazing and confinement dairy operations were the main focus of this review, although a number of papers specifically focused on grazing operations were also included. Of the nineteen comparative papers (comparing such measures as net farm income, debt load, and/or milk yield from grazing-based and confinement dairies) identified, eleven were published in peer-reviewed journals. All but one of these peer-reviewed reports indicated that, while generally producing less milk, grazing operations enjoyed equal or greater net farm income (as one measure) than confinement-based operations (due, primarily, to lower expenses). Similar conclusions can be drawn from web-based reports and reviews. However, there was considerable variation among papers in the methods and measures used to reflect economic performance.

There is a vast and cosmopolitan literature on milk quality as it relates to human health; with this research covering such issues as the quantity of milk produced and associated organoleptic properties, as well as the nutrient and micronutrient content. This review section was based –for the most part- on studies that focused on pasture-based milk production. While pasture-based dairies generally produced less milk per cow than confinement operations, milk from grazing cows was shown to contain higher levels of unsaturated fatty acids, particularly conjugated linoleic acid (CLA). Differences in organoleptic properties, and protein, milk fat, and carotenoid content were also noted.

From the rich tradition of research investigating the animal welfare implications of various livestock production systems, seventeen peer-reviewed studies of animal welfare as it relates to pasture-based milk production were identified for this last review section. These studies originated from a wide variety of countries (in addition to the U.S.), e.g., Canada, Denmark, Ireland, and New Zealand, and specifically examined such issues as heat stress, lying behavior, grooming and abnormal behavior, lameness, body condition and milk production ('performance'), and udder health. Overall, the provision of pasture access was associated with a decreased incidence of lameness and teat injuries, fewer abnormal behaviors, and longer bouts of resting. The addition of shade and/or evaporative cooling to pastured cows was associated with lower respiration rate, body temperature, and improved maintenance of body weight and body condition scores. A general review of this research area, however, suggested a greater recognition of the 'multivariate nature' of animal welfare assessment, e.g., accounting for the influence stockmanship and/or the genetic makeup of the animals as opposed to focusing solely on different production systems; as well as the adoption of long-term epidemiological approaches to the assessment of on-farm animal welfare (as opposed to experimental approaches).

ENVIRONMENTAL ISSUES

While there is a vast body of research examining the influence of animal agriculture on the environment (see Sharpley *et al.* 2003 [1]; Aillery *et al.* 2005 [2]; Farm Foundation 2006 [3]; Steinfeld *et al.* 2006 [4] for reviews), material salient for the practices of modern dairy production, including intensive/confinement, mixed and grazing-based operations, will be highlighted in this particular literature review. Specifically, this review will focus on research that characterized efforts at mitigating: i) the release of excess nitrogen and phosphorous from fertilizers, manure, and dairy wastes into soil and water systems, ii) the release of ammonia and other volatile gases from lagoon storage facilities, and iii) potential contributions to climate change in the form of greenhouse gas emissions.

Terrestrial Applications of Fertilizers, Manure, and Dairy Wastes:

Although nitrogen and phosphorous are nutrients essential for plant growth, problems arise when there is an excess of these nutrients available, particularly for aquatic ecosystems and groundwater supplies. Adding excess nitrogen and –in particular- phosphorous to rivers, lakes, and streams can lead to an overgrowth of algae and a sharp decrease in the amount of oxygen available to other aquatic organisms (a process known as *eutrophication*). Summertime fish kills, the loss of oxygen-sensitive species from streams and lakes, and unsightly algal masses along shorelines are evidence of eutrophication of a particular water body [2, 5]. In addition, the presence of nitrogen (in the form of nitrite or nitrate) in groundwater, as well as municipal and private water supplies [6-8] can result in serious health issues if nitrogen levels are not reduced [9, 10].

Raising dairy cattle –as with other forms of animal agriculture- can contribute excess nitrogen and phosphorous to soil and water systems in a variety of ways and at a variety of scales [1, 7, 11-14]. (1) Keeping large numbers of animals on an individual farm, or within a particular watershed, can exceed the capacity of the surrounding land to absorb the nutrients contained in their excreta. The practice of importing feed, either to supplement milk production from a grass-based system or as full rations for confined animals, further exacerbates these problems. (2) The presence of pastured dairy cattle in or near water bodies can introduce nitrogen and phosphorous directly into aquatic ecosystems. If cattle are confined, then the spreading of liquid manure and dairy house wastes prior to heavy rainfall events can result in contamination as well [15]. For intensively managed grazing operations, the injudicious application of fertilizer can be problematic in this way as well [6, 15-19]. (3) The phosphorous content of cattle feed and/or the use of phosphorous supplements can result in manure with considerably higher phosphorous content than the surrounding land can absorb, particularly if that manure is spread only in accordance with nitrogen standards [20]. Each of these issues will be examined, with particular reference to intensive, pasture-based, and mixed dairy production systems as appropriate.

(1) Animal Numbers

Studies have also determined that the concentration of animal production within certain regions of the U.S. (globally, as well) can lead to an overabundance of nitrogen and phosphorous in the soils and aquatic ecosystems of those regions [1, 8, 14, 21, 22]. While this research looked at all forms of animal agriculture, geographic concentration of dairy production does also occur, e.g., while the Great Lakes region still dominates in terms of dairy production, the greatest growth (and geographic concentration) has occurred in the 'Far West' states, particularly California and Washington [23-25]. The problems of excess nitrogen and phosphorous are also seen within individual watersheds; and this has been shown for watersheds containing both intensive dairy facilities and grass-based operations [6, 10]. Additionally, studies have examined stocking rates within individual fields (for mixed and intensive rotational grazing operations). Overstocking cattle[2] not only results in larger amounts of manure produced on a per field basis [26], but degradation of the pasture can lead to phosphorous and nitrogen entering waterbodies via leaching and erosion [6, 18, 27-29].

As has been mentioned, the importation of feed, both as a supplement to pasture forage as well as the primary ration for confined animals, can exacerbate the problems associated with increased numbers of dairy cattle within a particular region, watershed, or farm [6, 8, 13, 30, 31]. Whereas traditional mixed farm systems grew their own feed crops, and then use the resulting manures as fertilizers for those crops; the importation of feed by modern dairy producers results in a *net* input of on-farm nutrients which do not typically get recycled back into feed crop production systems [1]. This can result in a simple but serious imbalance between *nutrients in* (in the form of feed and supplements) and *nutrients out* (in the form of dairy products, manure, and dairy wastewater), and this occurs at regional, watershed, and individual farm levels [1, 11, 12, 31]. Although this problem is commonly associated with intensive dairy operations, the problem of an imbalance between nutrient inputs and outputs can also be seen with pasture-based systems that supplement with feed and/or apply fertilizer to the fields [15-18, 30].

(2) Direct Impacts on Water Quality

Pastured cattle can present a problem if allowed access to natural waterbodies, both in terms of physically degrading the stream bank and shoreline as well as in terms of their well-known tendency to defaecate after drinking [10, 18, 32, 33]. Manure can also enter waterbodies via runoff from fields (both crops and pastures), and this problem is most

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[2] McDowell *et al*. (2008) [26] describe stocking rates between 1.5 and 3.5 cows ha^{-1} for a typical pasture-based dairy operation. Powell, Jackson-Smith and Satter (2002) [28] suggest that Wisconsin dairy farms stock at 0.7 AU (animal units) ha^{-1} in order to avoid importing feed (assuming an average weight of 654 kg for lactating cows and 250 kg for heifers, this works out to between 1 and 2 animals per hectare). However, Stout *et al*. (2000) [6] report that cumulating seasonal stocking rates as low as 200 animal days (approximately equivalent to 1 cow ha^{-1}) can lead to nitrate leaching into the groundwater below the pasture; although they caution that this depends on the soil type, and other land use within the watershed.

apparent during heavy rainfall events [13, 15, 16, 19, 32, 34]. The tendency of pastured cattle to congregate in shady areas, or near feeding stations, can result in the uneven deposition of faeces and urine within fields, resulting in excessive nitrogen and phosphorus in the soils immediately beneath the congregation areas (which may eventually leach into nearby ground and surface water supplies) [6, 20, 32]. The application of manure can also result in excess phosphorous in the soil and, ultimately, surface and groundwater bodies. When manure is spread on crops, the rates and amounts are typically calculated based on the manure's nitrogen content, and this results in an overapplication of phosphorous (particularly if cattle are supplied with phosphorous in their feed rations)[1, 8, 11, 12, 22, 35]. Runoff of nitrogen and phosphorous is also associated with management intensive grazing systems when fertilizers are used to boost forage production [6, 17, 34].

(3) Use of Feed and Supplements

Feed and supplements provided both to pastured and confined dairy cattle can result in manure with a high phosphorous content, and can exacerbate many of the problems listed above [17, 21, 27, 28, 33, 35-37]. Researchers are examining ways to mitigate these problems by reducing the amount of phosphorous fed to dairy cows, increased milking frequency, as well as through the adoption of long-day photoperiod and the use of bovine somatotropin [12, 27, 28, 36, 38-40].

Other mitigation efforts focus on balancing nutrient inputs/outputs at the level of the farm, the watershed, and regionally, taking greater care in the timing of fertilizer and manure applications, increased testing for phosphorus and nitrogen in soil, and/or the use of riparian buffer strips and fencing to protect water bodies [10, 15-18, 21, 28, 41]. In addition, many studies suggest that cattle stocking rates be calibrated to ensure that nitrogen and phosphorus levels do not exceed the absorptive capacity of the surrounding land, or that cattle be confined for part of the year to avoid heavy rainfall events [27, 28, 42]. Finally, there is some evidence that the adoption of pasture-based livestock production and/or the production of perennial forages (as compared with conventional production practices and/or row crop production) can reduce nutrient losses, as long as proper manure and pasture management practices are followed [18, 21, 43-46].[3]

Volatilization of Ammonia from Manure and Manure Slurry:

Nitrogen can volatilize from manure in the form of ammonia; this process has been studied the most with respect to liquid manure stored in lagoons (from confinement operations), where up to 70% of the nitrogen in manure can be volatilized as ammonia (NH_3) [47, 48]. Studies that have measured and modeled this volatilization, suggest that up to 50% of ammonia is deposited within a 50 km radius of the originating lagoon [49, 50]. This suggests that water bodies within the vicinity of manure lagoons are at risk of receiving atmospheric nitrogen deposition, particularly if located in areas with high concentrations of manure lagoons. However, nitrogen volatilization can also occur from the faeces deposited by cattle on pasture, as well as from the manure slurry when it is spread on fields

[3] Similar conclusions can be found in a review conducted by Jennifer Taylor and Steve Neary (2008) for the University of Wisconsin-Madison Center for Integrated Agricultural Systems. For PDFs of this report and accompanying bibliography, go to http://www.cias.wisc.edu/crops-and-livestock/how-does-managed-grazing-affect-wisconsins-environment/ (last accessed August 10, 2009).

[20, 21]; and nitrogen volatilization is highest when cattle are fed a high protein diet, and/or the forage has a high protein content [30]. Unfortunately, there is some preliminary evidence that many of the techniques aimed at mitigating nitrogen losses via ammonia volatilization, e.g., injecting manure slurry into the ground, can make more nitrogen available for conversion to N_2O, a potent greenhouse gas [51].

Contributions to Climate Change:

Recent reports from the United Nations Intergovernmental Panel on Climate Change (IPCC) [52], the United Nations Food and Agriculture Organization (FAO) [4, 53], and the United States Environmental Protection Agency (EPA) [54] have documented the contributions of livestock production in general to climate change on global and national scales. The following information is based on a review published in the Annual Review of Environment and Resources [53].

Overall, ruminant livestock production contributes to the production of the greenhouse gases (GHGs) nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2). On a global scale, *extensive* (pasture-based) ruminant livestock production contributes CO_2 through the desertification of existing pastures as well as the destruction of forests to create new pastures [53]. The release of CH_4 is through the enteric fermentation of beef and dairy cattle and via bacterial processes in freshly excreted dung [55-58], while N_2O (along with NH_3, as already discussed) contributions come from manure and urine excretions [55, 57]. In *intensive* ruminant livestock production, CO_2 is released through the use of chemical fertilizers in crop and pasture production, fossil fuels for the operation of farm machinery and feed processing, the loss of forest for crop production, and carbon loss from soils used for feed production. Methane (CH_4) is produced via the enteric fermentation of beef and dairy cattle, from their freshly deposited manure, and from the *anaerobic* decomposition processes that occur in manure storage lagoons [58, 59]. In intensive livestock systems, the release of N_2O is associated with fertilizer use for crop and pasture production [60], *aerobic* and *anaerobic* decomposition of cattle waste in manure storage lagoons and dry waste piles [57, 58, 61], and from manure slurry when it is spread on fields [53, 57, 60, 61].

Specifically, Steinfeld and Wassenar (2005) [53] report that enteric fermentation in the U.S. accounts for 71% of global agricultural methane emissions (the majority of which is from beef and dairy cattle). This accounted for 19% of total GHG emissions in the U.S.. These numbers are different from those reported in a 2008 paper by the U.S. EPA [54], which reports that the agriculture sector is responsible for 6% of total U.S. GHG emissions. Of this, 23% is due to the release of CH_4 from enteric fermentation, and another 7% from manure management techniques. Beef and dairy cattle are largely responsible for enteric methane emissions (71% and 24%, respectively), but manure and other wastes stored in anaerobic lagoons releases CH_4 as well. The majority of agricultural nitrous oxide (N_2O) emissions in the U.S. come from cropping practices and fertilizer application (72%), and the storage and spreading of manure (27%).

Similarly, a recent study has pointed to dairy cattle as a major source of nitrogen, with these animals contributing approximately 15% of global nitrogen emissions (as NH_3 and N_2O) [62]. The nitrous oxide emissions in particular are associated with the use of proteinenriched feeds (and tend to increase linearly with milk production), the urine and dung deposited during grazing, the storage and application of liquid wastes, intensive pasture-management techniques, trampling (compaction) of pasture soils, and water-logged soils [62]. This same study also reports that it is very difficult to calculate N_2O emissions as they vary considerably with the type of waste, the soil type, as well as how the land has been managed previously; these authors highlight the need for more studies of the nitrous oxide emissions associated with livestock production [62].

Summary:

There is a great deal of research –much of it based in the United States- on the environmental effects of dairy farming, including intensive/confinement, mixed, pasture-based, and management-intensive rotational grazing (MIRG) operations. The vast majority of the studies included in this review have focused on the fate and management of excess nitrogen and phosphorous, and their effects on terrestrial and aquatic ecosystems, as well as air quality. Many environmental mitigation efforts were suggested, including balancing nutrient inputs/outputs at the level of the farm, the watershed, and regionally; taking greater care in the timing of fertilizer and manure applications; increased testing for phosphorus and nitrogen in soil; and the use of riparian buffer strips and fencing to protect water bodies. In addition, many studies suggested that cattle stocking rates be calibrated to ensure that nitrogen and phosphorus levels do not exceed the absorptive capacity of the surrounding land, and/or that cattle be confined for part of the year to avoid heavy rainfall events. There was some evidence that the adoption of pasture-based livestock production and/or the production of perennial forages (as compared with conventional production practices and/or row crop production) can reduce nutrient losses, as long as proper manure and pasture management practices are followed. However, there are an increasing number of studies linking dairy farming practices, e.g., feed formulations, stocking density, and pasture and manure management, with greenhouse gas emissions. Almost all of these climate-change focused studies are based in New Zealand, Australia and the European Union.

SOCIAL ISSUES

Much of the literature examining the social impacts of dairy farming has focused on the structural changes that have occurred in this industry since WWII. This particular literature does not concentrate so much on the type of dairy operation, e.g., confinement, mixed, or grazing-based, but instead focuses on the size and number of dairy operations, their use of non-family labor, and degree of vertical integration. This section will briefly review these structural changes, their effect on communities and individual farmers, and will conclude with a summary of what role management intensive rotational grazing (MIRG or IRG) dairies are seen to play in ameliorating these structural changes[4].

[4] Similar conclusions can be found in an annotated bibliography (M.J. Mariola, K. Stiles and S. Lloyd (2005) *The Social Implications of Management Intensive Rotational Grazing*) prepared for the University of Wisconsin-Madison Center for Integrated Agricultural Systems. For PDFs of this bibliography, go to

Structural Changes:

As has been amply documented, the main structural change in the dairy industry that has been indentified is a *decrease* in the number of dairy farms, and an *increase* in the size of those remaining [23-25, 63-66]. The consolidation of dairy operations has been accompanied by an increase in the use of production-enhancing technologies, e.g., rBST (recombinant bovine somatotropin), Total Mixed Ration (TMR) machinery, free stall barns, and more efficient milking parlors [25, 64, 67-69]. As farms modernize and increase in size, there is also a concomitant increased reliance on hired (as opposed to family) labor [64, 70]. There has also been a growth in the involvement of large corporations, e.g., Dean Foods, in dairy production, along with an increased prevalence of vertically integrated supply chains connecting individual dairy producers with national and international processing and distributing operations [63, 71, 72].

While small, specialty dairy farms have been able to persist within niche markets [69, 73, 74], the greatest concern in the literature has been with the loss of medium-sized dairy operations [64, 68, 75, 76]. However, a variety of authors have examined this trend more closely; and while the Western and Southwestern regions of the United States has seen the greatest growth of large, industrial dairy operations [25, 63, 64, 66], these authors have noted the persistence of small and medium sized-dairies throughout Wisconsin and the Northeastern US [63, 64]. In addition, a series of papers written specifically about structural changes in the Wisconsin dairy industry, reveals that much of this change has been driven (at least in Wisconsin) by the expansion of existing dairy farms, exiting (retiring) older farmers who tended to have smaller operations, and by the paucity of new (younger) entrants into dairy farming [75, 77, 78].

Effects of Structural Change

Community Effects:

Much of the information on the community effects of industrialized farming (in general) comes from an extensive review by Lobao and Stofferahn [70] and Stofferahn [79]. For these authors, industrial farms were defined by their size, integration into production and marketing relationships, and their use of hired labor. Community effects were categorized into 'socioeconomic well-being', 'community social fabric', and 'environmental outcomes' categories. Overall, these authors found that approximately 57% of the studies included in their review revealed negative effects, 25% indicated mixed (positive and negative) effects, and 18% had no statistical evidence for detrimental effects on the community. Specifically, negative effects included a decline in property values, increased crime, higher unemployment, and a decline in civic involvement; while positive effects referred to such issues as increased community income, decreased food costs, and an increase in retail sales.

The few authors that have looked specifically at dairy farm structure and community effects found similarly mixed results. For example Jackson-Smith and Gillespie [80] found

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http://www.cias.wisc.edu/the-social-implications-of-management-intensive-grazing-a-bibliography/#section1 (last accessed August 10, 2009).

dairy herd size to be positively correlated with complaints about air and water pollution, negatively correlated with 'connection to neighbors', and positively correlated with community involvement. While Foltz *et al.* [81] found that the percentage of local input purchases (including feed) was negatively related to herd size, they also suggest that an increase in employment opportunities on these larger farms may offset this (as long as hiring remains local and the pay is appropriate). Campbell [82], focusing on the use of rBGH (recombinant bovine growth hormone, also referred to as rBST), found no connection between the prevalence of this technology and benefits to the surrounding community. He also suggests that rBGH accentuates structural changes by increasing the productivity of larger farms and with greater pressure on small and medium-sized farms as a result. Looking at these relationships somewhat differently, Lyson, Guptil and Gillespie [67] found that farmer community engagement and involvement were positively associated with milk production and gross farm sales among small and medium-sized dairy farms in New York State.

Effects on Individual Farmers:

Structural changes in the dairy industry have had an effect on individual farmers and farm operations in a variety of ways. These include an increased reliance on hired labor [64], but also the necessity of spouses taking on off-farm work to supplement farm production [64, 77]. Also, authors have reported that modernization and expansion has profoundly shifted the relationship that farmers have with their cows, e.g., a dairy operation becomes one based on the management of technology rather than cows [64], or a focus on cows as simply 'teats and feet', rather than individual animals [69]. Similarly, Welsh and Lyson [73] noted with larger dairy operations, there is often a shift away from reliance on knowledge and innovation to a focus on technology, inputs and economies of scale.

A study by Bewley, Palmer and Jackson-Smith [83] reported both positive and negative outcomes associated with the expansion of dairy operations. These authors reported that farmers with large dairy herds (greater than 360 cows) were more satisfied with milk production, disposable income, time away from the farm, and overall quality of life as compared with proprietors of smaller operations. The difficulties encountered with expansion included managing hired labor, securing the necessary capital for expansion, manure management, and obtaining permits [83]. However, a 1997 poll of Wisconsin dairy farmers [68] revealed pessimism about the future of farming, e.g., the difficulty for new farmers in securing capital or the ability of older farmers to pass their operations on to the next generation, and worries about competition from dairy operations in the West and Southwest, as well as the cost-price squeeze associated with the falling price of milk (see also [75]).

Implications of Adopting Rotational Grazing:

The vast majority of the studies on adoption of rotational grazing are from the University of Wisconsin-Madison, although there are a smaller number of reports from the Northeast US. Overall, these studies stress that the adoption of a managed grass or pasture-based dairy technique is essential for the survival of small and medium sized dairy farms [63, 84, 85] in the face of increased competition from large, industrial-style dairies. The benefits to farmers in adopting rotational grazing techniques included improved quality of life, larger net farm income, a closer relationship with the cows, the surrounding community, and the land, as well as a greater focus on individual knowledge and innovation.

Improved quality of life for graziers [85] comes from such things as greater flexibility in work hours, more time for leisure, family and community activities, and the involvement of children in on-farm operations [84, 86, 87]. Authors report that management intensive rotational grazing (referred to as IRG or MIRG) allows farmers to retain managerial and decision-making control [63], and that farmers report this type of farming to be intellectually challenging and rewarding of ingenuity rather than endurance [88]. For Liebhardt [84], rotational grazing puts 'farmers in charge' and allows cows to 'do what they were built to do'.

Increased net farm income[5] (measured on a per farm, per cow, or per CWT EQ basis) from the adoption of MIRG are due to the fact that this dairy production technique has much lower operating costs than conventional dairies; feed, energy, technology, and labor costs are all much less, as is the capital required for start-up [84, 87-89]. For these reasons, managed grazing-based dairies are particularly appealing to young farmers and those entering farming for the first time [85]. Taylor and Foltz [86] report that graziers in Wisconsin have a similar average total annual farm income than other dairies, but with half the number of cows and considerably less debt.

Three studies compared these issues across different types of dairy operations. Barham, Brock and Foltz [90] compared conventional, organic, and MIRG dairies and found that organic production resulted in larger price premiums for the milk and greater quality of life for the farmer. Organic dairy farmers also reported greater optimism in the future viability of their dairy operations than either MIRG or conventional farmers. Lloyd *et al.* [91] compared non-intensive pasture, managed grazing (MG), small confinement, and large confinement operations. MG and large confinement operators reported the greatest quality of life among these categories. While large confinement operators noted the highest amount of satisfaction from having money, possessions, and status etc.; satisfaction from 'being' (realizing one's full potential and nature) *and* 'serving' (contributing to others well-being) was also high for large confinement and MG operators. Overall, on-farm family income was highest for small and large confinement operations, and reliance on off-farm income was greatest for farms using MG and non-intensive pasture.

However, Foltz and Lang [92] worried that many of these MIRG studies are not random, and that farmers most likely to graze are also more likely to profit from it (profit was measured as total farm receipts – total farm expenses). They based their study on a random sample of Connecticut farmers to determine if the adoption of MIRG lead to decreased costs and increased profits. They found that adoption of MIRG had no significant influence on profitability, and no significant lowering of costs per cow. The increased profits for the MIRG operations in their study were associated with off-farm income and

[5] As will be explained in the following section (Economic Issues), there was considerable variation in the way economic performance or profitability was measured (net farm income being the most common).

the fact that the farmers were much younger; although there was some evidence for increased profits with increased frequency of pasture rotation.

Summary:

For this review, almost half of the studies looking at the social impacts of dairy farming are focused on structural changes associated with the shift to large intensive/confinement systems. Within this body of research there are a number of studies that have examined the community effects of this structural change (most of these are summarized in the Stofferahn (2006) [79] and Lobao and Stofferahn (2008) [79] review papers), as well as what these changes have meant for individual farmers. Of these studies, approximately 1/3 originated in Wisconsin (from the University of Wisconsin-Madison). Fewer than 10 studies examining the structural, community, and individual changes associated with pasture-based dairying or MIRG were identified, of these approximately ½ were based in Wisconsin. This particular literature does not concentrate so much on the type of dairy operation, e.g., confinement, mixed, or grazing-based, but instead focuses on the size and number of dairy operations, their use of non-family labor, and degree of vertical integration. These structural changes and their effect on communities and individual farmers were reviewed, as well as the role of management intensive rotational grazing (MIRG or IRG) practices in ameliorating these structural changes. Overall, these studies concluded that the adoption of a managed grass or pasture-based dairy technique is essential for the survival of small and medium sized dairy farms in the face of increased competition from large, confinement dairies. The benefits to farmers in adopting rotational grazing techniques included improved quality of life, economic performance, e.g. greater net farm income, a closer relationship with the cows, the surrounding community, and the land, as well as a greater focus on individual knowledge and innovation.

ECONOMIC ISSUES

While many of the issues mentioned in the previous section could fall under this heading as well, e.g., structural changes in the dairy industry, this section is based on articles that specifically examined is based on articles that specifically examined such measures as net farm income, debt load, or return on assets. Papers that were based on a comparative study of grazing and confinement dairy operations were the main focus of this review, although a number of papers specifically focused on grazing operations were also included. Of the nineteen comparative papers (comparing such issues as net farm income, debt, and/or milk yield from grazing-based and confinement dairies) found, eleven were published in peer-reviewed journals. All but one of these peer-reviewed reports [93] indicated that, while generally producing less milk [94, 95], grazing operations enjoyed equal or greater net farm income than confinement-based operations (due, primarily, to lower expenses or less debt), e.g. Elberhi and Ford (1995) [96], Nichols and Knoblauch (1996) [89], and Fontanelli *et al.* (2005) [97]. Similar conclusions can be drawn from web-based reports and reviews, e.g., Conner and Hamm (2007) [98]; Conner *et al.* (2007) [99]; Wittenberg and Wolf (2006a,b) [100, 101]; Taylor and Foltz (2006) [86]; Kriegl and Frank (2004) [102], and Ostrom and Jackson-Smith (2000) [85].

However, there was a great deal of variation in the methods and measures researchers used to capture economic performance, ranging from surveys to Monte-Carlo simulation methods [96], and from Net Farm Income From Operations (NFIFO) [103] to 'Return on Assets' measures [104]. In addition, the most recent of the peer-reviewed papers found was from 2004. Finally, most of these studies originated in New York State, Pennsylvania, and Wisconsin (with Connecticut, Michigan, North Carolina, and Vermont rounding out the list). One investigation of stocking density and milk yields in grazing-based dairies was based in Australia [105]. A number of these studies will be described in more detail below.

Parker *et al.* (1992) [106] used a linked spreadsheet model to simulate the effects of alternative dairy feeding systems on profitability (among other parameters). These authors found greater per cow and per herd gross margins for grazing systems, and suggested that "an average Pennsylvania dairy farm could reduce operating costs by $6000-$7000 annually, but overall income would not be improved if production per cow fell by more than 450 kg per lactation" (pp. 2595-2596). Other authors, using a dynamic simulation model (Monte-Carlo) [96], and 'FLIPSIM' (Farm Level Income Policy Simulator) found cost savings ($1.20 to 1.42 per cwt milk), and a 14-25% greater (depending on the forages grown) annual net cash income for grazing operations. A DAFOSYM (Dairy Forage System) model was also used to compare economic returns for grazing and confinement dairy operations [30]. In this study, the net return to management was $19, 285 for a grazing farm using no supplement, $53, 741 for a grazing farm using high supplementation, and $7255 for the confinement operation (based on a farm with an annual output of 615, 000 kg milk).

Other authors used on-farm experimental scenarios to document differences in profitability among grazing and confinement operations. Tozer *et al.* (2003) [107] used a variety of feeding treatments (pasture, pasture + TMR, TMR) to determine a number of income and expense measures. These authors found that, while expenses were lower for the pasture-only scenario ($2.38 vs. $4,16 per cow per day – with the pTMR treatment intermediate), confinement feeding of TMR yielded the greatest herd net income over cost ($55, 728 vs. $58, 884 –with the pTMR treatment intermediate). Finally, although the TMR treatment yielded $2.76 more income per cow per day than the pasture treatment, this advantage shrank to $0.30 when calculated as income minus costs per day per cow. White *et al.* (2002) [108], found no statistically significant difference in income over feed costs when comparing pastured cows vs. confined cows.

Dartt *et al.* (1999) [109] conducted an analysis of the economic performance of a paired cohort (matched by herd size) of management intensive grazing (MIG) and confinement dairy operations in Michigan. MIG operations had significantly higher total livestock revenue per cow ($262.00 vs $173.00), and higher capital efficiency; higher capital efficiency is referring to the fact that MIG farms "generated significantly more farm production per dollar of assets (11% more) than did conventionally managed farms" (p. 2419). While accounting net farm income (NFI) was higher for MIG operations, economic net farm income was lower as compared to conventional operations[6]. These differences

[6] As defined by Dartt *et al*. (1999) [109] accounting NFI = (revenue – expenses + interest expense +

were not statistically significant. Gloy *et al.* (2002) [104] used financial reports and operational data in a regression analysis of 294 New York dairy farm (grazing and confinement) operations. A comparison of 'rate of return on assets' (ROA)[7] for these farm management types revealed a higher ROA measure for grazing farms.

A number of studies looked at the effect of supplementation, grazing intensity, and/or stocking rate on the profitability of grazing operations [30, 105, 110-114]. Overall, economic benefits accrue from increasing the stocking rate (or reducing pasture allowance) and via the use of supplements. For example, in a study by Tozer, Bargo and Muller (2004) [110] income ($/cow/day) ranged from $4.89 for the low pasture allowance/no supplementation treatment, to $7.34 for high pasture allowance with supplementation. However, net returns over season were greatest for the low pasture allowance with supplementation treatment, $55,253-59,892 (depending on the model specifications). For Soder and Rotz (2001) [30], computer simulations revealed a net return to management ranging from -$6294 to $19,285 for grazing farms using no supplementation, and $34,456 to$74,892 for grazing farms using a high level of supplementation (variation due to model specifications).

Hanson *et al.* (1998) [111] reported the management return to farms using MIG was $129.02, more than double the return for producers of hay and silage. These authors also noted that while increasing the intensity of pasture use resulted in 3% less milk per cow (as compared with stable or reduced intensity pasture use), these operations had approximately 9% higher annual per cow returns. Farms with increasing intensity of pasture use also had greater net cash income per cow ($327.00 vs. $301.00), although their debt per cow was higher. Similarly, Foltz and Lang (2003) [114] found that full adopters of MIRG enjoyed more profit than partial adopters.

Summary:

While many of the social issues touched on in the previous section could be considered economic issues as well, e.g., structural changes in the dairy industry, the economic section is based on articles that specifically examined such measures as net farm income, debt, or return on assets. Papers that were based on a comparative study of grazing and confinement dairy operations were the main focus of this review, although a number of papers specifically focused on grazing operations were also included. Of the nineteen comparative papers (comparing such measures as net farm income, debt load, and/or milk yield from grazing-based and confinement dairies) identified, eleven were published in peer-reviewed journals. All but one of these peer-reviewed reports indicated that, while generally producing less milk, grazing operations enjoyed equal or greater net farm income (as one measure) than confinement-based operations (due, primarily, to lower expenses). Similar conclusions can be drawn from web-based reports and reviews. However, there

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inventory changes) ÷ average herd size; whereas economic NFI = ((revenue – expenses) + interest expense + inventory changes – ($7 * unpaid labor hours) – (0.04 * average farm assets)) ÷ average herd size

[7] Gloy *et al*. (2002) [104] deemed this a preferable economic measure for capturing net farm income across a variety of farm sizes.

was considerable variation among papers in the methods and measures used to reflect economic performance.

HUMAN HEALTH ISSUES

There is a vast and cosmopolitan literature on milk quality as it relates to human health; with this research covering such issues as the quantity of milk produced and associated organoleptic properties, as well as the nutrient and micronutrient content [115, 116]. This review is based –for the most part- on studies that focus on pasture-based milk production.

Micronutrient Content, Organoleptic Qualities, and Milk Yields:

There is interest in the potential for milk from pastured cows to meet a variety of nutritional needs [115, 117]. Knowles *et al.* (2006) made specific mention of the significant capacity of dairy producers –particularly pastoral producers- to manipulate the micronutrient content of the milk, e.g., selenium, cobalt, B12, iodine, and iron, via such techniques as rumen modification, trait selection, and the use of carefully formulated feeda and supplements.

Carotenoids, chemical compounds with well-documented health benefits, e.g., as antioxidants or in the role they play in eye health, are particularly associated with pastured milk production [118]. Carotenoids also contribute to the yellowish hue of pasture-produced milk and cheeses [119]. It was noted that fresh forages are particularly rich in carotenoids, and that these compounds are not typically associated with either dried forages or manufactured feeds [118].

Several studies have noted that the organoleptic qualities, e.g., color, texture and flavor/odor, of milk from pastured cows differ as compared to conventionally produced milk [117, 119, 120]. Milk from pastured cows was described as having 'salty', 'grassy', and 'mothball' flavors [119], or 'grassy' and 'oceanic' flavors [117]; whereas conventionally produced milk had 'sweet feed' and 'malty' flavors and aromas [119]. Cheese from cows on pasture or pasture plus grain also had a distinct flavor, e.g., 'grassy' with 'sulfur' and 'brothy' notes; yellowish color, and softer texture as compared to cows fed TMR indoors [120, 121]. It should be noted that these studies relied on trained panelists to assess these organoleptic qualities, and that (lay) consumers could not –for the most part- detect differences between conventionally and pasture produced milk products [119, 121]. Although in one study consumers did exhibit a preference for cheese from pastured cows [120].

In studies that compared milk from pastured and conventionally raised cows, most made note that grazing cows produced less milk [95, 120, 122-124]. However, Schroeder *et al.* (2003) found no difference in the volume of milk produced by these two systems [125], while Wales *et al.* (2009) found that supplementing pastured cows with feed concentrates (rolled barley, steamed corn, and molasses) resulted in a level of milk production similar to conventional confinement dairy systems [126]. Finally, in a study comparing milk production among Holstein and Jersey cows, only Holsteins exhibited a decrease in milk production on pasture [127].

Research examining the effect of supplementation and/or different stocking rates on the milk production of pastured cows report mixed results. Delahoy *et al*. (2003), comparing the effect of cracked corn vs. steam-flaked corn or ground corn vs. non forage fiber, found no difference in milk production among grazing cows provided these supplements [128]. However, these authors did report a decrease in plasma and milk urea N with corn supplementation, as well as an increase in milk protein. Similar results were found by McCormick *et al*. (2001) [129] (utilizing supplements that varied in crude protein content and/or rumen undegradable protein), who also reported higher milk fat concentration with supplements high crude protein. Fike *et al*. (2007) [130] found that increased stocking rate (10 cows vs 7.5 cows/ha) and supplementation (0.5 vs 0.33 kg supplement/kg daily milk production) increased milk production on bermudagrass pasture. Overall, grazing cows on bermudagrass pasture produced 112 kg milk/ha/day as compared to grazing on a tropical legume (90 kg milk/ha/day). McDonald *et al*. (2008) [131] found that while milk production per cow decreased linearly with stocking rate (2.2 to 4.3 cows/ha), milk production per hectare increased linearly with stocking rate (from 11, 071 to 14, 828 kg of milk/ha).

Protein, Fat, and Fatty Acid Content:

The protein and milk fat content of milk from pastured cows was also generally lower than that of conventionally produced milk, but with some variation as well. For most studies reporting protein and milk fat content, cows fed TMR (total mixed rations) or feed concentrate supplements had higher levels of these parameters than cows on pasture (with no supplements) [94, 95, 120, 124-126]. However, White *et al.* [127] found only a significant increase in milk fat content -but not protein- in milk from cows fed TMR (as compared with grass-fed cows); and AbuGhazaleh *et al.* [123] found no differences in protein and milk fat levels, although in this study the pastured cows were provided with a grain supplement (cracked corn, soybean meal, molasses, and fish and sunflower oils).

Researchers from a wide range of countries and across the US have noted that pasture-based dairy operations produce milk with a beneficial fatty acid profile as compared to milk from conventional dairy operations (and which feed their cows silage, dried forages, and/or TMR). These authors are specifically referring to an *increase* in long-chain fatty acids -including CLA (conjugated linoleic acid), as well as a *decrease* in short- and medium-chain fatty acids and saturated fatty acids, [115, 122-125, 132-135].

Studies have reported the CLA content of the milk from pastured cows to be 2x, e.g., 1.09 vs 0.46 g/100 g milk fat [124]; 3x, e.g., 1.63 vs 0.52 g / 100g milk fat [121]; and up to 5x higher, e.g., 2.21 vs 3.9 g/100 g milk fat [136] than that found in milk from dairy cows raised in confinement operations. However, many of these studies make note of the fact that, while CLA has been associated with enhanced immune function, cardiovascular health, and reduced cancer, diabetes, and obesity risks in cell and animal models, these benefits have not yet been consistently observed in controlled human trials [137].

Overall, research has established a connection between the CLA content of milk and the fresh, green, and high fiber forage available to cows on pasture [124, 135, 136, 138, 139]. However, the CLA content of milk from a pasture-based dairy system can vary considerably, with seasonal differences being noted most often, e.g., CLA levels are highest in the spring and summer months [127, 132, 135, 137, 138], as well as significant differences between individual cows [124, 140], and between different breeds of cows [127].

Researchers have also examined various means for increasing the CLA content of milk from pastured and confined cows alike, e.g., grain, TMR, plant or fish oil supplements, with mixed results. Although Kay *et al.* [141] did not see an increase in CLA concentration associated with the addition of a sunflower oil supplement to grazing cows' diet, AbuGazaleh *et al.* [123] was able to increase CLA in the milk from pastured cows (but not confinement cows) by adding sunflower and fish oils (species not specified) to their diet. Similar results were noted by Chilliard *et al.* [142] and Lawson *et al.* [140]. The addition of soybean and linseed oil 'protein gel composites' to the diets of confined cows also increased the amount of polyunsaturated fatty acids (including CLA) in their milk [143].

Providing a 'high energy supplement' (not specified) to grazing cows can decrease the CLA content of their milk, e.g., from 1.5 g/100g milk fat with no supplementation (100% pasture) to 1.1 g/100 g milk fat at 9 kg/day high energy supplement [139][8,9]. However, others, comparing the fatty acid profile of milk from confinement cows (fed only TMR) to milk from pastured cows provided supplements noted a 2.7 (pasture + corn supplement) to 4.7-fold (pasture + corn + fatty acid supplement) increase in the CLA content of the milk [125]. Similarly, Bargo *et al.* [122] compared the CLA content of milk from (i) confinement cows (fed TMR), (ii) pastured cows fed a TMR supplement, and (iii) pastured cows fed a feed concentrate supplement. These authors found a 105% increase in the CLA content of the milk from pastured cows (fed the concentrate) as compared to cows fed TMR only (from 0.59 to 1.21 g CLA/100 g milk fat). A smaller increase (relative to TMR only) was noted in the milk from pastured cows fed a TMR supplement.

Summary:

This review section was based –for the most part- on studies that focused on pasture-based milk production. While most studies indicated that pasture-based dairies generally produced less milk per cow than confinement operations, milk from grazing cows was shown to contain higher levels of unsaturated fatty acids, particularly conjugated linoleic acid (CLA). While providing supplemental feed (e.g., TMR) to pastured cows can increase milk production, the use of such supplements may result in a decrease in the beneficial

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[8] These authors note that CLA levels increased to 1.4 g /100 g milk fat at the highest level of supplementation (11 kg/day), but that overall the milk fat level decreased in this treatment as well.
[9] Many of these authors also note that, overall, the amount of short- and medium-chain fatty acids and saturated fatty acids in milk *increases* with increased grain/TMR supplementation (as compared to milk from cows on pasture only).

fatty acid content of the milk. Differences in organoleptic properties, protein, milk fat, and carotenoid content were also noted.

ANIMAL WELFARE ISSUES

As with the literature pertaining to milk production and quality, there is a rich tradition of research investigating the animal welfare implications of various livestock production systems, including systems used by dairy producers. Much of the literature on animal welfare in dairy production looked at the implications of various forms of confinement operations, e.g., tie stalls vs. loose housing; some common topics include: stocking density and cow behavior [144, 145], physiological responses [146], lameness and pain [147], weaning and calf behavior [148, 149], social behavior [149-152], and cow comfort, lying behavior, and floor type/use of bedding [147, 153].

A number of review papers are available as well, e.g., see Boyle *et al.* (2008) [154] for a web-based review from Ireland. Specifically, Rushen (2003) [155] laments that there has been too great a reliance on physiological and behavioral measures, and insufficient consideration given to health problems. He suggests a greater recognition of the "multivariate nature of animal welfare assessment" (p. 201), e.g., accounting for the influence stockmanship and/or the genetic makeup of the animals as opposed to focusing solely on different production systems. Rushen (2003) also suggests greater use long-term epidemiological approaches in the assessment of on-farm animal welfare; the epidemiological approach, he argues, would allow for the consideration of multiple interacting variables; this is in contrast to the more common experimental approach, which manipulates and examines variables in isolation. In her review, Mench (2008) [156] suggests that there has been a slower increase in animal welfare research in the U.S. relative to the European Union; but sees promise in the expanding use of 'applied ethology' (broadly, animal behavior) methodology. Finally, Fulwider *et al.* (2008) [157] conducted a large survey of management practices (with animal welfare implications) on dairy farms across the Northeastern and North Central U.S.. The majority of survey respondents (77.9%) felt that quality of life for dairy cows had improved over the last 20 years.

The remainder of this section will focus specifically on peer-reviewed studies of animal welfare issues as they relate to pasture-based milk production. Seventeen published reports were identified for this review, originating from a wide variety of countries (in addition to the U.S.), e.g., Canada, Denmark, Ireland, and New Zealand. These studies specifically examined issues related to heat stress, lying behavior, grooming and abnormal behavior, lameness, and body condition, mastitis, and milk production (broadly, 'performance').

Heat stress is a problem in many dairy operations (in temperate, tropical, and subtropical climates alike), and can decrease milk production and result in a loss of body condition [158], particularly in high producing dairy cows (due to their higher metabolic rate) [159]. Several studies have investigated the use of shade structures and sprinkler systems in pasture-based dairy operations, with positive results [158, 160, 161]. Tucker *et al.* (2008) [158] used an experimental design of three shade treatments and a control (no shade) and found that as the temperature increased, the use of shade structures increased (particularly those offering 50% and 99% shade). These authors found lower body temperatures and respiration rates among cows in these shade treatments, and suggested that shade is necessary to mitigate production losses (milk and/or body weight); findings that were echoed by Kendall *et al.* (2006) [162]. A similar experiment was performed using both shade and/or sprinkler treatments for pastured dairy cows, and these authors found the greatest cooling effect (and protection from insects) in the shade + sprinkler treatment [160].

Lying behavior is thought to be a good indicator of cow comfort [163], and a number of studies have sought to establish the influence of housing type, bedding materials, and winter confinement facilities on the lying behavior of dairy cows. One study compared the lying behavior of cows at pasture and in three winter confinement facilities: indoor matted cubicles, unsheltered out-wintering pad (OWP) and sheltered OWP [164]. In general, cows at pasture spend more time feeding (and less time lying) than cows in winter confinement; however, there was no difference in the feeding and lying times among the winter confinement treatments. Krohn and Munksgaard (1993) [165] used 4 experimental treatments to study the effect of housing type on lying behavior: (i) loose housing with free access to pasture, (ii) tie stalls with concrete floor and 1 kg straw, no exercise, (iii) tie stall with rubber mats and 2 kg of straw, no exercise, and (iv) treatment (iii) plus 1 hour of exercise. These authors found no difference in lying behavior among the tethered groups, but found that duration of lying behavior was longer for tethered cows as compared to those in loose housing (this was attributed to the difficulty/discomfort cows had in lying down and getting up, see also [147]). Cows in loose housing/free access to pasture had no inflammation of knees and hocks, longer resting 'bouts' (lying interrupted by short periods of standing), and were able to lie flat on their sides when on pasture. Teat trampling was highest in treatment (ii). Using the same experimental design, Krohn (1994) [166] found higher levels of abnormal and displacement behavior (e.g., sniffing and licking equipment/housing) among the tethered cows (treatments (ii) to (iv)), but a decrease in these behaviors when cows were on pasture (treatments (i) and (iv)) (see also Phillips (2002) [151].

Lameness among dairy cows is serious issue, affecting cow comfort and milk production alike; and a number of studies have examined this issue with respect to pasture-based milk production and/or pasture access. Phillips' (1990) [167] found an increased incidence of lameness when pastured cows were confined for night feeding of silage (as compared to the pastured control), e.g., 44 vs. 24 cows, and an increase in the number of hoof lesions requiring treatment, e.g., 83 vs. 121 lesions for control and experimental treatments respectively. Hernandez-Mendo *et al.* (2007) [168] provided cows with 4 weeks on pasture and noted an improvement in their gait (0.22 units per week, on a gait score scale of 1-5), compared to cows not provided pasture access. Similar to Krohn and Munksgaard (1993), these authors also recorded periods of lying of shorter duration on pasture (10.9 vs. 12.3 hours/day), but more bouts of lying (15.3 vs. 12.2), relative to confined cows. Regula *et al.* (2004) [169], utilizing a regression analysis of Swiss dairy husbandry systems: (i) tie stalls

+ with regular[10] summer exercise but minimal outdoor access in winter (a mode of < 3 days per week) ('TM' husbandry system), (ii) tie stalls + year-round exercise (a mode of 3-5 days per week) ('TR' husbandry system), and (iii) loose housing + access to pasture (a mode of >5 days per week) ('LR' husbandry system), found that such "indicators of animal health and welfare" (p. 255) as lameness, hock injuries, callosities at carpal joints, and teat and skin injuries decreased with increased exercise. Overall, cows in the 'TM' husbandry system exhibiting the highest clinical prevalence of these indicators, whereas cows in the 'LR' husbandry system exhibited the lowest clinical prevalence (with cows in the 'TR' husbandry system intermediate in these measures). Finally, in a study focused on pastured Holstein-Friesians [170], cows of higher genetic merit (as per Economic Breeding Index) had lower lameness and hoof problems, but that the use of concentrated feeds increased the incidence and severity of digital dermatitis.

For pastured cows, the provision of TMR, rBST, and/or evaporative cooling (fans and misters when confined during the day) is associated with improved weight maintenance and body condition scores [94, 95, 161]. Indeed, Fontanelli *et al*. (2005) found that, overall, grazing cows lost more weight compared to those in confinement and fed TMR. Similar results were reported by Washburn *et al*. (2002) [171], and Kolver and Muller (1998) [95]. However, in a study comparing pastured Holstein-Friesian and Jersey cows [172], a decrease in body weight and/or body condition scores was associated with a decrease in somatic cell counts (SCC); and although body condition was not significantly associated with incidence of clinical mastitis (CM), heaver cows were more likely to be diagnosed with CM. These authors point to the need for more objective measures of animal welfare, suggesting that cows with low body weight and/or body condition scores are not necessarily 'welfare-challenged' (p. 647).

Of the studies reporting somatic cell counts (SCC) or mastitis as related to management practices, Goldberg *et al.* (1992) found lower SCC in the bulk milk from a pasture-based dairy operation as compared to a confinement dairy operation [173], Washburn *et al*. (2002) [171] reported 1.8 times the rate of clinical mastitis (and 8 times the rate of culling for mastitis) among confinement cows as compared to cows on pasture, while Toledo *et al.* (2002) found lower SCC in the milk from an organic dairy operation [174], and the remainder found no difference between conventional, pasture-based, and/or organic operations [120, 175, 176]. One author did suggest that bacteria responsible for mastitis are different for grazing animals (*Streptococcus uberis*) as compared to animals in confinement (*E. coli*) [176], and Compton *et al.* (2007) reported that mastitis among grazing dairy cows emerges as a result of such issues as poor udder hygiene, udder edema, and host susceptibility [177]. Similarly, Pedernara *et al*. (2008) [178] suggested that the increased incidence in mastitis among grazing cows provided supplements to achieve higher milk yields may have been associated with the use of concrete feeding pads (where the supplements were provided).

[10] Swiss animal welfare regulations define 'regular exercise' as a minimum of 26 days of exercise per month in summer, and 13 days of exercise per month in winter (Regula *et al*. 2004) [169].

Summary:

From the rich tradition of research investigating the animal welfare implications of various livestock production systems, seventeen peer-reviewed studies of animal welfare as it relates to pasture-based milk production were identified for this last review section. These studies originated from a wide variety of countries (in addition to the U.S.), e.g., Canada, Denmark, Ireland, and New Zealand, and specifically examined such issues as heat stress, lying behavior, grooming and abnormal behavior, lameness, body condition and milk production ('performance'), and udder health. Overall, the provision of pasture access was associated with a decreased incidence of lameness and teat injuries, fewer abnormal behaviors, and longer bouts of resting. The addition of shade and/or evaporative cooling to pastured cows was associated with lower respiration rate, body temperature, and improved maintenance of body weight and body condition scores. A general review of this research area, however, suggested a greater recognition of the multivariate nature of animal welfare assessment, e.g., accounting for the influence stockmanship and/or the genetic makeup of the animals as opposed to focusing solely on different production systems; as well as the adoption of long-term epidemiological approaches to the assessment of on-farm animal welfare (as opposed to experimental approaches).

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