MEAT AND THE ENVIRONMENT – FUTURE DIRECTIONS

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Abstract – The need for sustainable food production from animals is paramount to future resiliency and viability of the agri-food sector in many parts of the world. Ability to mitigate greenhouse gas emissions, biodiversity loss, unsustainable water use, and air and water pollution are critical elements of future sustainability of crop and animal food productions systems. This paper reviews some of the policies and technologies available to the meat sector, as well as barriers to progress. One barrier for animal agriculture is related to our ability to earn and maintain public trust. Our capacity and need to engage in a science and ethics dialogue may be a critical step in towards retention of not only a social licence to operate, but support for the changes required to improve future sustainability of the meat sector.

Key words: animal agriculture, environmental footprint, technology.

THE ISSUES

There are growing environmental concerns about the role of livestock agriculture as this sector strives to meet increased global demand for healthy food while maintaining or improving its natural resource base. United Nations projections of a world population increase from the current 7.0 to 8.1-10.5 billion people by 2050 [1]; economic models suggesting increased global prosperity; and adoption of technologies to improve the efficiency of animal production have led to projections for significant increases (+115 %) in animal agriculture over the next 35 to 40 years [2]. It is well recognized that long-term economic sustainability of all agriculture production systems is dependent upon a healthy environment; however, it is not always true that environmental stewardship is linked to short-term economic benefit. The threat of excessive adverse impacts on our environment will influence the meat sector's ability to capitalize on new economic opportunities. Thus, ability to capitalize on economic opportunity in developing and developed regions of the world will be linked to ability to improve or maintain the land and water resources required to produce animal feed. Equally important in many developed countries, the meat sector must regain public confidence that good environmental and animal stewardship practices will be employed, if it is to capture a significant share of global demand for meat.

Many of the environmental impacts of meat production are the same as those of food production in general, with relative differences between meat and other food production systems linked to environmental cost per unit food energy or protein output from the system. As an example, Schneider and Kumar [3] calculated land requirements per calorie of food produced, and determined that one thousand calories from beef, pork, wheat flour, and potatoes requires about 9, 4, 0.4, and 0.3 square meters of land, respectively. Nutrient utilization patterns provide another example. A shift away from grassland production for beef cattle, improved animal genetics, feeding practices and health care have resulted in relatively dramatic improvements in utilization efficiency of nutrient inputs such as nitrogen (N) and phosphorus (P) for livestock relative to crop production over the last decades [4]. However, nutrient recovery for food production by plants is still superior to that achieved with animals.

Mekonnen and Hoekstra [5] calculated that about 27% of the water footprint of humans is related to the production of animal products. Growing feed for meat producing animals can represent as much as 98% of this water use. The water footprint concept is an indicator of water use measured in terms of water volumes consumed or polluted in relation to food produced. Hoekstra and Chapagain [6] defined the water footprint as three components: the blue water footprint is water that is evaporated from surface and ground water; the green water footprint is the volume of water evaporated from rainwater stored in soil; and the grey water footprint is the volume of polluted water. The global-average water footprint of pig, sheep and bovine meat was 2.15, 4.25 and 10.19 L/calorie, compared with 0.51 L/calorie for cereal crops. When compared on the basis of protein, the estimates were 57, 63 and 112 L/g protein, respectively, compared with 21 L/g protein for cereal crops. Environmental cost:benefit ratios such as these are the basis upon which most arguments for reduced inclusion of animal protein in the human diet or for dietary shifts away from beef toward poultry or pork are made.

Animal agriculture, and more specifically the red meat industry, is considered to be a major contributor to climate change. Of the 245 million tonnes of meat produced globally in 2005, O'Mara [7] reported pork was produced in the highest quality, with production concentrated in China, Western Europe and North America. Chicken meat production is now higher than beef production, with both production systems having a more uniform global distribution. Numerous efforts have been made to calculate the relative contributions of enteric methane emissions from ruminant animals and greenhouse gas emissions associated with animal manure and waste water. The International Panel on Climate Change [8] estimated livestock contributions to be 8–10.8% of global greenhouse gas emissions, on the basis of lifecycle analysis, the contribution of livestock has been calculated to be as high as 18% of global emissions [9]. Current estimates [7] suggest Asia is the largest contributor to global enteric CH_4 emissions with Latin America, Africa, Western Europe and North America being significant sources. These emissions are dominated by emissions from cattle. When GHG emissions are measured relative to food produced, the four most efficient regions are Eastern and Western Europe, North America, and the non-EU former Soviet Union which produced 46.3% of ruminant meat and milk energy and only 25.5% of enteric CH_4 emissions in 2005. In comparison, the three least efficient producers (Asia, Africa, Latin America) produced an equivalent amount (47.1%) of ruminant meat and milk energy, and almost 69% of enteric CH_4 emissions in 2005 [7]. Livestock-related emissions will increase as world population and food demand increases; enteric CH_4 emissions are projected to grow by over 30% from 2000 to 2020.

Agricultural environmental impacts are generally associated with either expansion of the land base or increased intensification. The bulk of future expansion of the agricultural land base is expected to be in Latin America and Africa. Most land base expansion is associated with cropping systems, however, ruminant (sheep, goats, cattle) production systems contribute to this expansion because animal grazing is often the first step in conversion of land supporting natural ecosystems, with conversion to crop land occurring thereafter. Grasslands for grazing ruminants represent 3.38 billion hectares, more than 26 % of the earth's available land base [10]. Current expansion is generally associated with tropical regions of the world [11]; however, recent climate change models suggest that expansion into boreal fringes will be feasible in the future.

Intensification of animal agriculture refers to either an increased output per unit land or the application of technology to increase meat output relative to water, nutrient, energy and labour inputs. Characteristics of intensification include increased management and monitoring inputs as well as increased use of technologies to achieve better efficiencies of production, consistency of desired product quality and reduced waste. Intensification has allowed more rapid improvement in animal genetics, feeding practices and animal health care, leading to an improvement in nutrient and water utilization in the feedlot or barn. When intensification is evaluated at a systems level, intensive animal agriculture has been associated increased dependence on concentrate feeds (i.e. feed grains, plant protein meals), which has impact on nutrient cycling, water use and biodiversity in the total agriculture system.

Intensive animal production systems frequently require increased scale or size to reduce risk associated with lower profit margins. The US Environmental Protection Agency (EPA) first coined the term “concentrated animal feeding operation” or CAFO in 1976, defining large livestock and poultry operations as point sources for pollutant discharge to water systems. Since then, there has been a public love-hate relationship with CAFOs, now often considered synonymous with all intensive animal agriculture. Intensification has provided consumers with consistent supplies of high quality and safe meat products at relative low cost. These same consumers, however, voice strong objection to any potential environmental degradation associated with large, intensive animal operations. Environmental concerns associated with intensive animal agriculture operations include concentration of nutrients, zoonotic pathogens, antibiotics, hormones and other chemicals. In some cases the animal is directly associated with the environmental release, as is the case for enteric methane emissions from ruminant animals such as cattle, sheep and goats, or for release of respiratory zoonotic pathogens from poultry and swine. In most other cases, this uncontrolled release is associated with poor manure and waste water storage facilities, improper manure or waste water incorporation on to land or adverse weather events such as floods. Coupled with nuisance problems such as the presence of odorous volatile compounds, competition for access to water rights and renewable energy, both neighbors of intensive animal agriculture and consumers are requiring more regulatory oversight, and in some cases cessation of operation.

Value of animal agriculture to our global ecosystems is less frequently addressed, with most focus placed on value of grasslands. The majority of grasslands supporting sheep, goats and cattle are can be characterized as extensive, natural or semi-natural areas. Ruminant meat production is often the only food production system that can be carried out due to poor landscape characteristics or weather conditions for crop agriculture. As well, some grazing areas are retained as a result of policies recognizing the importance of ecological services they provide, such as carbon sequestration, conservation of biodiversity, water management or public access to green space. These and other values are not well quantified to date. As an example, pasture-based farming is known to play a central role in the prevention of forest fires in Mediterranean regions [11] and grass fires in the North American Great Plains. Data on reduced economic risk to residents of those regions, or reduced GHG emissions from fire are not known. Ecological benefit associated with animal agriculture can include more effective nutrient and water cycling in the rural landscapes. Urban centres have become point sources for nutrient and other contaminants in water systems, with many centres threatened by limited future water supplies. Animal agriculture provides a venue by which nutrient and water recycling can occur in a location closer to crop agriculture, supporting recycling of these inputs in an effective, efficient manner. Other benefits are linked to local food security, public health and wellbeing, particularly in regions of the world with limited food choice and limited access to medical care.

ROLE OF POLICY

Future direction for a healthy meat sector requires a policy framework that will create incentives for environmentally-enhancing innovation at multiple levels. Advances can be associated with incremental, radical or system-level innovation. Incremental innovation reflects minor modifications to processes or products such as increment increases in animal feed efficiency or improvements to manure and waste water containment. Radical innovation would reflect response to a discontinuance of a technology or process, as might occur with the ban of antibiotic use in livestock feed. An example of system-level innovation would be novel protein products replacing animal meat products. Drivers for innovation and the adoption of environmental technologies include sector image, personal commitment of the producer or business manager, market pressure, pressure from environmental organizations and regulation.

The effects of environmental policy or regulation on innovation depend on the design of the policy instrument and the techno-economic and political context in which they are used. That market-based incentives are reported to have a stronger impact on the rate and direction of technological innovation compared to the incentives associated to command-and-control instruments[13, 14]. However, many agri-environmental policies arise from identification of environmental issues as isolated concepts. Further, this policy approach is often politically driven and based on the premise that it is more cost-effective to take preventative action against environmental degradation than it is to fund cleanup of problems after the fact. Increasingly, we see that this approach limits ability to move towards more holistic environmental stewardship strategies and acts as a disincentive to innovation. Consequences can include reduced investment in innovation, postponing of mitigative behaviour by the industry and relocation of operations to less restrictive regions of the world.

Environmental impacts associated with adoption of innovation in meat production must consider the total agriculture system and should not be restricted to those elements commonly defined as animal husbandry. Bouwman et al. [4] applied five scenarios to a baseline model developed by International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), which depicts the world developing over the next decades in a similar manner as it does today and a target population of 9.4 billion in 2050. Scenarios tested for a time frame ending in 2050 included: extensification, where 10% of animal production in mixed systems is returned to pastoral use; improved animal feed efficiency, resulting in 10% lower N and P excretion; improved manure storage systems resulting in 20% lower ammonia emissions from housing and storage systems; better integration of manure management with cropping systems; and a change in the human diet, with 10% of projected beef consumption replaced by poultry meat. The baseline scenario suggests that efficiency of nutrient utilization in livestock and crop production systems will continue to improve in all regions of the world; however, N and P losses to the environment will increase dramatically because the nutrient demand of the growing population will increase more quickly. The five scenarios achieved modest reductions in N and P surpluses, with a net potential reduction in global N and P surpluses of 12 and 20%, respectively. More importantly, this exercise demonstrated the risk of applying any strategy at a global level. For example, a shift from beef to poultry consumption was beneficial only in regions where intensive cattle production and intensively managed grasslands were found. Encouraging this shift in other regions, with natural grasslands, was not attractive because the land base often was not suitable for crop production. Technologies resulting in improved feed efficiency were more universally successful, reducing global N and P surpluses by 2.9 and 5.6%, respectively, due to slight increases in fertilizer use for the better quality feed requirements. Bouwman et al. [4] effectively demonstrated significant differences in regional capacity to benefit from single technologies or strategies, and the value of policies that support integrated, systems level solutions.

To successfully attract innovative solutions, future policy and law will need to be more outcome-based, supporting innovative and site specific solutions with well-defined sustainability indices linked to outcomes. These policies will accept that solutions will require a mix of expertise; including physical and biological sciences, engineering, business and policy. Already we see companies that have applied "issues integration" to look at multiple environmental situations, whether opportunities or issues facing the organization.

A key element to successful implementation and delivery of outcome-based policy is transparency, allowing information to flow within and across organizations. Not only will this support rapid evaluation, adoption and improvement of technologies; this transparency will become a critical element for retention of the right to operate through regained or maintained public confidence. As an example, on February 22, 2012 founding members announced the formation of the Global Roundtable for Sustainable Beef, an independent non-profit organization to advance continuous improvement across the global beef industry through a commitment to a global beef supply chain that is environmentally sound, socially responsible and economically viable (http://www.sustainablelivestock.org/home). The founding members are an impressive list, including Allflex, Allianca de Terra, Cargill, Elanco, Grupo de Trabalho da Pecuaria Sustentavel (GTPS), JBS, McDonald's, Merck Animal Health, National Wildlife Federation, Rainforest Alliance, Rountable for Sustainable Beef Australia, Solidaridad, The Nature Conservancy and World Wildlife Fund. As a second example, in the State of Minnesota, tax payers voted for a 25 year tax designed to improve and protect that state's water resources by working in partnership with local organizations and private landowners (http://www.dnr.state.mn.us/news/features/amendment.html). Agriculture business and farmers are a key component to this process. In the Netherlands, negotiated agreements or "Dutch Covenants" consisting of a target and timetable for attaining an agreed upon environmental objective are being developed between and industry sector and government authorities. While the covenants have not all been equally successful; Bressers et al [15] cited a number of informed sources indicating that they have resulted in industry being responsive and often proactive in improving environmental performance. Negotiations tend to be focused upon implementation processes and cost sharing, with continued dialogue and joint monitoring of progress for the duration of these agreements. Each of these models involves partnerships, information sharing, and a focus on solutions to achieve environmental objectives.

PROCESS AND PRODUCT TECHNOLOGIES SUPPORTING HEALTHY MEAT

Animal feed is the major cost in meat production, and feed production is responsible for much of the environmental footprint associated with animal products. Public and private sector scientists are aggressively applying advances in genomics, microbiology, nutrition, and engineering to achieve incremental improvements in feed production, animal feed utilization and nutrient recycling from manure and waste water. Some examples follow.

Transgenic forage (grass and legume) crops will play a major role in providing the increased feed resources required to meet growth of the meat sector, by increasing productivity of existing grasslands. Genetic engineering coupled with traditional plant breeding has resulted in rapid yield increases in several major cash crops, including maize, soybean, cotton and canola, but progress with forage (grass and legume) crops and low acreage feed grains has been slower. James [16] reported that the accumulated growth from 1996 to 2010 for transgenic annual crops exceeded 1 billion ha, with GMO crops growing in 29 different countries in 2010. None-the-less, significant recent progress has been made in genetic modification of forages. Enhanced drought tolerance, cold tolerance, salt tolerance, and increased disease resistance has been achieved using transgenic approaches in a broad range of commonly grown grass and legume crops, providing opportunity to significantly increase yield with less inputs costs. As well, transgenic approaches that delay plant flowering, delay leaf senescence, or improve dry matter digestibility improve nutrient utilization and reduce feed required by meat producing animals. Traits specifically linked to pest and disease resistance and more efficient water and nutrient use can significantly lower chemical inputs on this land base, with further environmental opportunities linked to increased carbon sequestration and soil health.

The delayed progress in commercialization is related to the fact that most forage plants reproduce by outcrossing, creating a major biosafety concern related to pollen-mediated transgene flow. In January 2011, the US Department of Agriculture announced that it would deregulate Roundup Ready" RR alfalfa without restrictions, which is the first transgenic forage crop to be deregulated in the US. Wang and Brummer [17] provide an excellent overview of that deregulation process and describe new technologies such as the intragenic or cisgenenic approaches now available for cost-effective genetic engineering of many forage species. Should adoption of genetically modified forage crops mimic what was observed for annual crops, there is excellent potential to increase yield and reduce the environmental footprint associated with feed sourcing for the global red meat sector in the next ten years. This benefit could include the pork industry if nutrient availability from crops such as alfalfa and annual forages improves to the extent that they can be included in pig diets.

In recent years, the genomes of chickens, pigs, cows and sheep have been partially or completely sequenced. Coupled with the rapid progress in next generation sequencing technologies, selection of better animal breeds with improved fertility, feed utilization efficiencies and disease resistance will advance quickly. The pork genome, as one example, has helped to identify genes that are involved in immune or physiological processes relevant to efficient pork production [18]. Genomics technologies will facilitate the industry's need to rapidly adapt to changes in production environment such as increased restrictions on drug and antibiotic use, increased animal densities, disease threats and increased costs of traditional feed sources. Genomics technologies will revolutionize our ability to develop bacteria and enzymes that can be added to animal feed to improve gut health, decontaminate low quality feeds and increase mineral and energy utilization from conventional and alternative feed sources.

Precision feeding technologies generate efficiencies by accounting for the inherent variation in groups of animals. Opportunities for precision feeding in meat production are linked to improved feed utilization, rapid identification of animal health issues and reduced animal variation at slaughter. Technology allowing real-time monitoring of individual animal behaviour and weight change, improved models to predict animal nutrient requirements to physiological change, and accurate delivery of feed to individual animals are tools associated with future livestock precision feeding systems [19].

Future innovation in design of manure storage, processing and waste water recycling facilities will be linked to the pairing of biotechnologists with process engineers. Designer microbes will provide new opportunities for efficient processing of animal manures and waste waters to support extraction of high value bioproducts and more efficient recycling of water and nutrients at a local level.

Innovation that is likely to radically change the environmental footprint of agriculture and meat production is harder to predict. Improved information sharing and communication has this potential. As a component of precision agriculture technology, information sharing has been used to achieve more efficient resource use and increased yield in crop production systems on our most productive lands. However, grasslands and small landowner holdings which represent the majority of the agricultural land base has experienced limited application of these technologies. Use of data already available from satellites, on-the-ground sensors and computer models that monitor and help forecast environmental conditions and forage crop needs could dramatically improve grassland management. Elements of an improved agroecological monitoring system might bridge remote sensing and ground-based monitoring systems with real-time, smart, wireless, internet-connected web sensors [20]. To be useful to decision makers, and to support greater transparency, these data management systems must be designed to aggregate, co-ordinate, organize and synchronize within and between monitoring networks [21]. On site access to this information could help producers determine trade-offs between production and environmental outcomes as a part of decision making processes for normal farm operations.

Traceability is another communication or information sharing system that can offer supply chain transparency regarding food production, processing and distribution; including the life cycle impacts of products. Informed consumers have the ability to shift markets through changes in their buying habits. However, to have a lasting positive environmental impact, claims and labels have to undergo validation.

Another radical innovation with potential to reduce the environmental footprint of meat production is the development of perennial grains and oilseeds. Perennial grains can address feed supply, and perhaps food security, issues from lands susceptible to or already experiencing salinity, soil erosion and degradation, nutrient leaching and eutrophication. Frequent tillage puts soil at risk of loss and degradation. Growing concentrate feeds using perennial plants is an options for rejuvenation or maintenance of vulnerable lands. Potential perennial versions of grain crops include wheat, rye, maize, rice, sorghum and sunflower, but it is perennial wheat in dry land agriculture systems that has received the most attention to date. Economic feasibility of perennial grain production systems is expected to be closely linked to its use as a dual-crop for grazing ruminants such as sheep and cattle. Dual-crop is defined as a crop produces grain for harvest and is then used as a high quality forage source by animals. While work with perennial grains is still in its infancy, Bell et al. [22] modeled the potential economics of perennial wheat achieving only 60% of annual wheat crop yield with traditional dryland cropping in southern Australia. The model estimated a potential 44% increase in sheep stocking rates, reduced need to access off-farm supplementary feed and more than 35% increase in profit per ha.

System level innovations are likely associated with our ability to access alternate meat sources as a means of reducing the environmental footprint. Alternative meat producing organisms such as rabbits or insects have the potential to yield high quality meat products efficiency, but consumer acceptance has limited adoption. Of greater interest is the increased attention focused on cultured meat, sometimes referred to as in vitro meat, lab meat or factory grown meat. Post [23] provides a comprehensive overview of future opportunities and challenges associated with production of cultured meat from stem cells. Successful use of bioreactors supporting skeletal muscle cell cultures for meat production will involve thousands of variables to optimize culture conditions. Post [22] suggests that current culture protocols have largely developed through trial and error, with the theoretical basis for a systematic approach is still lacking. This makes it difficult to assess what the net environmental benefits will be. Further, it is well recognized that the rate at which cultured meat products enter the market place will be influenced by ability to compete with its livestock counterpart with respect to nutritional qualities, food safety, as well as preferences related to colour, taste and texture.

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