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Social benefits of niche agricultural products: a conceptual framework

Abstract

Niche agricultural products are growing in economic importance. This growth is driven mainly by the increased demand for more healthy, nutritious, fresh and locally grown food products. There is obviously a potential increase in private benefits to producers/landowners as a result of increased production of the underlying crops to satisfy this demand. What is less obvious is the potential to also generate increased social benefits, particularly as they relate to energy conservation, alternative energy or biogas development and carbon sequestration. In other words, calories and kilo-calories are becoming more linked. The objective of this analysis is to develop a conceptual framework to illustrate the linkages among production at the local level, farm-level profitability and regional economic and environmental benefits. Using an optimal control approach, the authors apply this framework to the case of pasture-based beef (PBB) in Appalachia. PBB is an alternative to conventional, grain-based beef production. The idea is to determine to what extent a transition to PBB would enhance farm-level profitability while enabling surrounding communities to benefit from higher quality food products, environmental improvement, economic development and, ultimately, quality of life. Such a framework is particularly useful in policy formulation. For example, it can be used to determine under what combination of market and policy outcomes it is optimal – from both private and social perspectives – for a given PBB farmer to switch between cattle farming, energy farming and carbon farming.

Keywords: social benefits, niche products, sustainability, energy, environmental policy.
JEL Classification: Q56, Q57, O13.

Introduction

Niche agricultural products such as organic foods, farm-raised trout and pasture-based beef are growing in economic importance. This growth is driven in part by growing awareness of health, nutrition and environmental issues, accompanied by increasing demand for food products that are more healthy, nutritious, fresh and locally grown. There is obviously a potential increase in private benefits to producers and landowners as a result of increased production of the underlying crops to satisfy this demand. What is less obvious is the potential to also generate increased social benefits, particularly as they relate to energy conservation, alternative energy development and carbon sequestration. The main objective of this analysis is to develop a conceptual framework to illustrate the linkages among production at the local level, farm-level profitability and regional economic and environmental benefits. Using an optimal control approach and data from secondary sources, we apply this framework to the case of pasture-based beef (PBB) in Appalachia. The latter is an interesting study area because of the close relationship among natural resources, economic development and quality of life.

Background. PBB is growing in importance in pasture-rich Appalachia, and is considered to be an alternative to traditional, grain-finished beef. The increased use of pasture as the primary diet for cattle in the beef industry has been attributed to positive effects not only in terms of animal welfare but also to human health, the land resource and our ecosystem. Approximately 27 billion pounds of beef were consumed in the U.S. in 2009, most of which was produced on pastures domestically. The market value of the beef produced was $73 billion (Mathews and MacConnell, 2010). In 2005, approximately $230 was spent on beef products per U.S. household (Evans, 2007).

A marketing claim that livestock is "pasture-raised" means animals have had "continuous and unconfined access to pasture throughout their life cycle" according to the U.S. Department of Agriculture (USDA). The American Grass-Fed Association, defines the closely related "grass-fed" as "food products from animals that have eaten nothing but their mother's milk and fresh grass or grass-type hay from birth to harvest all their lives" (Paine et al., 2009).

Specifically, raising cows on pasture improves water quality, decreases soil erosion while enhancing green space (Paine et al., 2009). In fact, growing pasture for beef production can reduce soil erosion by up to 93 percent compared to cultivating corn, making soil more biologically active and enhancing soil fauna and flora (Shinn, undated). In addition, studies have demonstrated that the waste produced from livestock can be used as natural fertilizer as well as a source of alternative energy which eventually maintains land quality and provides renewable fuels to farmers, reducing dependency on products derived from fossil fuels (Fullhage et al., 1993, Pimentel and Pimentel, 2008). These practices make this industry more attractive since it becomes more self-reliant while preserving agricultural lands and the environment to the benefit of society. Figure 1 illustrates the concept proposed in this paper.

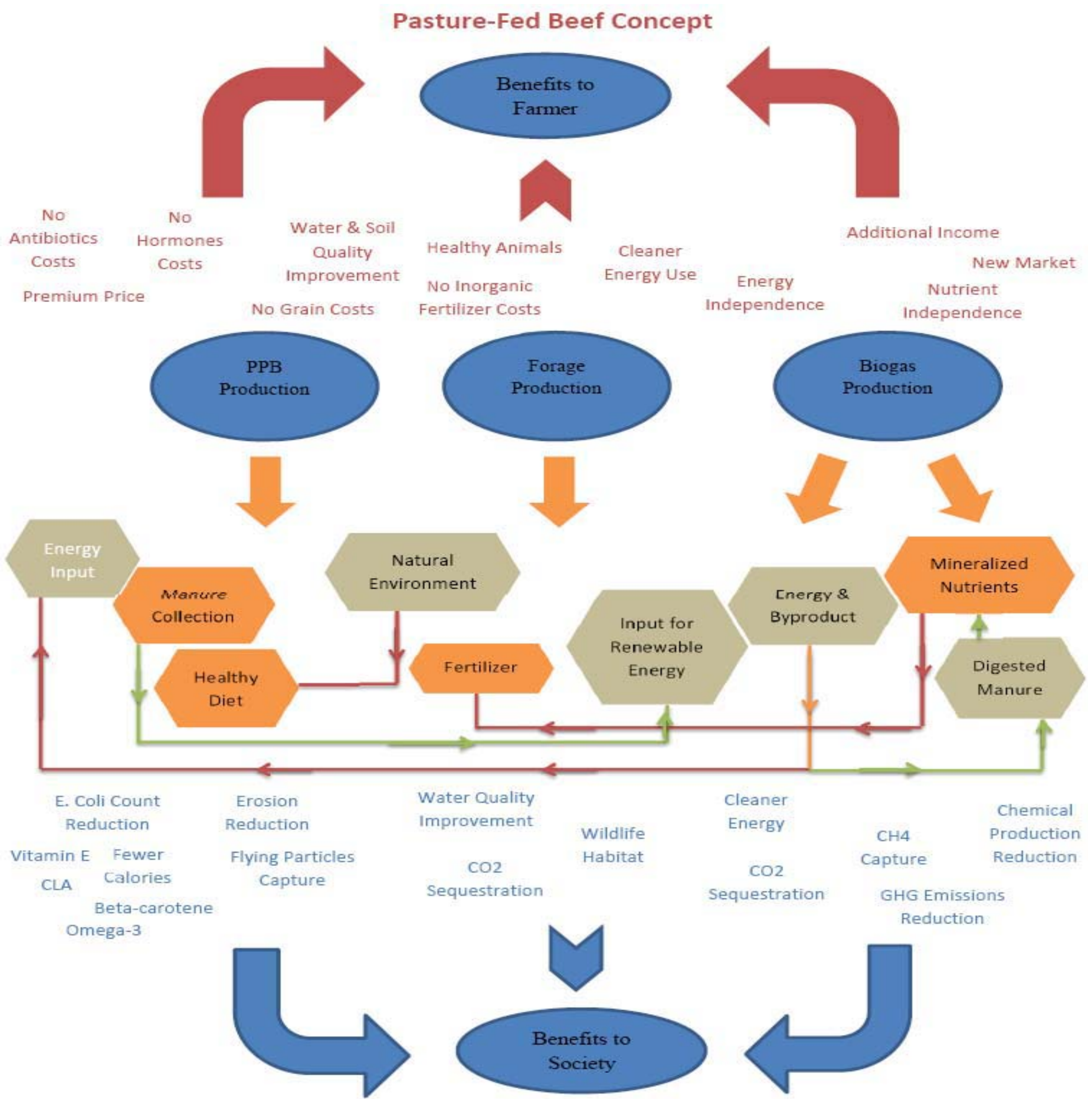


Fig. 1. Pasture-fed beef concept

As previously stated, land can be degraded if not managed using sustainable practices. The use of inorganic fertilizers generally increases grain production; however, this is not a sustainable practice since chemicals ultimately deteriorate soil fertility in the long run (Portelli, 2008). Also, unlike pasture-based beef (PBB) practices, annual row-crop production requires tillage which diminishes water conservation as well as soil organic matter.

Since the PBB industry promises significant reduction in the negative externalities associated with conventional practices while contributing to the local and regional economy, PBB needs evaluation as an alternative management strategy. The economic value of this sector to the US is clearly large and well documented. What is less obvious is the ecosystem value of this production, and its associated contribution (or detraction) to the multi-attribute functions increasingly expected by society and policymakers from the land resource.

1. The study area

The study area is West Virginia (WV), characteristic of Appalachia in general. Although efforts to improve the well-documented economic malaise in the Appalachian region have been conducted by governmental agencies through educational programs, health care accessibility and, more recently, obesity-reduction programs, economic stagnation persists in the study area (Shubert, 2010). The Appalachian area has been identified as the "most economically distressed" region in the U.S. (D'Souza, 2010). Moreover, agricultural activities such as livestock have caused environmental problems in Appalachia (Holmes et al., 2004). Furthermore, land use in the central Appalachian coal region is limited due to its steep slopes. This restricts its potential use for practices other than developing industrial, residential and commercial enterprises (Zipper and Skousen, undated). Given the fact that Appalachia faces resource limitations for economic development, production systems in which resources are optimized must be evaluated. One such system is pasture-based beef.

Environmental contamination and health issues are also a growing concern in the region. For instance, the Washington Monument used to be seen from a distance of 75 miles away along the Appalachian Trail. However, the pollution caused by congestion today is so persistent that this national monument is no longer observed as used to happen until about 40 years ago (Chidester, 2010). In fact, Chattanooga, an Appalachian city, was ranked number 4 out of 100 U.S. cities as among the worst cities to live in with asthma (Asthma and Allergy Foundation of America, 2009). In addition, several locations, like for example, the Chesapeake Bay have identified inorganic fertilizers and pesticide use as being of vital concern in the Appalachian catchment area (Conservation Breeding Specialist Group, 2008). Moreover, the state of WV, the only one contained wholly within the Appalachian region, has an obesity rate that consistently ranks in the top three among U.S. states (D'Souza, 2010). People's health has been affected by industries such as farming, coal mining and chemical manufacturing which tend to be prominent in the area, and which increases human exposure to hazardous substances (Stevens and Deal, 2010).

The combination of a highly mountainous terrain and existing farm resource endowments (a WV farm is 194 acres on average, of which 48 percent is devoted to pasture) makes grass-fed cattle production well suited to WV (Evans, 2007). According to the 2007 Census of Agriculture WV has a total of 10,653 beef farms (National Agricultural Statistics Service, NASS, 2009).

By linking the pasture resource to landowner objectives (increased productivity, profitability and income opportunities) as well as to societal goals (sustainable land use, enhanced water quality and climate change mitigation), this study can provide knowledge and recommendations to enhance socio-economic and environmental conditions in Appalachia. Furthermore, this paper advances the literature by developing a theoretical model in which relevant elements within the PBB industry can be applied to practical situations in order to optimize on-farm profitability and social welfare.

1.1. Pasture as a primary input. The use of grass as the primary diet for cattle in the beef industry has the potential to generate positive benefits in terms of animal welfare, human health, farms and the ecosystem as follows.

1.1.1. Animal welfare. Management-intensive grazing such as rotational grazing (upon which PBB is based) contributes to improving cattle immune systems and decreasing animal stress. Under PBB, cattle are exposed to a more natural diet that is more easily digested, in the process substantially reducing the chances of disruption in rumen function as often occurs with animals under conventional practices (Evans, 2007). Although conventional practices might bring economies of scale through feedlot methods, the crowded conditions in which steers are raised enhance "stress-induced immunological deficiencies" sometimes leading to death and morbidity through acquired illness (Evans, 2007). Figure 2 provides an illustration of the potential negative impacts of grain-fed beef practiceson farmers and surrounding communities.

1.1.2. Human health. Management-intensive grazing techniques are beneficial to human health through green space and a healthier end product. Recent literature (cited in Evans et al., 2007) confirms that grass-fed meat provides higher health benefits to humans than grain-fed beef. Studies have proven that a 6-ounce steak produced from a pasture fed cattle can provide 100 fewer calories, up to 6 times more Omega-3s (a nutrient for obesity and other diseases prevention) and conjugated linoleic acid (more effective cancer fighter) than a comparable 6-ounce steak from a grain-fed steer. This would be 17,733 calories less per year for a typical beef consumer without impacting normal intake routine (Robinson, 2002). PBB is also an excellent source of vitamin E which contributes to the prevention of immune disorders, lung disease diabetes and eye illnesses (Portelli, 2008).

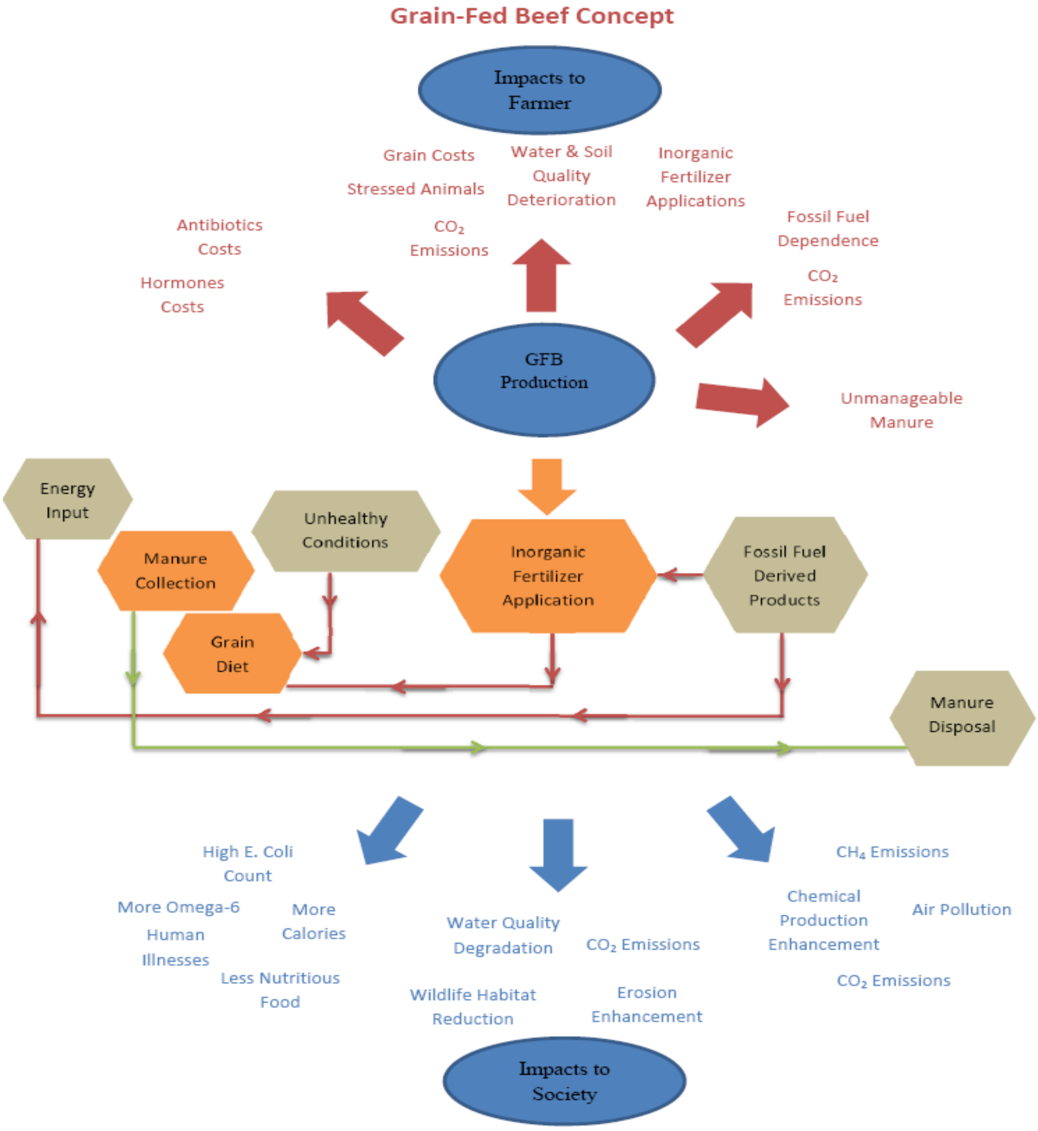


Fig. 2. Grain-fed beef concept

1.2. Energy input. The use of pasture-based production techniques also demand potentially less energy input than confined animal feeding operations (CAFOs). It is estimated that one cattle unit requires around 74 gallons of crude oil if it is pasture-fed while a grain-fed cow consumes 208 gallons of crude oil from conception to the finishing phase before slaughter (Lee et al., 2010). In general, a total of 930 gallons of gasoline per year is needed for the process of cultivating, processing and distributing the amount of food required for a four-member family (Hemert and Holmes, 2007).

1.3. Renewable energy. Today, most of the farms that use livestock manure for biogas production are under CAFOs since their infrastructure design makes it easier to collect animal wastes than under pastured-fed methods. However, if pasture-based systems are able to develop effective manure collection techniques, farmers could produce biogas, leading to the development of an additional, renewable, energy source. For instance, manure collection can be achievable under pastured-fed techniques when animals are fed with hay during winter which takes place in an indoor facility. This might be a starting point in order to integrate renewable energy sources into the PBB industry.

Anaerobic digesters convert animal waste (methane) to biogas and eventually into electricity making it appealing to farmers, the environment and utility companies. In fact, based on the most recent renewable energy production survey conducted by NASS, the number of renewable energy technologies installed on U.S. farms such as anaerobic digesters have increased considerably in the last decade. For instance, approximately 121 cattle operations are using anaerobic digesters in 29 states (West Virginia Department of Agriculture, 2011). Methane is 25 times more harmful than CO_2, and is one of the major contributors of greenhouse gas (GHG) emissions (Ramanathan and Victor, 2010). When captured and utilized as a renewable energy source, methane contributes significantly to reducing the greenhouse effect. Methane, the major element of natural gas, can be carried by pipeline to the local power grid for use in electric generators (State Energy Conservation Office, undated). This practice also potentially helps reduce costs to farmers by providing their own energy as well as decreasing human health problems associated with conventional fuels.

1.4. Natural fertilizer. The use of manure to maintain the required nutrients for soil fertility is essential not only to support sustainable practices that reduce input costs associated with crop production but also to keep potential pollutants away from the atmosphere, streams and the nearby farm population. When manure is used for the production of biogas, its nutrient content is not affected, enabling retention of nitrogen, potassium and phosphorus with their valuable characteristics (Pimentel and Pimentel, 2008). In fact, this manure, known as digested slurry or digested manure, is very effective in enhancing porosity and fertility as well as providing humus to the soil (TaTEDO-Centre for Sustainable Modern Energy Initiatives, undated). However, manure generated in conventional beef production practices can also destroy crops due to its high content of heavy metals, hormone remains, nitrogen and phosphorus (Portelli, 2008).

1.5. Carbon sequestration. Another name used when beef is produced under 100 percent pasture-based conditions is "carbon farming" since it reduces global warming (Shinn, undated). For instance, a reduction of approximately 14 billion pounds of CO_2 from the atmosphere would take place if all the acres of land (16 million acres) devoted to grow corn for cattle feedlot in the U.S. were to be used for forage (Portelli, 2008). Furthermore, the combination of water from the soil, carbon dioxide from the air and energy from sunlight enable crops to produce organic compounds leading carbon to become an important component in soil organic matter (Sundermeier et al., 2005). In addition, it was determined that the use of biogas produced from cattle manure in a year would contribute to reducing about 4 percent (99 million tons) of GHG emission in the U.S. (Cuellar and Webber, 2008).

2. A conceptual framework

The use of dynamic approaches in the analysis of agricultural and resource problems has increased in recent years (Cacho, 1998). An optimal control (OC) model reflecting this dynamic approach is used here. A control variable can be seen as a policy tool that is able to impact state variables which means that any selected control path involves a linked state path (Chiang, 2000).

2.1. Control and state variable selection. The selection of control and state variables in OC models has been widely studied. Cacho (1998) employs an OC model using a meat production function in which grass is the primary input while stocking rate and fertilizer applications have an indirect control over production. The author considers state variables such as soil depth and animal weight, and control variables such as stocking rate to capture seasonal variations on an annual basis. Cacho (1998) also considers soil quality and rainfall influence on grass production through soil fertility, providing a description of biophysical interaction between state variables that eventually have an effect on meat production. According to the author, the interaction among animals, plants, the resource base and climate is clearly seen through grazing systems. Since meat is the only output, for simplicity, the author induces the paths of control variables through time which eventually maximizes discounted profits gained from meat production. The use of simulation models allows one to determine the level of each decision variable through the passage of time in which the objective function can be maximized (Cacho, 1998). On the other hand, Saliba (1985) explores the interactions between management choices, soil loss through erosion and farmland productivity. The author analyzes four models developed by other researchers and concluded that none of them directly address the relationship between soil erosion and soil productivity. In addition, tradeoffs among intensity of crop rotation, soil conservation practices and production inputs are not sufficiently explained, which the author attempts to overcome using their own model (Saliba, 1985).

McConnell (1983) formulated an economic model where the use of soil can be optimized from a social and private perspective. McConnell developed a production function in which explanatory variables such as technological change, soil loss and soil depth are considered to express the effect on output. The author also considers the value of a farm to society in which the social discount rate assesses the welfare value of distant future generations while the private discount rate represents the capital market. McConnell concludes that farmers would conserve the soil base, if they are aware that it will have an impact on farm resale value (McConnell, 1983). Likewise, Saliba (1985) states that a profit maximizing farmer analyzes the contributions and costs of soil and other inputs in crop yield when making decisions regarding input use and conservation methods. Saliba (1985) states that entrepreneurs have two alternatives to maintain crop production by either: (1) substituting better varieties of plants and commercial fertilizers among other inputs; or

(2) implementing techniques such as conservational tillage instead of conventional tillage. Saliba (1985) introduces conservation effort, input levels and crop rotations as decision variables. The author establishes that if soil productivity affects land market value, it makes sense to conserve productivity since it would provide some incentive to farmers even toward the end of the farmer's planning horizon (Saliba, 1985).

Other approaches integrate a spatial component into the OC model. For instance, Brock and Xepapadeas (2009) formulate an OC model in which spatial effects of accumulated state variables in other locations are considered influencing given sites in an abstract format in which locations are not specified allowing for a broad application. They establish that the integration of the model kernel expressions is an appropriate tool for dynamic economics when spatial effects are taken into account. For this approach, Brock and Xepapadeas (2009) apply the use of an influence kernel as a technique to model the spatial interactions with the main purpose of illustrating the effects of state variables situated at different spatial locations on a state variable set at a given location. They indicate that this approach provides a valuable foundation for methodical studies of clustering and agglomeration in dynamic economic models. The authors examine the emergence of economic agglomeration from the spatial homogeneity and spatial heterogeneity that might emerge from optimized behavior. They also employ Fourier techniques as an approach to develop the necessary and sufficient conditions for the emergence of optimal agglomeration (Brock and Xepapadeas, 2009).

2.1. Application to the pasture-based beef sector. The framework developed here is intended to capture the effects of PBB systems not only on the farmer's profitability, but also on the environment and society by virtue of the fact that they act in an interconnected system. In order to identify the optimal solution that benefits both the farmer and society based on sustainable practices, an OC modeling approach is considered. Although the existing literature seems to lead to potential positive impacts toward farmers and society through the introduction of the PBB industry, there is still a need for finding methods in which PBB practices can optimize the use of their resources or inputs by integrating current climate, energy and production challenges. As Chiang (2000) and Saliba (1985) propose, OC theory allows decision variables to respond over time to accrued influences of previous control management choices on state variables and crop production. This model is intended to capture the dynamic effects that take place on two-interconnected production functions that eventually determine the profitability of a farmer. Management-intensive grazing practices allow farmers to identify the optimal choice between grass production and cattle needs in the production of beef.

This model is intended to integrate the OC approaches used by Cacho (1998), McConnell (1983), and Saliba (1985). Also, the inclusion of biogas production and digested manure in the PBB industry seems to be ignored throughout the literature reviewed. The combination of all these components in this model makes this approach appropriate in the sense that it contributes to the literature on sustainability. This model allows us to evaluate if the management practices considered on beef farms lead us to achieve mutual benefits between the farmer and society. This can be reached when the optimal private path equals the socially optimal path. Table 1 contains a description of the variables used in this model.

2.1.1. Farmer's perspective. Assuming that the value of the land at the end of the planning horizon T is not considered, the objective function in which the entrepreneur maximizes the present value of the profit stream (McConnell, 1983; Saliba, 1985) is:

$$\underset{\gamma}{\text{Max}}: \; J = \int_0^T e^{-rt}[p_\alpha f(\gamma_t) + p_\xi f(\omega_t(\gamma)) - c_\alpha\gamma - c_\xi\omega - cz]dt \,. \tag{1}$$

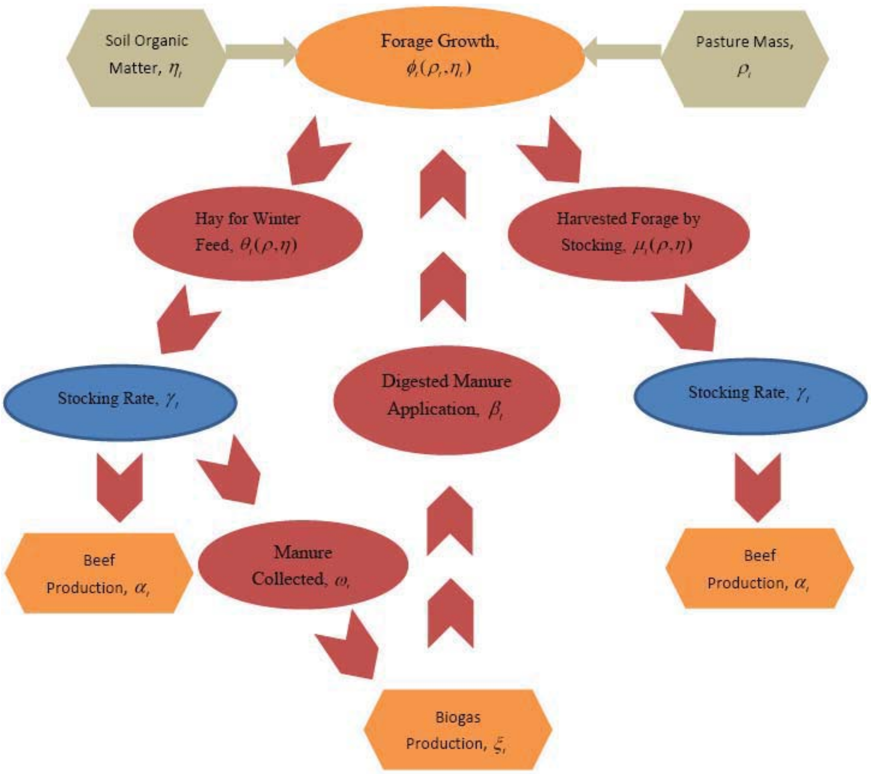
Equation (1) represents the objective function of the farmer which is to maximize the discounted accumulated profits over the planning horizon T. Figure 3 provides a simplified overview of the state variables paths when decision variables are taken into account.

Table 1. Definition of variables

Definition of variables			
Variable type/function	Variable symbol	Description	Units
Control	γ	Stocking rate	Head/hectare
State	ρ	Pasture mass	Ton/hectare
	η	Soil organic matter	Ton/hectare
Prices	p_a	Price of beef	$/ton
	p_ξ	Price of biogas	$/ton

Table 1 (cont.). Definition of variables

Definition of variables			
Variable type/function	Variable symbol	Description	Units
Costs	c_a	Beef production costs	\$/ton
	c_ξ	Biogas production costs	\$/ton
	cz	Fixed costs	\$/ton
Others	α	Beef production	Ton/hectare
	ξ	Biogas production	Ton/head
	μ	Harvested forage by stocking	Ton/hectare
	β	Digested manure application	Ton/hectare
	ϕ	Forage growth	Ton/hectare
	θ	Hay for winter feed	Ton/hectare
	ζ	Nutrients accumulation	Ton/hectare
	τ	Carbon sequestrated from the air	Ton/hectare
	ω	Amount of manure collected	Ton/head
	υ	Average precipitation	Inches
	$k\rho_{t+1}$	% of pasture mass at the end of the feeding season	Ton/head
	e^{-rt}	Continuous time discount factor	
	$e^{-\delta t}$	Continuous time welfare factor	
	δ	Welfare value of future generations	
	r	Private discount rate	
	t	Specific time period	
	T	End of the planning horizon	



Note: Sustainable management practices permit regeneration of resources.

Fig. 3. Paths of soil organic matter and pasture mass

Subject to changes in pasture mass available and soil organic matter accumulation per hectare and their corresponding initial amounts at the beginning of the feeding season:

$$\Delta\rho_t = \rho_{t+1} - \rho_t = f(\gamma_t, \eta_t, \rho_t, \beta_t, \nu_t) . \quad (2)$$

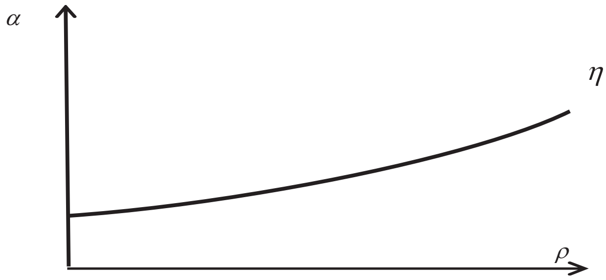
Equation (2), is the change in pasture mass produced per hectare which depends on the amount of pasture mass at the beginning of the feeding season available, ρ_t, for harvested forage by grazing, μ_t, and hay for winter feed, θ_t, and the amount pasture mass available at the end of the feeding season, ρ_{t+1}. The change in pasture mass available basically represents the growth of forage, ϕ:

$$\phi_t = f(\gamma_t, \eta_t, \rho_t, \beta_t, \upsilon_t) \ . \quad (3)$$

Equation (3) defines the forage growth function which is basically a function of stocking rate, γ_t, the soil organic matter, η_t, pasture mass at the beginning of the feeding season, ρ_t, digested manure or natural nutrients application, β_t and average precipitation, v_t, a weather condition. Most of these are implicitly affected by the amount of carbon available in the soil. The impacts of each variable on this function are the following.

While the stocking rate influences negatively forage growth, $\frac{\partial \phi}{\partial \gamma} < 0$, digested manure or nutrient application as well as soil organic matter available counteract, $\frac{\partial \phi}{\partial \beta} > 0$ and $\frac{\partial \phi}{\partial \eta} > 0$, this negative effect since they both increase nutrient savailability which enhances forage growth per hectare. In addition, this function, $\frac{\partial \phi}{\partial \rho_t} > 0$, is positively affected by the pasture mass available at the beginning of the feeding season. Furthermore, precipitation generally influences forage growth positively, $\frac{\partial \phi}{\partial v_t} > 0$. All these influences imply that forage growth would influence beef production as well as biogas production. Thus, the contribution of hay for winter season and harvested forage by stocking would impact positively beef production, $\frac{\partial \alpha}{\partial \phi} > 0$ and biogas production, $\frac{\partial \xi}{\partial \rho} > 0$, since forage is the primary diet in this beef industry which eventually would be transformed into manure, the primary input in the biogas production process.

Steady state condition 1. As previously mentioned, the change of pasture mass available per hectare is influenced by the stocking rate, the soil organic matter accumulation rate, the pasture mass at the beginning of the feeding season, the nutrient application rate and the average precipitation. In other words, pasture mass is on a steady state condition or reaches equilibrium due to the influences of each variable on forage growth, $\phi = \eta + \rho_t + \beta + v - \gamma$, in which sustainable management decisions are considered. This means that the change on pasture mass is optimized when management decisions are employed through sustainable practices. This happens when stocking rate is optimized. This contributes to the levels of beef and biogas production since the resources available are efficiently utilized when the pasture mass system is at a stable stage during a given period of time. The relationship between the pasture mass, soil organic matter and beef yield is presented in Figure 4.



Note: Soil organic matter influences pasture mass positively which improves beef production.

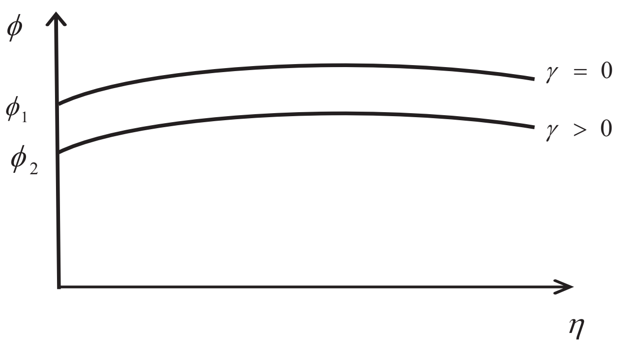
Fig. 4. Effects of soil organic matter on pasture mass and beef production

$$\rho(t = 0) = \rho_0 \ . \quad (4)$$

Equation (4) represents the initial pasture mass available per hectare at the beginning of the feeding season. The effects of stocking rate on forage growth and their relationship with soil organic matter are illustrated in Figure 5.

$$\Delta\eta = \eta_{t+1} - \eta_t = f(\gamma_t, \beta_t, \kappa\rho_{t+1}, \eta_t, \tau_t) \ . \quad (5)$$

Equation (5) is the change in soil organic matter accumulated per hectare which depends on the soil organic matter at the start of the feeding season, η_t, and the amount of soil organic matter available at the end of the feeding season, η_{t+1}. The change in soil organic matter is essentially the nutrient accumulation function, ς.



Note: Stocking rate negatively influences both pasture mass as well as soil organic matter availability while soil organic matter improves pasture mass.

Fig. 5. Effects of stocking rate on forage growth and their relationship with soil organic matter

$$\varsigma = f(\gamma_t, \beta_t, \kappa\rho_{t+1}, \eta_t, \tau_t) \ . \quad (6)$$

Equation (6) defines the nutrient accumulation function which is a function of the stocking rate, $\gamma(t)$, the digested manure application, $\beta(t)$, the percentage of the remaining pasture mass at the end of the feeding season, $\kappa\rho_{t+1}$, in which κ is a constant term with values $0<\kappa<1$, the soil organic matter available at the beginning of the feeding season, $\eta(t)$, and carbon sequestration from the air, $\tau(t)$. The influences of each variable on this function are shown as follows.

The stocking rate negatively influences the nutrient accumulation function, $\frac{\partial\varsigma}{\partial\gamma}<0$, since it is extracted from the soil through harvested forage, by stocking and hay production. On the other hand, the percentage of the remaining pasture mass at the end of the feeding season, $\frac{\partial\varsigma}{\partial\kappa\rho_{t+1}}>0$, and the digested manure application, $\frac{\partial\varsigma}{\partial\beta}>0$, contribute in counteracting this negative impact. In addition, the soil organic matter at the beginning of the feeding season, $\frac{\partial\varsigma}{\partial\eta_t}>0$, as well as the carbon sequestrated from the air through pasturelands, $\frac{\partial\varsigma}{\partial\tau}>0$, would influence this function positively. The fact that the availability of nutrients enhances forage growth for stocking implies that nutrient accumulation would positively influence beef production, $\frac{\partial\alpha}{\partial\varsigma}>0$, through the increase of pasture production for grazing and winter season which would increase the animal's weight. Likewise, nutrients would impact biogas production in a positive manner, $\frac{\partial\xi}{\partial\varsigma}>0$, through the contribution of pasture growth. This occurs due to the fact that the forage harvested as hay for winter feeding is positively influenced to nutrient accumulation which would eventually be transformed into manure and utilized as an input for biogas production.

Steady state condition 2. As already discussed, the change of soil organic matter accumulated per hectare is influenced by the stocking rate, digested manure or nutrient application, the percentage of the remaining pasture mass, the soil organic matter at the beginning of the feeding season and carbon sequestrated from the air. In other words, the soil organic matter is in steady state condition or reaches equilibrium due to the influences of each variable on the nutrient accumulation function, $\eta=\beta+\kappa\rho_{t+1}+\eta_t+\tau-\gamma$, in which sustainable management decisions are considered. This tells us that soil organic matter is optimized when the control variable, the stocking rate, is optimized. This would contribute to the levels of beef and biogas production since the resources available are efficiently utilized when the soil organic matter system is at a stable stage at a given period of time. The relationship between the soil organic matter, pasture mass and the biogas production is illustrated in Figure 6.

Assumption: hay is harvested at a steady state condition to feed the animals during the winter season:

$$\eta(t=0)=\eta_0. \quad (7)$$

Equation (7) represents the initial soil organic matter available per hectare at the beginning of the feeding season:

$$\alpha_t=f(\gamma_t). \quad (8)$$

Equation (8) represents beef production, explicitly presented in the objective function which depends on stocking rate, γ_t:

$$\xi_t=f(\omega_t(\gamma_t)). \quad (9)$$

Equation (9) represents biogas production explicitly incorporated in the objective function that depends on the amount of manure collected, ω_t, which is a function of the stocking rate, $\gamma(t)$.

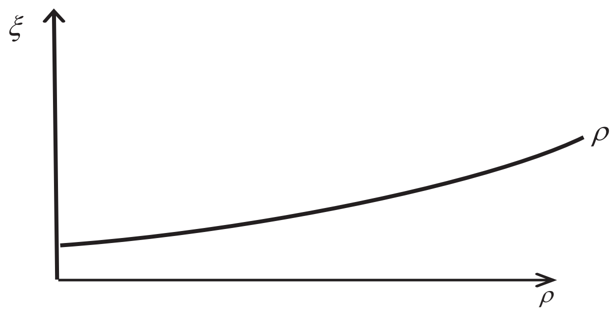


Fig. 6. Effects of soil organic matter on pasture mass and biogas production

As we can observe, the objective function is composed of total revenue gained from beef, $p_\alpha*\alpha_t$, and biogas sales, $p_\xi*\xi_t$, minus the variables costs associated with beef production, $c_\alpha*\gamma$, which depends on stocking rate; biogas production, $c_\xi*\omega$, which depends on the amount of manure collected and fixed costs, cz.

As Brock and Xepapadeas (2009) and Cacho (1998) suggest, subscripts *t* have been omitted for simplification. For this optimal control problem, there are four types of necessary conditions that will be explained below (Saliba, 1985). The Hamiltonian is composed of the integrand function plus the product of the co-state variables and their corresponding equation of motion (Chiang, 2000).

Equation (10) presents the Hamiltonian for this problem:

$$MaxH(\gamma,\rho,\eta,\lambda_{\rho},\lambda_{\eta}) = e^{-rt}[p_{\alpha} f(\gamma_t) + p_{\xi} f(\omega_t(\gamma)) - c_{\alpha}\gamma_t - c_{\xi}\omega_t - cz] + \lambda_{\rho}\Delta\rho + \lambda_{\eta}\Delta\eta \ . \quad (10)$$

The derivative of the Hamiltonian with respect to the control variable must be equal to zero according to the maximum principle (Saliba, 1985). The optimal path of γ is:

$$\text{For } \gamma: \ \frac{\partial H(.)}{\partial \gamma} = 0 \rightarrow p_{\alpha} f_{\gamma} - c_{\alpha}\gamma + p_{\xi} f_{\gamma} - c_{\xi}\omega + \lambda_{\rho}\frac{\partial \rho}{\partial \gamma} + \lambda_{\eta}\frac{\partial \eta}{\partial \gamma} = 0$$

$$\rightarrow -\lambda_{\rho}\frac{\partial \Delta\rho}{\partial \gamma} - \lambda_{\eta}\frac{\partial \Delta\eta}{\partial \gamma} = p_{\alpha} f_{\gamma} - c_{\alpha}\gamma + p_{\xi} f_{\gamma} - c_{\xi}\omega \ . \quad (11)$$

The right hand side (RHS) of equation (11) represents the benefits of higher stocking rate per hectare in terms of profits from beef and biogas production. On the other hand, the left hand side (LHS) implies the costs associated with an additional head per hectare in terms of the marginal value of increasing one additional animal per hectare to enhance beef and biogas production.

Another important variable is the auxiliary variable also known as the co-state variable which is basically a valuation variable (its value changes at different time periods), named the shadow price of the related state variable. This variable is integrated into the OC model through the Hamiltonian. The latter is used to maximize the control variable before employing the maximum principle (Chiang, 2000). In this model, the shadow price represents the amount of money farmers would be willing to pay (WTP) for an additional ton of pasture mass produced per hectare and an additional ton of soil organic matter per hectare. In fact, if the cost associated with any of these two state variables were less than the shadow price, the present value of the profit stream or the value of the objective function would increase. In contrast, if the associated costs were higher than the shadow price, then the value of the objective function would decrease while an equal cost would keep it unchanged. Every co-state equation presents the change rate of each co-state variable (Saliba, 1985). Thus, the optimal path of each co-state variable is represented through the marginal value (Cacho, 1998; Saliba, 1985) of λ_{ρ} and λ_{η}:

$$\frac{\partial H(.)}{\partial \rho} = r\lambda_{\rho} - \dot{\lambda}_{\rho} \ ,$$

$$\dot{\lambda}_{\rho} = r\lambda_{\rho} - \frac{\partial H(.)}{\partial \rho} \rightarrow \dot{\lambda}_{\rho} = r\lambda_{\rho} - p_{\alpha}\frac{\partial f_{\alpha}}{\partial \rho} - p_{\xi}\frac{\partial f_{\xi}}{\partial \rho} . \quad (12)$$

Equation (12) denotes that changes in the marginal value of pasture mass available per hectare at each point in time, $\dot{\lambda}_{\rho}$, depends on the product of the discount rate, r, and the current value of the co-state variable, λ_{ρ}, minus the product of beef price, p_{α}, and the influences of the change of pasture mass on the beef production function, $\frac{\partial f_{\alpha}}{\partial \rho}$, minus the product of the biogas price, p_{ξ}, and the influences of the change of pasture mass on the biogas production function, $\frac{\partial f_{\xi}}{\partial \rho}$. The implicit cost of pasture mass produced per hectare must grow at the rate of discount minus the contribution of the pasture mass available for stocking through the harvested forage as well as hay per hectare to the current returnsfrom beef and biogas production.

$$\rho(t=0) = \rho_0 \ , \quad (13)$$

$$\Delta\rho_t = \rho_{t+1} - \rho_t = f(\gamma_t, \eta_t, \rho_t, \beta_t, v_t) \ . \quad (14)$$

Equations (13) and (14) present the initial pasture mass available per hectare at the beginning of the grazing season and its change, respectively.

$$\frac{\partial H(.)}{\partial \eta} = r\lambda_{\eta} - \dot{\lambda}_{\eta} \ ,$$

$$\dot{\lambda}_{\eta} = r\lambda_{\mu} - \frac{\partial H(.)}{\partial \eta} \rightarrow \dot{\lambda}_{\eta} = r\lambda_{\eta} - p_{\alpha}\frac{\partial f_{\alpha}}{\partial \eta} - p_{\xi}\frac{\partial f_{\xi}}{\partial \eta} . \quad (15)$$

Equation (15) implies that the changes in the marginal value of soil organic matter per hectare at each point in time, $\dot{\lambda}_{\eta}$, depends on the product of the discount rate, r, and the current value of the co-state variable, λ_{η}; the product of the beef price, p_{α}, and the influences of the change of soil organic matter on the beef production function, $\frac{\partial f_{\alpha}}{\partial \eta}$; and the product of the biogas price, p_{ξ}, as well as the influences of the change of soil organic matter on the biogas production function, $\frac{\partial f_{\xi}}{\partial \eta}$. The implicit cost of soil organic matter per hectare must grow at the rate of discount minus its positive impact on forage production per hectare to current returns associated with beef and biogas production:

$$\eta(t=0)=\eta_0 , \quad (16)$$

$$\Delta\eta=\eta_{t+1}-\eta_t=f(\gamma_t,\beta_t,\kappa\rho_{t+1},\eta_t,\tau_t) . \quad (17)$$

Equation (16) and (17) represent the initial soil organic matter at the start of the feeding season per hectare and its change, respectively.

The state equations:

$$\frac{\partial H}{\partial\lambda_\rho}=\Delta\rho_t=\rho_{t+1}-\rho_t=f(\gamma_t,\eta_t,\rho_t,\beta_t,\nu_t) , \quad (18)$$

$$\frac{\partial H}{\partial\lambda_\eta}=\Delta\eta=\eta_{t+1}-\eta_t=f(\gamma_t,\beta_t,\kappa\rho_{t+1},\eta_t,\tau_t) . \quad (19)$$

Equations (18) and (19) are the state equations for every state variable. Equation (18) represents the state equation for pasture mass while equation (19) denotes the state equation for soil organic matter. These two equations are subject to the initial conditions of each state variable in order to solve them through the passage of time. These functional relationships are able to capture the effects of management decisions (control variables) on the state variables (Saliba, 1985).

The endpoint conditions consider the initial conditions of every state variable as well as the transversality condition:

$$\rho(t=0)=\rho_0 , \quad (20)$$

$$\eta(t=0)=\eta_0 . \quad (21)$$

The initial conditions for each state variable are shown in equations (20) and (21):

$$\lambda_\rho(T)=\frac{\partial J_\rho(T)}{\partial\rho(T)} , \quad (22)$$

$$\lambda_\eta(T)=\frac{\partial J_\eta(T)}{\partial\eta(T)} . \quad (23)$$

Equations (22) and (23) display the transversality conditions in the final period, *T*. This is the last condition considered in an optimal control model. This condition essentially represents what would occur in the final period of time (Chiang, 2000).

Following Saliba's (1985) approach, these equations establish how the marginal values of each state variable will influence the market price of its related product. In other words, at the planning horizon T, the marginal value of pasture mass and soil organic matter available per hectare would have an impact on the market value of beef price and biogas price. This occurs due to the fact that beef and biogas production are mutually dependent on both state variables through the interaction between the stocking rate, the feeding seasons based on the forage harvested as well as the hay for winter feed, as noted previously.

2.1.2. Social perspective. The objective function in which the value of the farm to society is maximized occurs when the optimal use of farm resources at the end of the planning horizon *T* is socially efficient.

$$\text{Max: } V=\int_0^T e^{-\delta t}[p_\alpha f(\gamma_t)+p_\xi f(\omega_t(\gamma)) - -c_\alpha\gamma-c_\xi\omega-cz]dt . \quad (24)$$

Equation (24) represents the total value of PBB farms to society.

As McConnell (1983) suggests, the socially efficient strategy would be equal to the private goal when the private discount rate, *r*, is equal to the value of the welfare of future generations, δ . This value represents the implementation of sustainable practices in the present period of time and is reflected at the end of the planning horizon (*T*). When this interaction, $\delta=r$, takes place and the market works efficiently, society and the farmer would be efficiently interconnected and the path of the stocking rate would be socially optimal. This would eventually influence the paths of the pasture mass and the soil organic matter per hectare. Therefore, the implementation of sustainable practices in the PBB industry would benefit the farmer as well as surrounding communities.

2.1.3. Illustrations. From this model, we can predict several benefits to the Appalachian region through the introduction of PBB when the sustainable practices proposed are implemented. Estimations of possible environmental, economic and social impacts (i.e., the optimal mix of cattle farming, biogas farming and carbon farming) will be based on factors such as relative prices and costs, numbers of farms, average farm acreage area, and any assumptions, as appropriate. An example illustration for one Appalachian state, WV, follows.

2.1.4. Economic benefits. Assume that the beef industry in WV has 10,653 beef farms (National Agricultural Statistics Service, 2009) in which each farm has 93 acres of pasture on average (Evans, 2007). Also, under the scenario that a 30 beef cow herd of 1,000 pounds cows with a 2,000 lb. bull (1 animal unit (AU) and 1.7 AU, respectively), then each farm would have a total of 93 thousand-pound cows for beef production and 96 animals for manure production (Williams and Hall, 1994). In other words, this industry depends on 990,729 pasture acres, 990,729 cows for beef production and 1,022,688 for manure production. Assuming that 75% of the WV population consumes beef and each household is composed of four members (Evans, 2007), an estimated 322,000 tons or 643,973,900 lbs. (65% of live animal weight) of beef hanging carcass and around 173,400 tons or 346,755,200 lbs. (35% of live animal weight) of the remnants for other products such as ground beef (Evans, 2007) would need to be produced to fully satisfy annual WV beef demand. This would bring around $78 million in direct and indirect impacts to the local economy.

2.1.5. Environment benefits. These are primarily associated with reduction of potential environmental hazards and/or increase in environmental outcomes. For example, the energy input required to raise approximately 1 million steers under pasture-based beef (Lee et al., 2010) is approximately 1.7 million barrels of oil for their lifetime. This would be 3.2 million barrels of oil (Lee et al., 2010) less than the energy needed for the same amount of animals under CAFOs or conventional methods. In addition, if we used the amount of pastureland under consideration (990,729 acres) for corn production, it would require approximately 38 million gallons of diesel (Shinn, undated) in the lifespan of corn production. In other words, the implementation of these practices would decrease: (1) machinery use in the field since there is no crop production for feeding animals as with the use of corn in conventional methods; (2) energy consumption from fossil fuels for processing the product; and (3) transportation costs since it is locally produced and distributed. In fact, the total amount of grasslands (one million acres) will be able to capture (Agnew, 2009) around 5.5 million tons of CO_2 per year. Thus, 1.5 million tons of carbon are sequestered underground (Agnew, 2009) which otherwise could have been released into the atmosphere contributing to the greenhouse effect. Moreover, the total amount of pastureland would absorb 802 million kilograms of flying particles (Mazereeuw, 2005) that could have been inhaled by the local population threatening human health through diseases such as asthma.

Also, this industry would be able to capture methane to be locally used as a renewable fuel and digested manure as natural fertilizer in farm fields. Under the scenario that 100% of the manure produced during the winter season only (180 days) in all the farms is collected, 174 million m^3 of biogas (methane) can be captured annually (Fowler, undated) from manure produced by all animals (assuming each steer weighs 1,000 lbs. on average including the bulls, although for acreage requirement the bulls were assumed to be 2,000 lbs.) that could be either pipelined and used directly as natural gas for heating or used to produce electricity. This amount of methane is equivalent (Fullhage et al., 1993) to 552 million kilowatt hours of electricity or around 552,000 megawatts hours per year. Moreover, this amount would be able to replace 229,100 tons of firewood (Pimentel and Pimentel, 2009) providing cleaner energy compared to fossil fuels which helps to reduce deforestation for energy purposes. In fact, if the amount of energy produced with biogas were to be produced by using fossil fuels instead, 134 million kg. of CO_2 would be released into the atmosphere (Greenpower, undated).

The possibility of new business development as a result of the development of the PBB industry in WV exists as well. After the capture of biogas for energy purposes, the digested manure could be applied as natural fertilizer. Any digested manure left over can be sold to be used in other green spaces or crop farms in the state in order to maintain soil fertility. Since digested slurry is an attractive natural fertilizer due to its high nutritional content, the possibility of creating a new market for a more natural fertilizer in WV eventually would provide more diversified products and additional income at the local level. These are methods that contribute to maximizing the resources available since they are reused as raw materials for the production of new products while reducing the chances of extracting more natural resources negatively impacting the ecosystem. In addition, the reduction of firewood for energy might have a positive effect on the forest industry, one of the key industries in the WV economy; because more wood would be available for the production of other goods such as furniture as a way of maximizing timber use since this is the primary input in this industry. The possibility of new firms within the lumber industry cannot be underestimated either.

2.1.6. Surface-minded lands. Under the same reasoning as illustrated above, the 190,000 acres of reclaimed surface-minded lands in the state can be considered for beef production. In fact, approximately 979 new farms can be developed in the area. This would expand the industry in the region since more pasture would be available which will eventually have a positive effect on WV agriculture, the ecosystem and the local community. This means that potential policy development to support these disadvantaged areas cannot be misjudged.

2.1.7. Potential benefits for the industry. The benefits that the beef industry itself would obtain from these improved management strategies cannot be overlooked. For instance, approximately $271 million would be saved in energy inputs if pasture-based practices are applied compared to the same amount of animals under conventional methods when a barrel of crude oil is priced at approximately $86 (Department of Energy, 2010). Also, these practices do not usually result in input costs associated with hormones, inorganic fertilizers, antibiotics and intensive labor while the production of alternative fuels provides power for the farm as well as the probability of selling it (an additional income for farmers) to utility companies or to nearby industries. In fact, a farm in Pennsylvania has been able to save approximately $60,000 annually by converting animal waste into energy applying anaerobic bio-digester technology (Bogo, undated).

Moreover, having healthier animals would help them live longer, reducing costs associated with medications to combat animal diseases while eventually providing high quality product to customers. The use of certain pasture varieties also contributes to reducing input costs. For instance, the use of a particular grass such as ball clover helps reduce labor costs since it reproduces itself with no need of replanting the seed for more than 10 years (Moseley, 2009). Thus, an appropriate selection of cover or grass species among other factors is needed to develop a sustainable industry.

In addition, the share of production inputs among agricultural firms, like for example, natural fertilizers, energy, knowledge, labor, and space among others would provide substantial impacts as well as economic development. Consumers would benefit from the agglomeration economies since their quality of life improves through fresh and healthier food, improved environment and the reduction of GHG emissions. Thus, a potential for localized economies in the Appalachian region would take place for the wellbeing of farmers and future generations.

Conclusions

The next step is to operationalize the OC approach using an agent-based model. When considering agent-based modeling, it is essential to select a procedural language such as NetLogo. The agent-based program allows choosing important elements such as stocks, variables, flows and links to perform the simulationin a dynamic format. For instance, each of these elements is identified through the production function equations and are linked together so that it simulates the flows of the stocks and its effects over time. In this model, the amount of cattle, pasturelands, the manure collected and digested manure can be categorized as stocks.

Published data and parameters identified in previous studies can be utilized to estimate this model. The amount of beef cows, beef farms, beef production and manure produced in WV during different periods of time can also be employed in NetLogo. Other data that might be integrated based on different time periods include prices of beef, natural gas and gasoline, and costs of inorganic fertilizer as well as manure.

The model has limitations, some of which we intend to address in subsequent research. For example, if locations are explicitly stated in the equations, the model can be improved to make inferences about agglomeration economies. This would allow us to examine the spatial effects among different locations in which the effects of state variables can cause some impact across space (Brock and Xepapadeas, 2009). This way, we are able to explicitly specify farm locations by county that might be influenced by the path of state variables from farms located in adjacent counties, leading to the evolution of a state system across both time and space, enabling inferences of possible economies of scale through agglomeration.

As implied, it is desirable to implement farm practices that would bring benefits not only to the private sector but also to society since it would be socially inappropriate to endorse practices that maximize private interests at the cost of society and the environment. When the use of natural resources promise the highest present value to the private sector compared to conserving it in a natural state for the wellbeing of society, it is very likely to experience divergence between the two sectors (Krutilla, 1967). However, the PBB industry promises an alternative that would contribute in optimizing our resources in a sustainable way to meet present needs without compromising future necessities. The combination of appropriate land use for sustainable production and proper waste management practices would maintain the required nutrients for high quality soil as well as improved water and air quality, so firms are able to obtain a premium from their high quality products while enhancing the ecosystem which eventually has a positive effect on society. Of course, the development of the PBB industry is not a panacea and might not reduce all the social and environmental problems encountered in Appalachia or other regions; indeed, there may be other niche products that could be more beneficial, thereby lending themselves to future research using the framework proposed here.

Acknowledgment

Funding for this research was provided by a USDA, ARS Multistate Cooperative Research Agreement. The helpful input of Tom Griggs, Don Lacombe, and Tim Phipps in this study is gratefully acknowledged.

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