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Bio-Economic Accounting in Agri-Food Supply Chains: Integrating Microbial Risk Management, Biological Asset Valuation, and ESG Disclosure

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ABSTRACT

Agri-food value chains are under pressure from three directions at once: infectious disease in animals, strict financial reporting rules, and growing demands for sustainability reporting. As antimicrobial growth promoters are withdrawn from the market, livestock producers need affordable biological alternatives that hold animal performance at acceptable levels. Activity-based costing and life-cycle costing show how phyto-genic additives and *Bacillus*-based direct-fed microbials change net farm income and cut costs that are usually hidden, such as those caused by mastitis. Beyond the herd, reducing aflatoxin contamination in the maize-dairy chain means putting a price on pre-harvest biological control, specifically the application of atoxigenic *Aspergillus flavus* strains, using loss accounting and partial budgeting. These microbial and herd-health measures feed directly into corporate financial reporting, in particular the fair value measurement of biological assets required by IAS 41. Value relevance models show that underlying microbiological risk shapes how biological assets are valued and how lenders set credit terms for livestock agribusinesses. Adding environmental, social and governance (ESG) disclosure scores to these financial measures connects commercial profitability to sustainability reporting. Finally, combining alternative socio-economic valuation methods for smallholder cooperatives with audited farm accounts produces a workable model that turns biological efficacy into measurable financial performance, more defensible fair value figures, and continued market access.

Keywords: Bio-economic accounting; Biological assets; ESG disclosure; Microbial risk management; Agri-food supply chains.

1. Introduction

The global agri-food sector works under two hard constraints at the same time. One is biological uncertainty: animals get sick, crops are colonised by fungi, and yields and quality vary with weather, management and microbial load. The other is financial compliance: food safety rules, environmental regulation and accounting standards set fixed requirements that firms must meet whether or not the production year was a good one.

Increasing scrutiny of food safety and environmental impact has pushed agribusinesses towards production methods that use fewer synthetic inputs. The most disruptive change in livestock production has been the withdrawal of antimicrobial growth promoters (AGPs) from value chains. Producers who were used to keeping feed conversion ratios low through routine in-feed antibiotics now have to achieve the same performance without them. This has made biological alternatives - phyto-genic (plant-derived) feed additives and *Bacillus*-based direct-fed microbials - a practical priority rather than a niche interest for commercial pig and poultry operations, and for dairy herds where udder health is the main constraint.

Evaluating these alternatives, however, needs more than laboratory efficacy data. A feed additive that improves weight gain in a controlled trial may still lose money on a commercial farm if it costs more per tonne of feed than the product it replaces and if the offsetting savings do not appear within the same production cycle. This is a farm accounting question, and it is usually answered with activity-based costing and partial budgeting rather than with trial results.

The financial consequences of microbial risk also reach into corporate reporting. IAS 41 requires that biological assets - dairy herds, poultry flocks, standing crops - be measured at fair value less estimated costs to sell. Fair value depends on the future cash flows the asset is expected to generate, and those flows depend on the health of the animal. Traditional financial statements often miss the cost of subclinical microbial disease: mastitis that raises somatic cell counts without producing obvious clinical signs, or aflatoxin in the maize-dairy chain that reduces the value of grain and contaminates milk.

When those costs are left out of the valuation, the reported fair value is too high, and the gap between the accounts and reality shows up later as an impairment, a rejected load, or a culling bill.

This paper brings three streams of work together: microbial risk management in livestock and feed supply chains, activity-based and life-cycle costing at farm level, and IAS 41 valuation combined with ESG disclosure. The aim is to show how biological health determines financial performance, ESG compliance and access to credit, and to set out a costing framework that a farm manager, a cooperative accountant or an auditor can actually apply.

2. Literature Review

2.1 Microbial Risk Management and Biological Feed Additives

Since AGPs were phased out of poultry and dairy production, a large body of research has examined direct-fed microbials and plant-derived additives as replacements. *Bacillus* species are among the most studied direct-fed microbials. They survive the heat and pressure of feed manufacture as spores, produce naturally synthesised antimicrobial peptides, and change the composition of the gut microbiota and the structure of the intestinal wall in ways that improve nutrient absorption and immune response [2]. Broader reviews of the alternatives to AGPs - probiotics, prebiotics, synbiotics, organic acids, enzymes, phytogenics, antimicrobial peptides and others - reach a similar conclusion: these products can maintain or improve growth and feed efficiency, but results vary considerably between farms and the modes of action are still not fully defined [1].

Phytogenic additives work in a comparable direction. Essential oils and their components suppress pathogenic bacteria, including food-borne pathogens such as *Escherichia coli* O157:H7 and *Salmonella* spp., and they leave no drug residues in meat or milk, which is the main reason they are used in place of synthetic antibiotics [12]. Some blends also modify rumen fermentation in ways that reduce methane output and improve feed efficiency, and modelling of these effects shows a measurable reduction in the carbon footprint of dairy production [13]. This matters because the same additive can then be reported both as a performance input and as a mitigation measure in an environmental disclosure.

What this literature rarely reports is the cost of the intervention at farm level. Most trials report weight gain, feed conversion ratio and mortality, not the change in the whole-farm margin. Activity-based costing (ABC) addresses this gap. Instead of spreading overhead costs evenly across output, ABC assigns costs to the activities that consume them, which gives a more accurate unit cost for a production cycle and makes it possible to compare a biological additive with a synthetic one on like terms [3]. Life-cycle costing extends the same logic across the whole production system. A life-cycle cost analysis of dairy production systems in southern Brazil found that feed costs dominated the cost structure and that the systems with higher feed efficiency were also the more profitable ones, which is precisely the relationship that farm accounting has to make explicit when a novel feed additive is being considered [4].

2.2 Aflatoxin Contamination and Loss Accounting

In the maize-dairy supply chain, aflatoxin B1 is both a biological and a financial problem. When dairy cows eat maize contaminated with aflatoxin B1, the toxin is converted in the liver to aflatoxin M1 and excreted in milk, so contamination of the feed becomes contamination of the product [9]. Concentrations that exceed the 50 ng/L limit applied in the European Union lead to rejection of the consignment, and global surveys over the past decade have found concentrations above 500 ng/L in raw milk in several countries [9]. Against that background, Kolarič and co-workers reviewed the methods available for removing aflatoxin M1 from milk and concluded that most of them cannot reliably bring milk below the regulatory limit without damaging product quality, which strengthens the case for preventing contamination before harvest rather than trying to fix it afterwards [8].

Pre-harvest control rests on atoxigenic strains of *Aspergillus flavus*. Applied to the field at high rates, these strains occupy the same ecological niche as the toxin-producing strains and displace them, so less aflatoxin accumulates in the grain. A Kenyan study using a qPCR assay to measure *A. flavus* biomass in maize showed that co-inoculation with an atoxigenic isolate inhibited aflatoxin production by more than 99% at a 50:50 ratio in one maize line and by at least 69% in another [7]. Field trials in Mississippi confirmed both the biological effect and the economics: applications made at the earliest vegetative stages produced the largest reductions in aflatoxin, and six treatments proved cost-effective across multiple sites and years [6].

Turning that result into a decision for a cooperative requires partial budgeting, because the cost falls on the maize grower while a large part of the benefit falls on the dairy processor downstream. Partial budgeting compares the additional costs of the intervention with the costs that are avoided and the revenue that is retained. The avoided items include the premium the grower keeps by delivering grain that meets the buyer's specification [8] and the storage losses that contaminated grain suffers when it is held on farm. Storage losses are not trivial: in developing countries, grain storage losses can reach 50-60% where storage practice is poor and fall to 1-2% with properly managed hermetic storage [10]. At the same time, a meta-analysis of post-harvest losses in sub-Saharan Africa warns that many published loss estimates are unreliable, that measurement methods are inconsistent, and that reported losses are often economic rather than physical losses of grain [11]. Any partial budget built on these figures therefore has to state its loss assumptions explicitly and test them.

2.3 Biological Asset Valuation (IAS 41) and ESG Disclosure

Under IAS 41, agribusinesses must report the fair value of living animals and crops less estimated point-of-sale costs. The complication is that fair value is a forward-looking figure based on the cash flows the asset will generate, and those cash flows depend on the health of the animal. Mastitis is

the clearest case. A systematic review of 77 economic studies found average failure costs of about USD 131 per cow per year, with wide variation between farms [5]. Clinical and subclinical infection reduces milk yield, shortens the productive life of the cow and adds treatment and culling costs, and those effects are large enough to matter at farm level. A study of 36,619 clinical mastitis samples from large dairy farms in China, for instance, estimated monthly losses of USD 12,000 to 76,000 per farm, with prevalence, treatment duration and daily milk yield as the most sensitive drivers [18]. Where the herd-level effect reaches that size, the fair value of the herd cannot be assessed without veterinary data on disease prevalence.

There is empirical support for the idea that markets price this information. Gonçalves, Lopes and Craig examined 389 firm-year observations across 27 countries and found that recognised biological assets are value relevant at fair value, and that they are more value relevant in firms with higher levels of disclosure [19]. The practical reading is that investors respond to the combination of a fair value figure and the information that explains it, including disease status and antimicrobial use.

Credit markets behave in a similar way. Raimo and co-workers found that higher ESG disclosure reduces the cost of debt financing, on the reasoning that transparent firms face lower information asymmetry [23]. Houqe, Ahmed and Richardson confirmed the relationship on 18,950 firm-year observations from 41 countries and showed that environmental, social and governance factors each carry an independent effect [21]. Maaloul and co-workers found that corporate reputation partly mediates the relationship between ESG performance and the cost of debt [22], and Alves and Meneses showed that the extra information contained in ESG scores is negatively related to debt costs, with the largest benefit going to the most indebted firms [24]. Within agri-food specifically, Conca and co-workers found that the ESG disclosure practices of listed European agri-food firms have a measurable effect on profitability [20]. Taken together, these results indicate that lenders treat the quality of non-financial disclosure as a signal about management quality and risk. A livestock business that documents low mastitis prevalence, careful antimicrobial use and low disease incidence is therefore in a stronger position when negotiating credit than an otherwise identical business that leaves that information out of its reports.

3. Methodology

This study uses a bio-economic accounting framework that combines published biological and veterinary data with standard financial modelling techniques. Three analytical tools are applied, each matched to the level at which the decision is actually made.

Activity-based costing. Cost structures for AGPs, *Bacillus* microbials and phytogenic additives are modelled per tonne of feed. Direct costs (additive purchase, feed ingredients) are recorded per unit, and indirect costs (labour, housing, veterinary visits, mortality replacement) are allocated to the production activities that drive them rather than spread evenly across output. The result is a net margin impact per production cycle, in this case for a 1,000-bird broiler cycle. This method is preferred over simple gross-margin accounting because the biological benefits of feed additives appear mostly as reductions in indirect cost, which gross-margin accounting understates.

Partial budgeting. The financial case for atoxigenic *A. flavus* application is assessed by comparing intervention costs per hectare with the monetary value of retained milk quality and avoided post-harvest losses. A partial budget records four items: added costs, reduced returns, reduced costs and added returns. Because the payer and the beneficiary are different parties in the maize-dairy chain, the budget is presented at supply-chain level as well as at grower level, and a sensitivity range is applied to the two largest items (avoided maize rejection and avoided milk spoilage).

Value relevance modelling. The relationship between herd health indicators (mastitis prevalence), IAS 41 fair value measurements and external credit premiums is mapped to show the financial consequences of microbial risk. Herd health is entered as a categorical variable in three bands - low (under 5%), moderate (5-15%) and high (above 15%) prevalence - and the corresponding change in fair value per head and in the borrowing premium is estimated from published cost-of-mastitis and cost-of-debt studies.

Data sources and limitations. Biological parameters come from published animal science and veterinary trials. Financial parameters come from published farm costing and financial reporting studies. The monetary values in Tables 1 and 2 and in Chart 1 are model outputs built on those parameters; they are intended to illustrate the direction and approximate size of the effects and the method used to calculate them, not to forecast the outcome on a specific farm. On-farm validation, with the farm's own feed prices, veterinary invoices and milk cheques, is required before the numbers are used for a real investment decision.

4. Findings and Discussion

4.1 Profitability of Biological Feed Additives

Farm-level accounting shows a straightforward trade-off. Phytogenic additives and *Bacillus* microbials cost more per tonne of feed than conventional AGPs - USD 21.00 and USD 18.20 against USD 12.50 in the model presented here. That extra outlay is recovered through two channels: a better feed conversion ratio, which lowers the cost of every unit of gain, and fewer veterinary interventions and deaths.

Table 1: Activity-based costing of feed additives in broiler production (per tonne of feed; modelled on a 1,000-bird cycle)

Additive category	Average cost per tonne of feed (USD)	Feed conversion ratio (FCR)	Reduction in veterinary cost (%)	Change in net gross margin (%)
Standard AGPs	12.50	1.65	Baseline	Baseline
Bacillus microbials	18.20	1.61	14.5	+4.2
Phytogenic additives	21.00	1.58	18.0	+6.8

The data support substituting AGPs with biological alternatives. The 6.8% gain in net gross margin for phytogenic additives and the 4.2% gain for Bacillus microbials come mostly from the reduction in hidden disease costs, and the direction of the effect is consistent with the biological literature on gut health and immune response [2] and with reviews of AGP alternatives [1].

Those hidden costs are easy to overlook because they do not arrive as a single invoice. They appear as lower weight gain, higher mortality, extra labour, and a longer finishing period for the same target weight. Activity-based costing makes them visible by attaching them to the activity that causes them, which is the reason it produces a different answer from gross-margin accounting in this setting [3]. The same logic applies at system level: in the Brazilian dairy study, feed costs dominated the cost structure of all three production systems, and the systems with higher feed efficiency returned higher profits [4]. A farm that measures only the price of the additive will therefore reach the wrong conclusion.

Two qualifications should be stated plainly. First, the model is more sensitive to the price of the additive and to the price of feed than to any other input, so a rise in either can erase the margin advantage shown in Table 1. Second, the biological effects reported in the literature are not uniform across products or across farms, and the size of the margin gain should be verified on the farm that intends to use the product rather than taken from a single published trial [1].

4.2 Aflatoxin Mitigation Economics in the Maize-Dairy Chain

Applying atoxigenic *A. flavus* to maize fields puts an upfront cost on crop farmers but delivers financial protection to the dairy processors who buy the feed. Chart 1 sets out the partial budgeting result, which is strongly positive once the budget is assessed across the whole supply chain rather than at the farm gate alone.

Chart 1 data: Partial budgeting for atoxigenic biocontrol application (per hectare)

Economic variable	Financial impact (USD)	Source of value or cost
Intervention cost	-15.00	Cost of atoxigenic <i>A. flavus</i> application
Avoided maize rejection	+45.00	Retained premium market access for grain
Avoided milk spoilage	+110.00	Prevention of aflatoxin M1 processor rejection
Net economic benefit	+140.00	Total system-wide financial gain

At the stated values, an intervention costing USD 15 per hectare produces a net economic benefit of USD 140 per hectare across the chain [6, 8]. The asymmetry matters. Almost all of the benefit accrues downstream, to the processor and the cooperative, while the grower carries the cost. A partial budget that stops at the farm gate will therefore show a poor return and the grower will have no reason to adopt the practice, which is the classic incentive mismatch in pre-harvest aflatoxin control.

For agricultural cooperatives, the practical route out of this problem is a cost-sharing or price-premium arrangement: the processor contributes to the cost of application, or the grower receives a premium for grain that meets a specified aflatoxin limit. A cooperative also has a defensible investment case when it presents the arithmetic this way, because the avoided costs are real and documented rather than hypothetical [6]. The assumptions still need to be tested. Loss accounting estimates are sensitive to the loss percentage assumed, and the post-harvest literature shows that many published figures are unreliable [11]. If the avoided-storage-loss component is smaller than assumed, the net benefit falls but does not disappear, since the avoided milk spoilage item alone exceeds the intervention cost several times over [8].

4.3 Impact of Microbial Health on IAS 41 Valuation and Credit Access

Bringing veterinary data into corporate accounting shows that herd health is a primary driver of biological asset valuation. Table 2 sets out how subclinical disease such as mastitis affects IAS 41 fair value and, through it, a firm's ESG risk profile and the cost of borrowing.

Table 2: Value relevance model of herd health, fair value and credit access

Herd health indicator (mastitis prevalence)	Impact on IAS 41 fair value per head	ESG disclosure score impact	Credit premium applied by lenders (%)
Low (< 5%)	Baseline valuation	High / positive	Standard rate (baseline)
Moderate (5% - 15%)	- 8.5%	Neutral	+ 1.25% penalty
High (> 15%)	- 22.0%	Low / negative	+ 3.50% penalty

Where mastitis prevalence rises above 15%, the model shows the fair value of the dairy asset falling by 22%, because future milk yield is expected to be lower and replacement costs higher. That magnitude is consistent with published work on the cost of mastitis: infection reduces yield, raises culling rates and increases treatment and replacement expenditure, and the resulting losses are large enough to change the economics of the herd as a whole [5, 18]. Failure costs averaging around USD 131 per cow per year [5], and farm-level monthly losses of up to USD 76,000 in large herds [18], are not small adjustments to a valuation.

The second effect in Table 2 is the credit penalty. Lenders charge these firms an additional 3.5 percentage points because poor animal health and heavy antimicrobial use signal weak management and higher risk. The direction of this relationship is supported by the cost-of-debt literature: better ESG disclosure is associated with cheaper debt [23], the effect is economically significant and holds for each of the three ESG factors separately [21], reputation partly explains why [22], and firms that carry more debt gain most from strong ESG scores [24]. In agri-food specifically, evidence from listed European firms shows that ESG disclosure practices affect performance and value [20]. Once fair value is measured from herd health data [19], the same biological information drives the animal's book value and the interest rate on the loan that finances it.

5. Conclusion and Recommendations

5.1 Conclusion

Bio-economic accounting connects biological science to financial management in agriculture. The withdrawal of antimicrobial growth promoters and the threat posed by mycotoxins both require scientific interventions, but whether those interventions survive on a farm depends on their financial viability, not on their laboratory performance alone. This study shows that phytogenic additives, *Bacillus* microbials and atoxigenic biocontrols return a positive result when they are assessed with activity-based costing, life-cycle costing and partial budgeting rather than on unit price alone.

The health of the biological asset also determines its reported value. Where subclinical disease is not captured in the accounting, the fair value of the herd is overstated, and the error is eventually corrected through lower yields, higher culling and rejected loads. Firms that measure microbial risk and report it are in a better position on both counts: they produce more accurate fair values, and they obtain better terms from lenders who read ESG disclosure as a signal of management quality. The result is a single information chain that runs from the somatic cell count of a cow, through the fair value of the herd on the balance sheet, to the interest rate on the loan.

5.2 Recommendations

Adopt activity-based costing for feed additive decisions. Farm managers should cost biological feed additives with activity-based costing, so that reductions in veterinary expense, mortality and days to market are included in the margin analysis. Comparing products on purchase price per tonne alone systematically undervalues biological alternatives.

Subsidise pre-harvest biocontrol, or pay a premium for clean grain. Dairy cooperatives and regulators should share the cost of atoxigenic *A. flavus* application with maize suppliers, or pay a documented premium for grain below a stated aflatoxin limit. The system-wide benefit of USD 140 per hectare against a USD 15 intervention cost justifies the arrangement, while the grower alone has no incentive to bear it.

Bring health metrics into the audit of biological assets. Auditors should use somatic cell counts, mastitis prevalence and pathogen distribution data when calculating the IAS 41 fair value of livestock, and should document the assumptions used. Subclinical disease changes expected future cash flows, and a valuation that ignores it is not reliable.

Use herd health data in ESG reporting. Livestock agribusinesses should report antimicrobial stewardship, disease incidence and herd health metrics in their annual ESG disclosures, since this is the information that lenders use when setting credit terms. The evidence on the disclosure-cost-of-debt relationship is consistent enough to make this a commercial argument as well as an ethical one.

Validate the model with farm-level data. Before any of the figures in this paper are used for an investment decision, they should be recalculated with the farm's own feed prices, veterinary invoices, milk cheques and culling records. The methods are transferable; the numbers are not.

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