

Effect of Azolla Supplementation on Milk Yield and Feed Cost in Lactating Murrah Buffaloes

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ABSTRACT

Azolla, a floating fern that hosts a nitrogen-fixing cyanobacterium, is widely recommended as a home-grown protein supplement for dairy animals, and it is often said to raise milk yield and lower feed cost. This narrative review asks whether those claims are plausible for lactating Murrah buffaloes and how much weight the evidence can carry. It draws on published work on the biology, composition and safety of Azolla, on protein and fibre nutrition in ruminants, and on the design and statistics of feeding trials, and it reports no new data. Azolla is best viewed as a source of rumen-degradable nitrogen and minerals whose composition varies with species and growing conditions, so a response in milk is most likely where the basal ration is short of nitrogen and least likely where it is not. Claims of lower cost depend on whether pond construction, water, nutrients, daily labour, failed batches and testing are counted, and on whether cost is expressed per litre of milk. Common weaknesses of trials, notably few animals, short duration, the animal treated as the replicate when animals share a pen, and an undescribed basal ration, limit how far reported effects can be generalised. The review concludes that a positive but modest effect is plausible, that its size in buffaloes is not established, and it lists what a decisive trial and cost account would contain.

Keywords: Azolla; Murrah buffalo; Milk yield; Feed cost; Protein supplement; Ruminant nutrition; Narrative review

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1. Introduction

Feed is usually the largest single cost in milk production, and protein is the most expensive part of the ration [1]. For dairy farmers in South Asia, where buffaloes supply a large share of the milk and smallholders work with thin margins, the price of oilseed cake and compounded concentrate is a constant concern [2]. A protein source that a household can grow in a shallow pond beside the cattle shed is therefore an attractive idea, and Azolla has been promoted for this purpose for decades.

Azolla is a small floating fern that lives in a partnership with a nitrogen-fixing cyanobacterium inside its leaves [3]. It grows quickly in still, nutrient-enriched water, it has long been used as a green manure in rice fields [4], and its biomass is rich in protein relative to most forages [5, 6]. Those features explain why it keeps returning to the discussion of feed for livestock, and why it is recommended so readily.

What is less clear is what the plant does for a lactating buffalo and what it costs to do it. A claim that Azolla raises milk yield and lowers feed cost

has two parts, a biological one and an economic one, and each can fail independently. Milk may rise in a short trial and fall back in a full lactation; feed cost may drop on paper and rise once labour, water and losses are counted. This review sets out what is known about Azolla as a feed, what plausible routes lead from a bowl of fern to a litre of milk, what a fair cost accounting would include, and how much weight the existing evidence can carry. The aim is a fair account of what is known and what is merely repeated.

The article is a narrative review. It draws on published work on Azolla biology, ruminant protein nutrition and the design of feeding trials, and it deliberately reports no new data. Where the literature on buffaloes is thin, we say so, and we describe the evidence a convincing trial would need to supply, instead of quoting figures we have not been able to check against their sources.

2. Literature Review

2.1 Azolla as a Plant and as a Feed

The symbiosis between Azolla and its cyanobacterial partner, long called *Anabaena azollae*, supplies the fern with fixed nitrogen and lets it grow without nitrogen fertiliser [3]. This explains its use in paddy fields as a biofertiliser and, by extension, its protein content. Reviews of its biology and agronomy describe a plant that doubles its biomass quickly under favourable conditions, tolerates a wide range of temperatures when well managed, and needs phosphorus more than any other applied nutrient [3, 7].

Composition is not fixed. Work on two common species showed that growth and nutrient content change with water temperature, nitrogen and phosphorus supply, light intensity and pH [5], and later work on productivity and chemical composition found differences between species and with carbon dioxide level [6]. A farmer feeding Azolla from one pond in one season is therefore feeding a material whose protein, fibre and mineral content may differ from the figure on a leaflet. Trials in which the composition of the fed Azolla is not reported leave the reader unable to judge what was actually supplied. This is why the same plant can look excellent in one report and unremarkable in the next.

Azolla has been evaluated as a feed for fish [8], poultry [9] and pigs [10], as well as for ruminants. In vitro work with rumen liquor from goats has examined its nutrient composition, methane production and digestibility [11]. The monogastric literature is relevant mainly as a source of cautions: aquatic ferns contain fibre fractions that

non-ruminants digest poorly, and inclusion levels that suit one species do not transfer to another. Ruminants are better placed to use fibrous feeds, but that advantage is a reason to test Azolla in ruminants, not a finding.

2.2 Safety and Quality Concerns

Aquatic plants accumulate what is in the water around them. Azolla has attracted interest as an agent of phytoremediation precisely because it takes up heavy metals and other contaminants [12]. For a feed, the same trait is a hazard: Azolla grown in water polluted with metals, or in ponds fed by industrial or sewage inflow, can carry those contaminants into the animal and, in time, into milk. The water source is thus part of the feed specification, not a detail of husbandry.

A second concern is cyanobacterial toxins. Several cyanobacterial groups have been reported to produce the neurotoxic amino acid beta-N-methylamino-L-alanine [13], and Azolla carries a cyanobacterium inside every leaf. Whether the fern's symbiont produces such compounds in amounts that matter for feeding has been a question for some years, and a prudent reading is that the question deserves explicit testing in any programme that feeds Azolla regularly, rather than being assumed away or assumed to be a problem. Table 1 compares Azolla with a conventional protein supplement on the points that matter for such a decision.

Table 1. Azolla compared with a conventional oilseed-cake supplement.

Attribute	Fresh Azolla (pond-grown)	Oilseed cake (purchased)
Supply	Grown and harvested on the farm	Bought from a trader or mill
Protein	Substantial on a dry basis, varies [5, 6]	High and fairly consistent
Dry matter	Low, mostly water	High
Main cost	Labour, water, pond and nutrients	Purchase price
Quality control	Variable; needs testing [12]	Standard grades, label claims
Safety questions	Water source, metals, cyanobacterial toxins [12, 13]	Storage moulds, adulteration

Note: Qualitative comparison. Azolla values vary with species, water and season; no figures are given because they depend on the batch.

2.3 Protein Nutrition of the Lactating Ruminant

A ruminant does not simply absorb the protein it is fed. Dietary protein is degraded in the rumen to peptides, amino acids and ammonia, which

bacteria use to build microbial protein; the amount that escapes degradation supplements the microbial supply [14, 15]. Microbial growth needs fermentable energy as much as nitrogen, and when ammonia is released faster than it can be captured, the surplus is lost in urine [16, 17]. A feed that is high in degradable nitrogen therefore helps only when the ration provides enough fermentable carbohydrate to use it.

The classic reviews on dairy protein nutrition show how modest the returns can be when protein is added to a diet that already meets requirements [15, 18]. The practical lesson is that the effect of a protein supplement depends on the diet it is added to. A buffalo on a poor basal ration of straw and a little concentrate may respond to extra protein quite differently from one on a balanced ration with good forage. A report that Azolla raised milk yield means little unless the basal ration, and its protein and energy supply, are described.

Intake and digestion matter as well. Fibre fractions determine how much a ruminant can eat and how quickly the feed leaves the rumen [19, 20], and the physical and metabolic controls on intake are central to how much milk a cow or buffalo can produce on a given ration [21]. Volatile fatty acids from fermentation provide most of the ruminant's energy [22], and the composition of the rumen microbial community responds to diet in ways that can be slow to settle [23]. Any change of feed needs an adaptation period, and a trial that measures too early may record the disturbance rather than the effect. A rumen that has been given time to adapt behaves differently from one that has not.

2.4 Buffaloes and Their Milk

Buffaloes differ from cattle in several ways that matter for feeding trials: they are often kept on low-quality roughage, they are well adapted to fibrous feeds, and in smallholder systems they are fed from what the household can gather or buy [2]. Standard requirement tables were developed for dairy cattle [24], and applying them to buffaloes involves assumptions that are rarely stated. Milk yield also follows a characteristic lactation curve that rises to a peak and declines [25], so the stage of lactation at which animals enter a trial can influence the apparent effect as much as the diet does.

Buffalo milk is generally richer in fat and total solids than cow milk, and in many markets the price paid to the producer reflects that richness [2]. A feed that shifts the fat or protein concentration therefore affects income as well as

volume, and a trial that reports only litres leaves part of the economic story untold. Composition can respond to the forage-to-concentrate balance and to rumen fermentation pattern [21, 22], which is a further reason to describe the whole ration.

2.5 Feed, Land, Water and the Wider Debate

The attraction of Azolla also rests on wider arguments about how livestock are fed. Much of the feed given to livestock could in principle be eaten by people, and a shift towards co-products and non-food biomass is widely seen as desirable [26]. Estimates of the environmental impact of animal products are large and vary greatly between producers [27], and the water footprint of feed crops is a substantial part of the total [28]. Livestock systems also differ in how efficiently they convert biomass to food and in the emissions they produce [29].

Azolla grows in water, however, and a protein feed that saves land may still use water. Production also needs phosphorus and, in warm climates, management against pests and temperature extremes [7]. The case for Azolla on environmental grounds is therefore plausible but conditional, and it should be argued with measured inputs, not assumed. Wider reviews of the future supply of animal-derived protein stress that alternative feed sources must be judged on the whole system [30]. Enteric methane is another consideration, and the mitigation literature is clear that effects seen in vitro need confirmation in animals before they can be counted on [31, 32].

2.6 Producing and Handling Azolla on the Farm

Azolla is a crop with its own husbandry. Accounts of its cultivation describe shallow, shaded and regularly topped-up water, a phosphorus source, periodic removal of part of the mat so that growth continues, and protection from heat and pests [3, 7]. The farmer who adopts it therefore becomes a grower of aquatic plants as well as a keeper of buffaloes, and the quantity harvested depends on how well that second job is done. Biomass yield and composition vary from farm to farm for the same reason [4, 5].

Handling matters as much as production. Fresh material carries water and pond debris and is usually washed before feeding; some farms mix it with concentrate to encourage intake, and some dry it, which changes the labour, the storage need and perhaps the nutrient value. Whatever the practice, introducing a new feed gradually is sensible for the rumen [16, 23], and a trial should state the form in which Azolla was fed, because

fresh and dried material are different products for the purposes of comparison.

3. Materials and Methods

3.1 Scope and Question

The review asks a single question in two parts: does supplementing lactating Murrah buffaloes with Azolla plausibly raise milk yield, and does it plausibly lower the cost of feed per unit of milk? The question was divided into the sub-questions that a trial would have to answer: what the animals were fed, how the Azolla was produced and characterised, how milk and intake were measured, how the design handled differences between animals and across the lactation, and how cost was calculated.

3.2 Literature Assembly

The review draws on peer-reviewed work in four areas: the biology, composition and safety of Azolla; ruminant protein and fibre nutrition; the structure of buffalo milk production and of feeding trials; and the wider literature on feed resources and environmental impact. Sources were chosen for relevance, citation in the field and the clarity of their methods. Studies of other species are used for what they teach about composition, safety and limits, not as evidence of effects in buffaloes.

We did not run a formal systematic search and we do not claim one. This is a narrative synthesis, and the choice of sources reflects the authors' judgement. The practical consequence is that the review is a better guide to what a good trial should contain than to the exact size of any reported effect, and it avoids quoting figures from individual buffalo trials that could not be checked against the primary papers for this article.

3.3 Appraisal Framework

To judge how far a report can be trusted, we used a short framework with four questions. Is the experimental unit the animal or the pen, and does the analysis match [33, 34]? Is the study large enough to detect a plausible effect, given what is known about the reliability of small studies [35, 36]? Are results reported as estimates with intervals instead of only as significance tests [37, 38]? And is cost accounted for completely, with each input priced? Table 2 lists the cost components we looked for.

Table 2. Cost components to record in an Azolla feed-cost analysis.

Component	What to record	Easily overlooked?
Pond or tank	Materials, lining, shade net, expected life	Often
Water	Volume, source, pumping or carrying	Often
Nutrients	Phosphorus, manure or other inputs	Sometimes
Labour	Hours to harvest, wash and feed, priced at local wage	Very often
Failed batches	Share lost to heat, pests or contamination	Often
Testing	Metals and microbial checks of the fern	Rarely done
Concentrate saved	Dry-matter basis, at the price paid	Rarely stated

Note: The last column is the authors' judgement of how easily an item is overlooked when a saving is claimed, not a measured frequency.

4. Results

4.1 What Azolla Offers a Lactating Buffalo

The composition studies describe a feed that is rich in protein and minerals, moderate in fibre and high in water when fresh [5, 6, 8]. For a ruminant on a basal ration of straw and concentrate, that protein is mostly degradable, so its value depends on the energy that accompanies it [14, 16]. Azolla can thus be best thought of as a source of rumen-degradable nitrogen and minerals, not as a bypass protein, and the response to it should be largest where the existing ration is short of nitrogen and smallest where it is not.

Fresh Azolla is mostly water, and a buffalo has finite capacity. A kilogram of fresh fern contributes far less dry matter than a kilogram of concentrate, so replacing concentrate with fresh Azolla on a weight basis is not a like-for-like swap. Reports that do not state whether Azolla was given fresh or dried, and on what dry-matter basis it replaced the concentrate, cannot be compared with one another [11, 20]. Such differences are small individually, but they accumulate across a lactation.

4.2 Plausible Routes to Higher Milk Yield

Several routes from Azolla to milk are plausible (Figure 1). If the basal diet is short of degradable nitrogen, extra nitrogen can raise microbial protein synthesis and hence the protein and energy supplied to the udder [14, 16]. If the minerals in Azolla correct a deficiency, milk may respond for reasons unrelated to protein. If Azolla improves palatability or intake, more of every

other nutrient is consumed [21]. And if it changes the rumen environment, digestibility of the basal ration may rise or fall [20, 23].

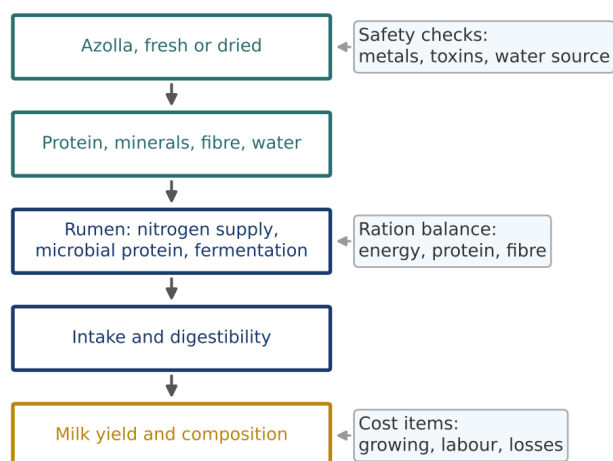


Figure 1. Routes from Azolla to milk and the checks that surround them (schematic, not data).

Each route predicts something different. Nitrogen-limited responses should be strongest on poor rations and fade as protein supply approaches requirement. Mineral-driven responses should appear whatever the protein supply and should vanish once the mineral gap is closed. Intake-driven responses should show up in dry-matter intake records. A trial that reports only a change in milk yield cannot say which route was at work, and so cannot say whether the result would transfer to a farm with a different ration. Read this way, absence of effect in a small trial is not evidence of absence.

The shape of the response is also uncertain. Feeding trials of protein supplements in dairy cattle typically show diminishing returns, and at high levels of a poorly matched feed, production can fall [15]. We therefore expect a rise followed by a plateau, and possibly a decline at high inclusion (Figure 2); the figure is a schematic of that expectation, not a plot of data. Most reports test only one or two inclusion levels, which cannot reveal the shape.

4.3 Feed Cost: What Must Be Counted

Claims of lower feed cost depend on what is included in the sum. The price of the Azolla itself is not a market price: it is the cost of building and maintaining a pond or tank, of the water and fertiliser it consumes, of the labour of harvesting and rinsing it daily, and of the production lost when a batch fails. Each of these is real even when it does not appear in a purchase ledger. Table 2 lists them, and a cost comparison that leaves out the ones that are hard to price will tend to flatter the fern. A cost advantage that disappears when

labour is priced is not an advantage a hired worker would see.

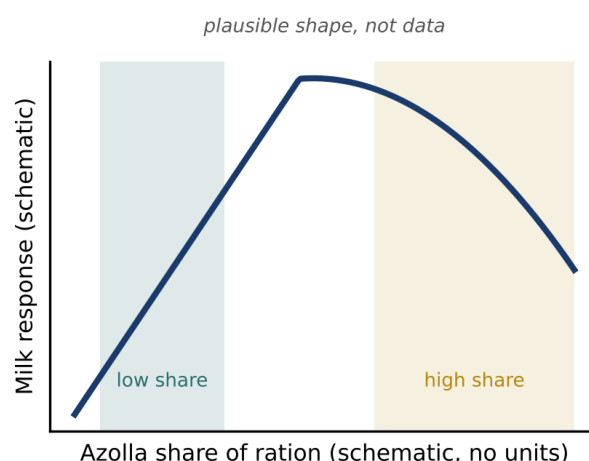


Figure 2. Expected shape of the response to inclusion level (schematic of a plausible pattern, not data).

The comparison also needs the right denominator. Cost per animal per day is not cost per litre of milk, and neither is the change in income over feed cost unless the price of milk is stated. The fat and protein content of buffalo milk matters for the price farmers receive, so a trial that shifts milk composition changes revenue as well as volume. Reports that give only a feed-cost figure, without milk yield and composition on the same animals over the same period, cannot establish an economic gain.

The labour component deserves emphasis. Azolla must be harvested, washed to remove contaminants and fed regularly, and in a smallholder household that labour is often family labour that is never paid for. A cost advantage that depends on treating this work as free is fragile, and it may not survive a change in household circumstances or scale.

Because the cost components move independently, a fair analysis presents a range instead of a point. A best case might assume free water and unpriced family labour; a base case would price labour at the local wage; a worst case would add purchased water and a share of failed batches. A saving that survives all three scenarios is robust, and one that exists only in the best case is not. Presenting the three side by side costs the authors of a trial little and gives the reader what is needed to judge transfer to a different farm.

4.4 Quality of the Evidence

Reports on Azolla in dairy animals commonly share a set of design limitations (Table 3). Animals are few, trials are short, and the animal is treated as the unit of replication even when animals share a pen, which inflates the apparent precision [33, 34].

Small studies in any field produce unstable estimates and tend to overstate effects when they reach significance [35, 36]. These problems are shared with much of applied animal science, and Azolla is not special in having them; they matter here because the case for the fern rests almost entirely on this kind of study.

Table 3. Common weaknesses of feeding trials and what follows from them.

Weakness	Consequence	Remedy
Few animals	Unstable, exaggerated effects [35]	Adequate numbers; report intervals
Animal as replicate in a shared pen	Overstated precision [33, 34]	Analyse at the unit fed
Short duration	Adaptation and lactation curve confounded [25]	Adaptation period; follow the lactation
Basal ration not described	Cannot judge transfer [24]	Report nutrient supply
Azolla not characterised	Dose unknown [5]	Report composition, dry matter
Partial cost accounting	Flatters the fern	Price every input

Note: Weaknesses are those discussed in the cited methodological literature; they are not attributed to any single study.

Statistical practice compounds the problem. Results reported only as significant or not significant discard the size of the effect, which is what a farmer needs, and a p-value is not the probability that an effect is real [37, 38]. Repeated measurements on the same animals through a lactation need models that respect their correlation, and with small numbers the choice of method for degrees of freedom affects the conclusion [39]. Where several outcomes are examined and only those that reach significance are discussed, the chance of a spurious finding rises. The point is not that a trial is poor, only that its result travels less far than its abstract suggests.

Stage of lactation is an under-appreciated source of bias. Because milk yield declines predictably after the peak [25], a trial that compares animals at different stages, or compares before and after without a control, will see changes that have nothing to do with the diet. Balanced allocation, or adjustment for stage and parity, is therefore essential. Where the same animals receive each treatment in turn, a washout period is needed to prevent carry-over from the previous diet. Figure 3 sketches how reports thin out as they are held to each appraisal question.

Put plainly, the literature supports only a cautious statement. Azolla is a protein- and mineral-rich

feed that ruminants can eat, the case for a response in milk yield is biologically plausible, and the case for a saving in feed cost depends on how the fern is produced and priced. The size of any effect in Murrah buffaloes is not established by evidence we can cite with confidence, and the best summary is that it is likely to be positive and modest where the ration is short of nitrogen, uncertain elsewhere, and dependent on the economics of production. That is a modest claim, and it is the one the evidence will currently bear.

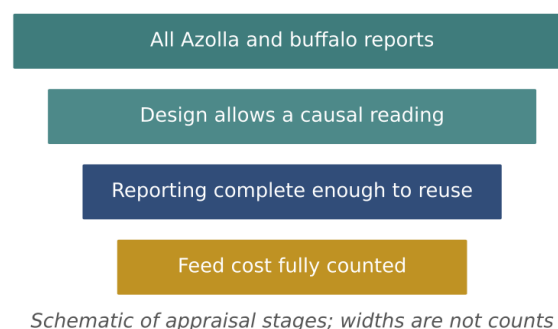


Figure 3. Schematic of appraisal stages; widths are not counts.

4.5 Reading a Claim of Benefit

A reader meeting a claim that Azolla improved milk yield can ask a short sequence of questions. What did the control animals eat, and in what amounts of dry matter? What replaced what, and on which basis? How many animals or groups were compared, and how was uncertainty reported [37]? Was intake recorded, since a change in intake can explain a change in milk without any special property of the fern [20, 21]? A report that answers all four is rare, and one that answers none should be read as an observation, not as evidence of effect.

Herds differ in genotype, parity, stage of lactation and management, and an effect found in one is not automatically expected in another. Methods that combine many trials in dairy nutrition treat the variation between studies as a result to be explained, not a nuisance to be averaged away [40, 41]. For Azolla, where trials are few and small, between-study variation cannot yet be separated from chance, and the honest summary is a range of plausible effects instead of a single number.

Claims about the environment need the same scrutiny. Reducing the competition between livestock feed and human food is a legitimate aim [26], but a feed that is grown in a pond still uses water, nutrients and labour, and its net benefit depends on what it replaces [29, 30]. Statements that Azolla is sustainable are best replaced by

measured inputs and outputs for the system in which it is used.

5. Discussion

5.1 Interpretation and Practical Reading

The main finding of this review is a conditional one. Azolla is most likely to help where the existing ration is limiting in degradable nitrogen or minerals, and least likely where the ration is already adequate. That fits what is known about dairy protein nutrition in general [15, 18], and it implies that the question for a farmer is not whether Azolla works but what is missing from the ration it would join. Nothing in this reading argues against feeding Azolla; it argues for measuring what happens when it is fed.

The second conditional is economic. Whether Azolla lowers cost depends on scale, labour, water and the price of the concentrate it replaces. A household with spare labour, a reliable water source and expensive concentrate may gain; one that must buy water or hire labour may not. The same arithmetic can come out differently on neighbouring farms, which is why a single trial in a single herd can mislead readers on both sides of the argument.

A third point concerns safety. The regular feeding of an aquatic plant that accumulates contaminants [12] and carries a cyanobacterial symbiont [13] calls for sensible precautions: a known and clean water source, periodic testing of the fern for metals, and attention to milk quality. These do not argue against the practice. They are the routine controls any new feed should pass, and they are cheap compared with the cost of a contamination problem in milk. These points apply with equal force to any novel feed, not only to Azolla.

Three findings would change this reading. A well-designed trial showing a clear and persistent rise in milk yield on a ration already adequate in nitrogen would suggest that Azolla works through a route other than protein supply, and would call for work on minerals or on the rumen. A cost analysis that included every item in Table 2 and still showed a saving on typical smallholdings would settle the economic case for those settings. And evidence of contaminant or toxin transfer to milk under realistic feeding would require the safety question to be moved to the front of any advisory message [12, 13].

5.2 Limitations

This is a narrative review and shares the limitations of that form. The selection of sources reflects judgement, no formal search or quality

scoring was done, and the review does not quote numerical results from individual buffalo trials, because these could not be checked against the primary reports for this article. A reader who needs an effect size should consult the original studies directly, applying the appraisal questions above, or wait for a formal systematic review with meta-analysis, which methods exist to support [40, 41].

The review also draws on evidence from other species and from in vitro work, which are imperfect proxies for lactating buffaloes. Composition studies describe the fern, not the animal, and non-ruminant studies describe animals with a very different digestive system. We have used them to frame hypotheses, and the conclusions should be read in that light. Reviews of this kind are more useful when they say where the evidence stops than when they smooth it over.

5.3 Implications for Trial Design

A trial that could settle the question would use enough animals to detect a modest effect, with the pen or group as the unit of analysis if animals share feed [34]. It would balance animals for stage of lactation, parity and yield before the trial, hold the basal ration constant and describe it fully, state the composition of the Azolla and how it was produced and fed, and allow an adequate adaptation period. It would test more than one inclusion level, so that the shape of the response can be seen, and it would record intake, milk yield, milk fat and protein, and body condition.

On the economic side, the trial would record every input used to grow the fern and price each one, report cost per litre of milk with milk composition and price stated, and report uncertainty around the difference instead of a single figure [37]. It would also follow animals for a full lactation or a long enough part of one to show that the response persists. These requirements are demanding, but they are the ones that distinguish a result a farmer can use from one that only supports a hunch.

5.4 Directions for Future Work

Three needs stand out. First, a formal systematic review with a transparent search and quality appraisal of ruminant trials, ideally with a meta-analysis that accounts for between-study differences [40, 41]. Second, well-powered trials in buffaloes with the design features above and a full economic accounting. Third, work on the safety of regularly fed Azolla in dairy animals, including contaminants and cyanobacterial toxins in the fern and, where relevant, in milk [12, 13].

5.5 Practical Reading for Advisers and Smallholders

For an adviser, the sensible position is neither to dismiss Azolla nor to promise results. A household that wishes to try it can do so as a small, recorded pilot: a group of animals receiving it alongside a comparable group that does not, in the same shed and on the same basal ration, with milk yield, milk composition, intake observations and body condition noted in the same way for both. Records of the hours spent and the inputs used are as important as the milk records, because the economic question cannot be answered without them [1, 37].

Such a pilot is not a substitute for a trial, and it should not be reported as one. It can nonetheless tell a household whether the practice is workable on its own farm, whether the pond and labour fit its routine, and whether any change in milk is large enough to notice against the ordinary variation between animals and months. Its value lies in local decision-making, and the broader question of effect size will be settled by designed trials and by systematic synthesis of their results [25, 41].

6. Conclusion

Azolla is a plausible feed for lactating buffaloes, rich in protein and minerals and cheap to produce under the right conditions. The evidence, as we can responsibly summarise it, does not yet establish how large its effect on milk yield is, or how much it saves, in Murrah buffaloes. What the literature does show is when the effect should be largest, what a fair trial and cost account would contain, and which safety checks should accompany routine feeding. Readers should treat claims of large gains with caution until they meet those standards.

For the practitioner the message is practical rather than discouraging. Azolla can be tried, provided the water is clean, the fern is tested, the ration is described and the costs are written down. For the researcher, the opportunity is a set of trials in buffaloes that are large enough, long enough and fully costed to turn a plausible idea into a measured result that smallholders can rely on.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

L.W. conceived the review and wrote the sections on buffalo production and feed economics. F.S. wrote the sections on feed composition and safety. L.D. wrote the sections on ruminant nutrition and trial design. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No animals were used and no ethical approval was required.

12. Data Availability

No new data were generated. All sources are cited in the reference list.

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