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Reframing the Utility of Azolla as a Protein Supplement in Cattle Farming Systems

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Abstract

The *Azolla* is a rapidly growing aquatic fern that has gained more and more interest as a possible source of protein to cattle, especially in small-scale and resource limited production. Although endowed with good nutritional qualities, there has been conflicting empirical evidence on its efficacy, thus creating polarized judgments regarding its usefulness. In this paper, we state that this great inconsistency can be greatly attributed to how *Azolla* has been framed and assessed conceptually in the literature. The literature has mostly evaluated *Azolla* as an alternative to traditional protein concentrates, a method which in most cases fails to inform on-farm feeding practices and system level limitations. In order to fill this gap, the paper will reposition *Azolla* as a protein supplement instead of a protein substitute and suggest a multi-lens utility model, which covers nutritional, economic, and system-level dimensions. The paper, through a systematic synthesis of the available evidence, establishes that the central contribution of *Azolla* is to increase protein adequacy, partially replacing bought feeds, and increasing system resilience in the context of low cash, low land, or low-quality feeds. The discussion reveals the reasons why *Azolla* is more inconsistent in its case when analyzed within the replacement-oriented models and defines the situations when the supplementation-based use is most likely to deliver any significant benefits. This reframing, that is, the reorientation of the evaluative emphasis towards system efficiencies and risk management, offers a more consistent point of departure of explaining the existing literature and informing future studies. This paper finds that *Azolla* use in cattle farming is not universal, but conditional and that context-specific experimental designs and extension strategies are essential.

Keywords: *Azolla*; cattle nutrition; protein supplementation; alternative feed resources; smallholder livestock systems; feed cost reduction; system-level evaluation

Introduction

Protein availability has become one of the most intractable limitations to cattle production systems especially in smallholder and semi-intensive production systems where the cost of feeds is the major factor to overall production costs (Leng, 1990; Van Soest, 1994). Traditional sources of protein, including oilseed cakes, commercial concentrates are becoming increasingly exposed to price volatility, supply chain shocks, and competition with human food systems. These pressures have heightened the desire to focus on alternative and local sources of proteins that can partly replace the reliance on bought feeds.

One such option is *Azolla* - a rapidly growing aquatic fern - which has received considerable research and extension literature. Due to a high crude protein content on a dry

matter basis, high biomass build up, and the low input needs *Azolla* has been suggested as a potential source of protein to cattle on numerous occasions. There have been mixed results with many experimental studies and on-farm demonstrations reporting improvements in milk products and feed efficiency, no or negative effects on intake and performance. Consequently, the value of *Azolla* in cattle diet is still debatable with findings across the research and production sites being quite diverse.

On further review of this literature, it is found that much of the inconsistency is not due to the inherent properties of *Azolla*, but rather can be explained by how its presence in cattle diets is conceptualized and assessed. A large percentage of the current research evaluates *Azolla* as an immediate substitute of standard protein concentrates, commonly in relatively large amounts and throughout brief experiments (Van Soest, 1994). These methodological conveniences can be insufficiently indicative of how *Azolla* is implemented - or might be deployed best - when it comes to farming system resources that are resource-limited. Practically, farmers do not often aim at entirely replacing the established sources of proteins with *Azolla*; rather, they use it to a certain extent to buffer deficiency of feeds or to lower the amount of cash spent or to increase the nutritional value of low-protein basal diets.

This experimental/real-world disconnection is significant in terms of its implications (Chatterjee *et al.*, 2013; Kumar *et al.*, 2012; Reddy *et al.*, 2009). When *Azolla* is viewed based more on substitute than on supplement, its performance is measured against the indicators that might blur its more realistic and cost effectively applicable contributions. This means that potential system level advantages - akin to a partial cost replacement, less risk, and enhanced adequacy of proteins within times of lowering scarcity - can be underestimated or completely ignored.

The aim of the given work is to fill this gap, by recasting the utility of *Azolla* in cattle farming systems. Instead of inquiring as to whether or not *Azolla* can be utilized in place of traditional protein sources, this paper explores how and within what limitations *Azolla* can be utilized as a protein supplement that reinforces the overall efficiency of the system. The paper aims to offer a more unified foundation on the analysis of the role of *Azolla* in cattle diets, and to explain why differing findings have been reached in the previous studies. Such reframing would be aimed at more context sensitive research designs, more practical feeding plans and extension suggestions in future.

Overview of *Azolla* as a Feed Resource

Botanical and Agronomic Characteristics

Azolla is a small free floating aquatic fern which is common in the tropics and subtropics. It is also marked by a quick vegetative growth, whereby biomass can increase by a factor of two or more with favourable conditions in a few days (Pillai *et al.*, 2002). One of the most remarkable facts about *Azolla* is that it is symbiotically related to nitrogen-fixed cyanobacteria that allows accumulating the nitrogen rich biomass without using any synthetic fertilizers. The same attribute explains its relatively good protein composition and its extensive use over time as part of the integrated farming systems especially in rice

agroecosystem.

Agronomically, *Azolla* can grow in shallow water bodies like lined pits, ponds or tanks under simple management systems. It uses less land, minimal labor and less capital. Post-soil factors that affect growth performance include availability of water, temperature, exposure to light and balance of nutrients; where maximum productivity is normally achieved at warm temperatures and at neutral to slightly acidic pH levels. These properties have made *Azolla* attractive as an on-farm biomass source in areas where there are limited land and cash resources.

Nutritional Profile Relevant to Cattle

Azolla has an average crude protein content of about 20-30 percent on a dry matter basis though the content varies with species, growth conditions, and the stage of harvest (Ghosh and Rana, 2016; Alalade and Iyayi, 2006). The protein fraction contains various essential amino acids making it possibly a useful supplementary protein source to ruminant diets. Besides protein, *Azolla* biomass comprises of minerals including calcium and phosphorus and iron and trace elements along with a range of fibre and ash. Similar nutritional content and feeding capabilities have been reported in non-ruminant animals such as broilers and ducks and support the expanded applicability of *Azolla* as an inexpensive yet high-protein nutritional source in production systems (Basak *et al.*, 2002, Becerra *et al.*, 1995, Prabina and Kumar, 2010).

Nevertheless, *Azolla* has a very high moisture value when picked fresh that is usually over 90 percent (Van Soest, 1994). This restricts its contribution to dry matter consumptions unless it is fed in large amounts or dried partially before feeding. The fibre proportion is typically low relative to traditional forages and some secondary compounds and cell wall constituents can affect palatability and digestibility at high levels of inclusion.

All in all, the nutritional content of *Azolla* indicates that its main role in cattle nutrition is to supplement protein levels, but not act as a source of bulk energy or roughage. The heterogeneity in composition between systems of production also underscores the need to view *Azolla* as a context-specific feed resource, as opposed to a standardized ingredient.

Review of Existing Literature on *Azolla* in Cattle Diets

Studies Reporting Positive Outcomes

An extensive literature indicates positive effects of addition of *Azolla* in the cattle feed, especially in protein supplementation and reduction of feed costs. Experimental and on-farm studies report increases in milk yield, milk composition, or feed ratio with the inclusion of *Azolla* at low to moderate inclusion levels (Chatterjee *et al.*, 2013; Kumar *et al.*, 2012). Such effects have frequently been ascribed to the fairly good proportion of crude protein in *Azolla* and its role in alleviating protein deficiencies in low-quality basal diets, which are dominated by crop residues or mature grasses.

Besides parameters of production, there are also studies, which cite economic advantages, in terms of a decrease in the utilization of purchased protein concentrates when

Azolla is grown and nourished on the farm. Such partial substitution, in smallholder settings, where feed expenditure represents a significant share of total production costs, has been linked with better net returns, and not with absolute productivity improvement. Such findings have been more eminent in systems with sufficient water supply, and low opportunity costs of family labor (Reddy *et al.*, 2009).

Studies Reporting Limited or Negative Outcomes

However, other studies demonstrate little or contradictory impacts of *Azolla* addition on cattle performance, and there are even negative results (Reddy *et al.*, 2009; Ghosh and Rana, 2016). Leeper feed consumption, low palatability and non-significant changes in milk production, weight gain have been noted particularly on inclusion of *Azolla* at high proportions or as a primary protein substitute. Digestibility limits and unequal distributions of nutrients have also been listed among the contributory factors.

These results are more often observed in controlled feeding experiments which seek to replace normal protein sources extensively and in the course of short term experimental periods. Here, the excessive moisture levels of the fresh *Azolla*, the possibility of anti-nutritional factors, and low provision of energy density in the diets might limit the animal performance. Some authors have determined that the practical usefulness of *Azolla* as cattle-feed is doubtful, especially in more intensive production systems, based on these findings.

Methodological Patterns and Limitations in Existing Studies

When analysed together, the conflicting findings of the literature disclose distinct methodological trends. A large number of research studies assessing *Azolla* in dairy diets have an experimental design that focuses on a large inclusion rate or direct substitution of commercial protein concentrates. These designs are frequently designed to focus on biological performance measures, such as milk yield or growth rate whilst minimal focus is directed towards outcomes of the economy or system constraints.

The duration of trials are often brief, which diminishes the possibility of recording adaptive feeding behaviour, longer-term intake control, or accruing economic outcomes (Leng, 1990). Furthermore, the heterogeneity of *Azolla* species, production, and processing (wet versus dry) and the composition of the basal diet adds to the heterogeneity that makes it more difficult to compare across studies.

Importantly, little research clearly adjusts its appraisal requirements to how *Azolla* is most extensively embraced by farmers - as an additional input added gradualistically to enhance protein sufficiency or minimize feed costs. This non-correspondence of experimental framing and practical application is one of the major constraints of the current literature and forms the foundation of re-visiting the utility of *Azolla* in a more context-specific way.

The Conceptual Fault Line: Replacement vs Supplementation

Although the accumulating body of research in the area of *Azolla* as a cattle feed resource has been growing, much of the discussion about its efficacy can be linked to a fundamental conceptual gap: is *Azolla* being considered a substitute to the traditional protein

sources, or merely an addition to the current feeding system? This difference although not explicit, carries a lot of implications on the design of experiments, interpretation of findings as well as practical recommendation.

Under a replacement-based model, *Azolla* would be placed as a direct competitor to existing protein concentrates e.g. oilseed cakes or commercial compound feeds. Researchers who have followed this method normally evaluate the performance of animals with a relatively high level of inclusion and predict that *Azolla* would also serve a similar role in nutrition. Although those designs provide definite performance standards against which one can compare them, they are also associated with strict performance requirements, which might not be consistent with the biological and physical properties of *Azolla*, especially its high levels of moisture and poor energy contribution. When compared in these conditions, *Azolla* is often compared by standards that are optimized to the use of dry, energy-dense protein feeds, and this is likely to give an unfavourable or inconclusive result.

In comparison, a supplementation-based approach considers *Azolla* as a component of supplementation that would help increase the nutritional sufficiency of basal diets but not to substitute them completely. In most smallholder systems and semi-intensive systems the diets of cattle are not limited by actual availability of feed but rather by the limitations of particular nutrients in the diets - the most important one being protein - in the low-cost forages and crop residues. In these circumstances, modest amounts of protein laden biomass can result in significant changes in rumen performance, nutrient usage and system efficiency (Leng, 1990; Leterme and Munoz, 2002). In this view, functional value of *Azolla* does not equate to commercial concentrates, but its ability to partially fill nutritional void with minimal money.

The preponderance of replacement-based assessments in the literature are partly due to methodological convenience and traditional norms of feed evaluation research. Such framing however clouds the context within which *Azolla* is most likely to be embraced and perpetuated. The farmers hardly aim at abandoning the traditional feeds, but they can improvisationally combine the new resources to cope with risk, spend less, and keep production unchanged despite the changing constraints. The conclusions would be underestimated when *Azolla* is not used to represent this adaptive logic in the experimental designs or portray incorrectly in which conditions it is most useful.

It is important to understand that this conceptual fault line is the key to interpreting the available evidence and to future research. The results of evaluations based on a supplementation framework are more likely to be sensitive to system-level impacts that are important to producers, such as displacement of feed cost, seasonal resilience, and local labour and resource fit. Based on this, it would be more logical to rebrand the role of *Azolla* as supplementation, rather than replacement, to offer a more consistent foundation to the evaluation of the impact it has on cattle farming systems, and help remove much of the perceived contradiction in the existing results.

A Reframed Utility Model for *Azolla*

In order to get beyond polarized judgments of the effectiveness of *Azolla*, the effects

it has on cattle nutrition need to be considered in a framework reflecting simultaneously biological functionality, economic rationality and system constraints. In this section, a repackaged utility model is suggested, building on the idea of *Azolla* not as a feed ingredient in its own right, but a situationalized protein supplement whose value is produced at the fringe of limited production systems. This model is designed around three lenses that are interrelated, namely nutritional utility, economic utility, and system-level utility.

Nutritional Utility Lens

In nutritional terms, the most significant potential of *Azolla* is its ability to supplement the dietary protein intake, but not replace the total protein intake. At low to moderate inclusion rates, *Azolla* has the potential to complement protein-deficient basal diets and promote better rumen microbial activity, especially in systems which depend on low-quality forages or crop residues. In this case, small increments in the supply of nitrogen may cause an excessively large enhancement in the use of nutrients (Leng, 1990).

Nonetheless, the nutritional value of *Azolla* is a given limit. Its moisture content is high, so it contributes less to the intake of dry matter, and its inclusion is excessive, leading to a decrease in intake or nutrient imbalance. Therefore, it is best that *Azolla* is utilized as a complementary input in a balanced ration in which its protein intake augments the functionality of the current feed constituents instead of trying to substitute them. This reframing does not focus on consideration of maximum inclusion levels, but rather on determining the best supplementation levels that are in line with animal needs and feeding behaviour.

Economic Utility Lens

Cost dynamics are more precise measures of *Azolla* economic value than absolute productivity measures. Most of smallholder systems do not aim to maximize the milk yield level or growth rate but to obtain an acceptable production effect with the minimal cash cost possible. *Azolla* helps towards this goal by partially replacing bought protein feeds with locally grown biomass grown with a minimal amount of outside input.

In this perspective, *Azolla* supplementation success must be measured based on feed cost per unit output as opposed to measuring output on its own (Reddy *et al.*, 2009). The net margins and financial risk can be enhanced even in the case where animal performance is not affected by spending less on commercial concentrates. This view can be used to understand the logic behind why *Azolla* adoption might continue with farmers even with small or unreliable biological responses in controlled trials.

System-Level Utility Lens

The interaction of the availability of resources, allocation of labour and the risk of production determines the relevance of *Azolla* at the system level. It is especially successful in the environment with the access to the water, limited land, and low opportunity cost of the family labour. *Azolla* is used in these environments as a scalable input, which can be increased or decreased, based on seasonal lack of feed or price variations or temporary

revenue limitations.

Notably, this utility at the system level is not universal in the production situations. The relative advantage of *Azolla* is less in systems that are more intensive with high costs of labour, where the formulation of the ration is strongly constrained, and where they use standardized feeds. This re-conceptualized model hence focuses more on conditional utility and not universal applicability, such that evaluation criteria is in line with the reality of the heterogeneous cattle farming system (Pillai *et al.*, 2002).

Implications for Practice and Research

Conceptualizing *Azolla* as protein supplement in limited cattle production systems has practical implications on its use, research and marketing. This section will translate the proposed utility model into practical implications to the farmers, researchers, and extension and policy actors with the focus on the correspondence between evaluation criteria and actual decision-making in the real world.

Implications for Farmers

The first implication to farmers, especially small farmers, is the necessity to re-adjust their expectations of *Azolla* in cattle diets. Not as an alternative to conventional protein concentrates, but as a supportive feed, *Azolla* can be rolled out with low to moderate inclusion rates. It is most useful in enhancing protein adequacy in basal diets when there is a shortage of feed or when the cost of the concentrate is high.

The practical feeding options are to feed *Azolla* with current forages or crop residues, either fresh or partially dried to decrease moisture content. Complementing *Azolla* with other feeds can help increase the consistency of consumption and reduce palatability challenge that comes with increasing the proportion of *Azolla*. Cultivation of *Azolla* should also be perceived by farmers as a risk-managing mechanism - a mechanism that increases nutritional resilience and decreases cash-based inputs dependence - and not as the way towards a quick rise in productivity.

Implications for Researchers

To the researchers, the reframed utility model demonstrates the need of balancing the experimental design with the functional role that *Azolla* would most probably perform in farms. In feeding tests, partial supplementation situations are more valuable than complete replacement design and a series of levels of inclusion should be tested that represent feasible on-farm conditions. Prolonged periods of trials might be required to record adaptive feeding reactions, seasonal and compounding financial impacts.

The outcome measures must not be limited to the usual production measures to capture the feed cost per unit of output, variability in performance and responsiveness to fluctuations in input prices. More focus on the composition of the basal diet, processing procedures, and local production specifications would also enhance comparability among studies. These changes would enable research results to enhance the decision-making of farmers as well as the extension advice.

Implications for Extension and Policy

In the case of extension services and policy initiatives, the most important implication is that there should be context-sensitive promotion of *Azolla*. The extension message must not pitch *Azolla* as a general-purpose replacement of commercial protein feeds but rather focus on its purpose as an inexpensive, low-cost complement to production settings. Adoption outcomes can be improved and disillusionment can be diminished by identifying and targeting farmer segments that are most likely to benefit - like those with chronic feed shortages, or high concentrate costs.

The support of the policy can hardly be more efficient than those that are dedicated to the capacity-building interventions, such as the training in the *Azolla* cultivation and implementation into the established feeding systems, and not just blanket promotion. Extension and policy efforts can better capture the comparative advantage and constraints of *Azolla* by providing a wider strategy to strengthen feed system resilience.

Conclusion

This controversy about the usefulness of *Azolla* as a protein source to cattle has continued to exist due to a lack of consistent experimental evidence and the polarizing conclusions throughout the literature. This article will contend that this inconsistency is not as much a result of the inherent nutritional restrictions of *Azolla* as much as it is the result of the way that its role has been constructed and assessed. Performance expectations when evaluated as a substitute product on the basis of its principal use as a substitute to traditional protein concentrates are not in keeping with the physical, nutritional or practical properties of the *Azolla* product.

A more consistent perception of the value of *Azolla* can be achieved by refraining that it is a protein supplement and not a protein substitute. With a nutritional, economic, and system-level perspective, *Azolla* can be identified as a marginal yet significant contribution to the nutritional and economic landscape of improving protein availability, substituting some of the bought feeds, and adding to the sustainability of the resource-limited cattle production system. This view can be used to unify the seemingly conflicting results of earlier research, and advise why *Azolla* introduction continues to be utilized in some production settings despite small or unpredictable biological reactions.

Notably, such reframing leaves the appraisal emphasis on the definitive productivity gains, as well as on the system efficiency and risk control. The most visible impact by *Azolla* is whereby cash, land or feed quality limits viability of traditional sources of protein. On the other hand, it becomes less relevant in highly intensive systems, where diets are highly optimized, labour costs are high. This conditional utility is important in the prevention of overpromising and unjustified rejection of *Azolla* as a feed resource.

In sum, no longer is it a question of whether or not *Azolla* is a viable protein source to cattle, but when, to what extent, and to what production systems it provides a significant benefit. A future research and practice grounded within this context-sensitive framework

offers a more rational direction of what is realistically evaluative, adoptive, and more workable conclusions that can be made concerning the role of *Azolla* in cattle nutrition.

Future Research Directions

Future studies of *Azolla* as a source of cattle feeds would be complemented by designs that clearly indicate its use as a supplementary input in limited production systems. To better represent adaptive intake responses, seasonal changes and cumulative economical outcomes, long-term feeding trials conducted with low to moderate inclusion levels using various bases diets are requisite. This type of research would give stronger evidence on the best supplementation levels and long-term effectiveness of supplementation.

A comparison of the effects of processing *Azolla* through various manipulations, including fresh versus partially or mixed with other rations, would help define the impact of moisture level and manipulation on intake, digestibility and labour needs. Cross-study comparability and synthesis would also be improved with increased standardization of reporting of cultivation conditions, species or strains used and nutrient composition.

Lastly, it would be reasonable to incorporate system-level indicators, such as the feed cost volatility, labour allocation, and risk exposure, within experimental and modelling strategies so that future studies can be more adept at aligning biological outputs with farmer-relevant decision metrics. This would enhance the evidence base of context-sensitive recommendations and facilitate more subtle evaluations of the role that *Azolla* plays in various cattle production systems.

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