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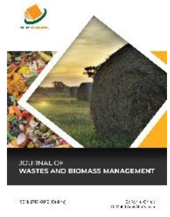

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RESEARCH ARTICLE

AZOLLA: POTENTIAL BIOFERTILIZER FOR INCREASING RICE PRODUCTIVITY, AND GOVERNMENT POLICY FOR IMPLEMENTATION

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ABSTRACT

Rice is the staple food for the significant population of Asia. Due to projected population growth in this region, the demand for this food is also predicted to be increased exponentially soon. Nitrogen (N) plays a dominant role in increasing rice yield as it is the most critical yield-limiting nutrient of rice. Chemical N fertilizers which are a major source in supplying N nutrients to rice, have adverse effects on overall soil and environmental health in the long term. The application of free-floating aquatic fern *Azolla* as a biofertilizer can be an alternative to improve rice yield without degrading the environment. It provides a natural source of many nutrients, especially N, improves the availability of other nutrients, plays a critical role in weed suppression, enhances soil organic matter, and improves efficiency of the inorganic fertilizers while maintaining the suitable soil pH condition for rice growth, which overall contribute to rice yield increment. Therefore, *Azolla* application has tremendous potential to improve soil health and boost yield sustainability.

KEYWORDS

Azolla, Biofertilizers, Rice, Sustainability, Yield.

1. INTRODUCTION

Asia, the most populated region globally, has been facing pressure to increase the yield of its primary staple food, rice. Moreover, the United Nations has projected population growth to be highest in most regions of Southeast Asia by the end of 2050 (United Nations, 2019). A group researchers mentioned that yield per land increment or expansion of cultivated land of rice could increase rice production (Molotoks et al., 2018). However, due to the lack of favorable land excluding forest area, it is almost impossible to expand cultivated land (Saito et al., 2019). Thus, a significant focus now lies in increasing yield per land, contributing highly to nutrient availability. Macronutrients Nitrogen (N) is critical yield-limiting nutrients of rice (Saito et al., 2019). Chemical N fertilizer plays a dominant role in supplying the nutrient requirement of rice is in Asia (Safriyani et al., 2020).

About 80% of supply is met by urea as a source of N fertilizer. However, in flooded conditions, any forms of chemical N fertilizer are prone to nutrient loss (Ghosh and Bhat, 1998). In addition, Continuous use of chemical fertilizer results in adverse environmental and health consequences in the long run (Yang et al., 2021a). Similarly, presented the decline in rice yield with time as a long-term effect of urea resulted from low Nitrogen use efficiency (NUE) (Ladha et al., 2000). Inefficient use of N fertilizers on irrigated rice and negative balances of potassium (K) were reported as the crucial reasons for rice yield growth decline in intensive irrigated rice farming (Dobermann et al., 1998; Dobermann, 2000).

Organic amendments have a positive role in vigorous crop growth and yield enhancement (Amanullah et al., 2016). Therefore, global interest in these substances as alternatives and supplements to chemical N fertilizers has been raised. Soil organic matter affects the soil's biological, chemical, and physical properties and overall health. It facilitates soil fertility by providing other mineral nutrients through mineralization, improving overall soil productivity (Zhao et al., 2016). Low organic matter in soil is one of the major constraints for decreased rice yield in Asian soils (Islam et al., 2010). The use of organic fertilizers can be an excellent alternative to inorganic fertilization in crop production for sustainable agriculture (Amanullah et al., 2015).

The application of *Azolla* as a biofertilizer provides natural source nutrients and has tremendous potential to improve soil health and boost yield sustainability (Akhtar et al., 2020). *Azolla*, a free-floating widely distributed aquatic fern, offers significant potential as an N source in rice production. The importance of *Azolla* as organic manure in rice was first demonstrated in North Vietnam in the year 1957 and subsequently introduced in the USA, Indonesia, Japan, Philippines, China, and India (Wagner, 1997). As it can grow compatibly with rice in waterlogged conditions, its potential for a nutrient supplement for rice has been stressed (Subedi and Shrestha, 2015). *Azolla* can fix atmospheric nitrogen due to its symbiotic relationship with blue-green algae *Cyanobacteria.*

Bilobed leaves of *Azolla* lie overlapped, where dorsal leaves cavity houses *Cyanobacteria,* which fixes atmospheric nitrogen, and relatively thin ventral leaves provide buoyancy that remains partially submerged in water. The symbiont liberates a substantial amount of biologically fixed nitrogen as the host absorbs ammonia through branched hairs present in the cavity. Unbranched hairs transport fixed carbon from the host to the *Cyanobiont* (Peters et al., 1989). An average of 35-50 % ammonia fixed by the cyanobacterium is released to the field, and for this reason, *Azolla* is used as a biofertilizer in the rice fields (Pereira, 2017). Nitrogen fixation and a high growth rate can enable *Azolla* to accumulate more than 10 kg N ha^{-1} day^{-1}.

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Thus, it is extensively used as a suitable biofertilizer in rice fields, improving N within few weeks and contributing up to 40–60 kg N ha^{-1} per rice crop (Kannaiyan, 1993). Application of inoculated *Azolla* 300 kg ha^{-1} into the rice after transplanting showed increased rice yield equivalent to urea application of 100 kg N ha^{-1}. Besides N replenishment in the rice field, it improves soil organic content, enhances the availability of other macronutrients, curbs NH_3 volatilization, and suppresses weeds that play a significant role in rice productivity (Bhuvaneshwari and Singh, 2015). In contrast to chemical fertilizer, it is eco-friendly and acts as soil remediation (Palengara, 2021).

This aquatic fern is used as a basis of green manure and decomposed organic material, widely known as compost (Razavipou et al., 2018). Since *Azolla* has various contributions in increasing rice yield without degrading the environment while meeting the desired result, it is imperative to shed light on the contribution of *Azolla* biofertilizer. Thus, an intensive review on *Azolla* that improves rice yield was carried out with the following objectives: i) To know the effects of *Azolla* in various factors which contribute to yield improvement of rice ii) To know the role of *Azolla* in yield of rice improvement.

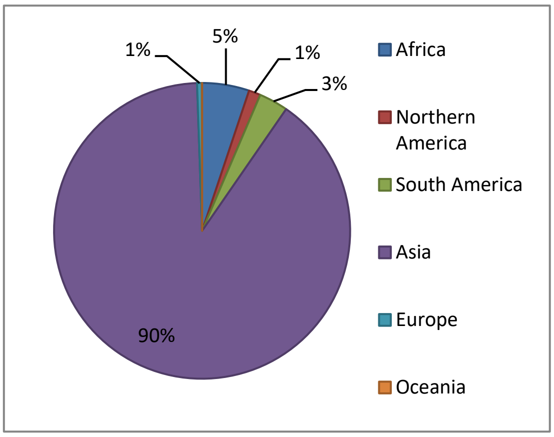

Figure 1: Rice production in world (Source: Using data of FAOSTAT 2019)

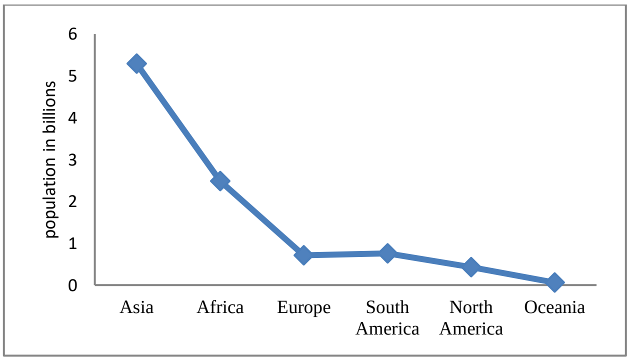

Figure 2: Projected population in 2050 (Source: Using World Population Prospects data – UN 2019)

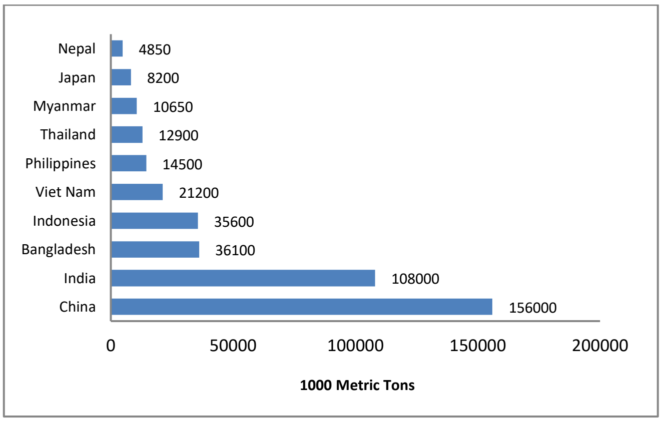

Figure 3: Milled Rice Domestic Consumption by Asian Country in 1000 MT (Source: Using data of United States Department of Agriculture – 2021)

2. Methodology

We collected information from more than 70 papers on the roles of *Azolla* in increasing rice yield. The collected information was arranged systematically under Headings, namely: Factors contributing to rice yield improvement, Contribution of *Azolla* in rice yield, limitations of use of *Azolla* in rice field, government policies to implement biofertilizers. Under the headings 'Factors contributing to rice yield improvement' subheadings: Soil organic matter content, availability of other mineral nutrients, Contribution of *Azolla* in weed suppression, nitrogen contribution, soil pH, increasing the efficiency of the inorganic fertilizers were listed. The research papers were collected from journal articles, proceedings, reports, and online internet sources.

Table 1: Distribution of *Azolla* spp. in Asia

S.N	*Azolla* species	Distribution
1.	*Azolla caroliniana*	Canton, Hong Kong
2.	*Azolla filiculoides*	China, Japan
3.	*Azolla pinnata*	Bangladesh, Burma, China, India, Indonesia, Japan, Korea, Malaysia, Nepal, New Caledonia, New Guinea, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam

Source: (Thomas A Lumpkin & Plucknett, 1980)

3. Discussion

3.1 Factors contributing to the rice yield improvement

3.1.1 *Soil organic matter content*

Azolla compost impact plant growth and yield positively and improve the organic matter in the soil (Gupta and Potalia, 1990). It maintains its reserve for a long time by releasing its content materials slowly, which provides advantages over raw, unrotted organic matter and chemical fertilizers (Kandel et al., 2020). The high organic C content of *Azolla* contributes to the increase in organic C. According to 90% of *Azolla* was degraded in 4 weeks (Watanabe et al., 1989). The *Azolla* that had been absorbed into the soil would shortly be mineralized. It would generate humic substances as a result of the mineralization process which would also yield soil organic C (Bhardwaj and Gaur, 1970). Some researchers found that incorporation of *Azolla* increased the organic matter and the rate of *Azolla* (Bhuvaneshwari and Kumar, 2013). It was reported that inoculation of *Azolla* built up a considerable soil organic carbon content (Setiawati et al., 2018; Setiawati et al., 2020). A group researcher finding suggested that *Azolla* and cow manure equal combination increased the soil organic C content ranging from 1.3– 1.7 % (Setiawati et al., 2018). Similarly, it was reported that *Azolla* treated soil oxidizable organic C increased 25.51% (Halder and Kheroar, 2013). Other researchers recorded a significant increase in the population of heterotrophic bacteria in addition to increasing cellulolytic and urea hydrolyzing activities (Kannaiyan and Subramani, 1992). Similarly, a study reported higher soil microbial populations of bacteria, fungi, actinomycetes, and higher enzyme activities in *Azolla* incorporated soil, increasing nutrient recycling in the soil (Krishnakumar et al., 2005).

Table 2: Composition of the Nutrients in different species of *Azolla*

Species	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Crude ash (%)
Azolla pinnata	20.4	3.33	15.5	17.2
Azolla Microphyll	20.2	3.5	15.8	16.3
Azolla filiculoides	19.7	4.2	10.3	18.5
Azolla rubra	19.0	4.1	14.2	15.5.
Azolla caroliniana	18.8	3.9	14.0	16.7
Azolla maxicana	18.6	3.8	15.1	17.2

Source: (Datta, 2011)

3.1.2 Availability of other mineral nutrients

Macronutrients Potassium (K), Phosphorous (P) are other yield-limiting nutrients of rice yield (Saito et al., 2019). *Azolla* has a remarkable ability to accumulate K in its tissues in a low K environment; it decomposes rapidly and releases nutrients N, P and K into the field after field water is drained (Bhuvaneshwari and Singh, 2015). It solubilizes Zinc (Zn), Iron (Fe), and Magnesium (Mg), making them available to the rice crop, and releases plant growth regulators and vitamins that promote the rice crop to grow faster (Bhusal and Thakur, 2021). Its continuous application increased the soil nutrient availability (Subedi and Shrestha, 2015). In general, the use of *Azolla* improves soil nutrient availability through biological activity, which also helps to build up the micro flora for mineralization. Mineralization is the process of decomposing organic compounds and releasing nutrients into the soil.

As a result, research suggests that *Azolla* need more P to develop properly (Rivai et al., 2013). However, when *Azolla* decayed, it released soil-available P into the soil (Watanabe et al., 1989). A study show result showed no significant difference at the beginning of available soil P in *Azolla* added paddy soils (Rivai et al., 2013). However, there was an 89% increase in *Azolla* added available soil P at rice panicle initiation. Similarly, found that P and Ca contents were also higher in *Azolla,* averaging 124.83 ppm and 345.3 mg/100g (Halder and Kheroar, 2013). A group researchers two subsequent year research similarly showed that *Azolla* treated soil showed a 29.12 % increase of K, and *Azolla* and cow dung treated soil showed a 42.94 % increase of P over the initial value (Dey et al., 2018). These findings show the positive results of integrated soil nutrient management practices, which are lacking in many Asian countries.

Table 3: Nutrient composition of *Azolla*

S.N	Constituents	Dry matter (%)
1	Ash	10
2	Calcium	0.4-1.0
3	Chlorophyll	0.34-0.55
4	Crude fat	3.3-3.6
5	Crude protein	14.0-30.0
6	Iron	0.06-0.26
7	Magnesium	0.5-0.65
8	Nitrogen	4.0-5.0
9	Phosphorus	0.5-0.9
10	Potassium	2.0-4.5
11	Soluble sugars	3.4-3.5
12	Starch	6.5

Source:(Salma & T, 2020)

3.1.3 Azolla in Weed suppression

Weed alone can reduce the Rice yield ranging from 15 – 20% and up to 50% in severe cases (Sureshkumar et al ., 2016). A thick *Azolla* mat in a rice field has the side benefit of suppressing weeds. *Azolla* covering water surface reduces light penetration of soil surface, resulting in the depreciation in the germination of weeds (70% of the weed). Thus, the growth of *Azolla* reduces aquatic weeds in flooded rice fields like *Echinochloa crus-Galli*, *Cyperus* sp., *Paspalum* sp. and so on and, therefore, lead to improved crop growth and productivity (Biswas et al., 2005; Monajjem and Hajipour, 2010). The degree of suppression increases with an increase in the percent of *Azolla* cover and water depth (Kalyanasundaram et al., 1999). Application of preassumed at 10 t ha^{-1} + *Azolla* at 1 t ha^{-1} recorded the least weed count and highest weed control index in rice crop, as the thallus growth formed a very thick mat on the surface of the water, curtailing the interception of light by weed seeds and seedlings (Gnanavel, 2015; Gnanavel and Kathiresan, 2002). A study reported that weeds were suppressed by 69 – 100% at rice flowering and 86 – 95 % at harvest depending upon weed species due to the use of the *Azolla* (Janiya and Moody, 1984).

3.1.4 Nitrogen contribution by Azolla

Nitrogen fertilization is one of the determining factors yields of grain in rice plants (Chaturvedi, 2005). *Azolla* would be easily decomposed in paddy fields and supply more N for rice growth (Raja et al., 2012). NUE and recovery of N by rice are very low as 10% and never exceeds 50% (Vlek and Byrnes, 1986). Loss from urea ranges from 11 –54% when it is broadcasted in a rice field after transplantation (Schnier, 1995). Thus, *Azolla* biofortification could be a potential approach to increase NUE in rice fields (Yao et al., 2018a). Lumpkin and Plucknett have stated that the association of *Azolla* and *Anabaena Azolla* can fix atmospheric N at a rate exceeding that of the legume Rhizobium symbiotic relationship (Lumpkin and Plucknett, 1985). The N-fixing capacity of *Azolla* has been estimated to be 1.1 kg N ha^{-1} day^{-1}, and this fixed N is sufficient to meet the entire N requirement of the rice crop within a few weeks (Lumpkin and Plucknett, 1980). *Azolla* compost is considered beneficial for urea fertilizer (Inubushi et al., 2014).

Azolla biofertilizer corporation increased the nitrogen recovery of the crop by 49 –64% and decreased N loss by 26 – 48% (Yao et al., 2018a). *Azolla* as green manure in waterlogged soil resulted in rapid mineralization with a release of 60 - 80 % of the N within two weeks (Ito and Watanabe, 1985). *Azolla filiculoides* incorporated in paddy soil in pots have the N fixation ability of 128 kg N ha^{-1} in 50 days (Tuzimura et al., 1957). *Azolla pinnata* incorporated in rice fields have an average N-fixing ability of 0.3-0.6 kg ha^{-1} day^{-1} (Becking, 1976). Similarly, Singh has reported the N-fixing ability of 2.3 ha day^{-1} in fallow paddy fields (Singh, 1980).

Farmers can manage around 30-60 kg N by incorporating *Azolla* at the rate of 16000 kg ha^{-1} in rice crops instead of supplying through N fertilizers, given the sustainability of soil health (Samal et al., 2020; Sanjay and Singh, 2020). A group researchers reported that symbiosis between *Azolla* and cyanobacteria supplied 30-60 kg ha^{-1} N fixation (Kollah et al., 2016). Inoculation of *Azolla* on flooded water decreases the NH_3 volatilization by 12–42% (Yao et al., 2018a). Basal application of *Azolla* at the rate of 10-12 t ha^{-1} enriches soil N content by 50-60 kg ha^{-1} and reduces 30-35 kg of N fertilizer requirement of rice crop.

Inoculation of green *Azolla* at the 500 kg ha^{-1} rate increases the soil N content by 50 kg ha^{-1} and reduces the nitrogen fertilizer by 20-30 kg ha^{-1} (Roy et al., 2016). A group researchers explained that *Azolla* grown in standing rice crop buffered soil N availability, absorbing available excess N in the early rice growth stage, and releasing N at a later stage, increasing NUE (Sisworo et al., 1990). Full *Azolla* cover on floodwater surface in rice field prevent the rapid increase of pH associated with urea hydrolysis, which indeed controls N volatilization; significant causes of low NUE (Kern and Vlek, 2007; Reddy et al., 1990). *Azolla* improves the N fertilizer efficiency (Macale and Vlek, 2004).

3.1.5 Soil pH

Soil pH influences myriads of soil biological, chemical, and physical properties and processes that affect plant growth and biomass yield (Neina, 2019). Slightly acidic to neutral pH of the soil in the field is a favorable environment for plant development since nearly all nutrients are available at this pH. Soil pH 6 is considered as a suitable conditions for rice growth (Abdul Halim et al., 2018). It was reported that in flooding condition, soil pH also increased simultaneously (Ding et al., 2019). Asghar found that incorporation of *Azolla* reduced the soil pH condition (Asghar, 2018). Similarly, findings suggested that application of *Azolla* maintained floodwater pH near to initial value compared to where *Azolla* was not incorporated (Zinov'ev and Sole, 2004; Kern and Vlek, 2007).

3.1.6 Increasing the efficiency of inorganic fertilizers

The influence of incorporated and associated *Azolla* allows better use of N and better conditions for assimilating other nutrients, thus improving crop nutrition (Samarajeewa et al., 2005). The physiological efficiency of *Azolla* N was significantly higher than that of urea N because the plants absorbed more N from the area than from the *Azolla* (Watanabe et al., 1989). The integrated use of organic and inorganic fertilizers is desirable to sustain crop yields and maintenance of soil health (Meelu and Singh, 1991; Prasanna et al., 2008). Adding chemical fertilizer to organic manure promotes the process of mineralization and thus increases nutrients in the soil (Hashimi et al., 2019).

Incorporation of the *Azolla* fern enables better use of the nitrogen added by the mineral fertilizer (Bhuvaneshwari and Singh, 2015; Manna & Singh, 1990). *Azolla* improves the N fertilizer efficiency (Macale and Vlek, 2004; Prasanna et al., 2004). The use of 86 kg N ha^{-1} and 1000 *Azolla* kg ha^{-1} application increased 15.54% rice growth, 25.49% yield and improved the N fertilizer agronomic efficiency (AE), agro-physiological efficiency (APE), utilization efficiency (UE), and N efficiency ratio (NER) in Indonesia (Safriyani et al., 2020). Ammonia volatilization (AV) from paddy fields is a principal pathway of N loss (Zhang et al., 2014).

Integrated use of N fertilizer reduction and *Azolla* cover markedly reduced AV and improved NUE compared with conventional N application rate (Kern and Vlek, 2007; Yao et al., 2018b). *Azolla* application in rice field significantly reduce NH_3 emission and enhance apparent nitrogen recovery efficiency (ANRE) without decreasing rice yield (Yang et al., 2021). *Azolla* has the ability to release the absorbed minerals through the process of mineralization during the decomposition. N and P, and other nutrients applied through inorganic sources are rapidly released back into the medium and made available for uptake by rice during grain development which might have been lost through the volatilization in absence of *Azolla* in the rice field, which increased the efficiency of the inorganic fertilizers (Subedi and Shrestha, 2015).

3.2 Contribution of Azolla in Rice Yields

Azolla application desirably affects plant growth and biological yield and increases OM, enhancing nutrient quality (Gupta and Potalia, 1990). *Azolla* incorporation in paddy fields increased grain yield, straw yield, caryopsis, and dry matter (Anjuli et al., 2004). Its incorporation increases the paddy yield by 8-14% (Yao et al., 2018a). The rice yield increases up to 13% when *Azolla* was used as a biofertilizer in rice crops (Watanabe, 1977). A study reported that *Azolla* application increased the yield components of rice (Kannaiyan and Rejeswari, 1983; Islam et al., 1984).

An increase in grain yields of rice from 14 - 40% has been reported, with *Azolla* being used as a dual crop and by 15-20 % being monocropping during the fallow season (Samal et al., 2020). A group researcher had reported the highest rice grain yield when the application of *Azolla* compost at 5.0% of soil weight, which was on average 13.8% higher than that of the non-amended control (Razavipour et al., 2018). Singh found that either the application of 30 - 40 kg N ha^{-1} through ammonium sulfate or incorporation of 8-10 t of *Azolla* ha^{-1} fresh produced the exact rice yield, 47% increase in grain yield over control (Singh, 1977).

A combination of *Azolla* with a lower dose of N in planted paddy fields gave a higher paddy yield. The judicious combination of *Azolla* and N provides a better yield (Singh, 1979). The rice yield can be increased by 36.6 -38% by using *Azolla* as a dual crop (Barthakur and Talukdar, 1983). *Azolla* dual cropping increases rice yield by 14-40% and 6-29% higher grain yield by growing *A. pinata* as a dual crop with rice (Moore, 1969; Le Van, 1963). The application of *Azolla* along with neem cake coated urea recorded the maximum grain yield of rice (Sukumar et al., 1988). These all findings show that the application of *Azolla* as a biofertilizer has positive and significant improvement in the rice yield.

3.3 Government Policies to implement biofertilizers

Many governments of Asian countries have implemented policies which have directly and indirectly supported in the biofertilizers implementation. The Indian government is advocating the use of biofertilizers by extending and providing subsidies. Through the National Project on Development and Use of Biofertilizers (NPDB), the Government of India has been encouraging the use of biofertilizers in agriculture (Ghosh, 2004). State level governments are also emphasizing the biofertilizers usages. The government of Odisha, for example, has trained farmers to utilize *Azolla* as a biofertilizers (Mishra and Dash, 2014). The government of Bangladesh has put forward the policies to support the production and implementation of bio-fertilizers. It has also supported the ongoing research on *Azolla* for wet land Boro rice: Mature technology (Goswami et al., 2014).

Similarly, Nepal's Agricultural Biodiversity Policy 2006 has emphasized on use of bio fertilizers (Amendment in 2014; Atreya, 2015). Countries; China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam government have shifted their focus in promoting sustainable agriculture, thus emphasizing the policies in biofertilizers promotion (Atieno et al., 2020). Thailand Institute of Scientific and Technological Research (TISTR) have selected and commercialized blue-green algae for use as biofertilizers. Over the last two decades, Thailand's biofertilizers research has been actively supported by BIOTEC and the Thailand Research Fund (TRF) (Damrongchai, 2000). China's policy "Action Plan for Zero Growth in the Application of Chemical Pesticides and Fertilizers," implemented in 2015, seek to cut chemical fertilizer use by at least 20% by 2020.

Biofertilizers promotion was recently added as a strategy in the 2013 National Development Plan for Bioindustry in China (Ruan et al., 2020). The government of China has assigned extension programs to promote biofertilizers to biofertilizers producer agencies (Atieno et al., 2020). Strategic Program on Development and Utilization of Biotechnology in Agricultural and Rural Development Until 2020 launched by Vietnam government in 2000 advocate the application of organic inputs like biofertilizers. This strategy is supported by policy frameworks with regulations on production, distribution and implementation of such bio-inputs (FAO, 2017). Philippines government has developed program to promote the use of *Azolla* incorporation instead of heavy incorporation of chemical fertilizer during rice production (Rosegrant et al.,1985).

3.4 Limitation of Use of Azolla in the rice field

Rice could not absorb all nutrients applied and increase the possibility of nutrient loss (Fageria and Moreira, 2011). Fageria reported 50-70% N loss through leaching, runoff, and denitrification (Fageria, 2014). Furthermore, some researchers reported that N physiological efficiency decreased as N fertilizer application increased (Eagle et al., 2001). Thus, the judicious application of the *Azolla* should be considered while applying it in the paddy field. The economics of using *Azolla* is fundamental because technology is very labor-intensive, and it is suitable for adoption in locations where farm labor is affordable. Sometimes, therefore, farmers may have little to no economic benefit in choosing *Azolla* over chemical fertilizer because the possible additional labor costs, irrigation of land resources, application of phosphate fertilizer, and pesticides may make *Azolla's* usage uneconomical (Kandel et al., 2020).

4. Conclusion

Nowadays, there is a major concern to meet the increasing demands of rice without degrading the environment and soil health in the long term. So, in recent times, most Asian countries governments have formulated policies advocating on use of biofertilizers. Considering these aspects, use of *Azolla* as a biofertilizers can be viable option for the rice producer as it increases rice productivity and also improves soil health sustainably. *Azolla* has the potential to suppress weed, increasing the availability of N, P, K, and other mineral nutrients, which all contribute to increasing the rice yield. *Azolla* biofertilizer has a tremendous ability to maintain suitable soil pH and fix organic C and N, improving mineralization, improving microbial activity, and status soil that can increase soil increase and ultimately enhance yield. Considering the agronomic benefits and reducing the urea (N-fertilizer) demand in the rice cropping system, *Azolla* could develop low-input cropping systems for rice production. However, before using *Azolla*, the economics of using *Azolla* should be considered because technology is very labor-intensive, and it is suitable for adoption in locations where farm labor is affordable. Sometimes farmers may have little to no economic benefit in choosing *Azolla* over chemical fertilizer because the possible additional labor costs, irrigation of land resources, phosphate fertilizer application, and pesticides may make *Azolla's* usage uneconomical. Thus, the economics of *Azolla* application in different farm conditions should be studied for better recommendation on using the *Azolla* as a potential biofertilizers for enhancing rice yield.

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