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ROLE OF AZOLLA AQUATIC MICROPHYLLA IN AGRO-ECOSYSTEM

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Abstract
Rapid urbanization and modernization contaminated the hydrosphere, lithosphere and atmosphere of the environment. Water and soil are contaminated with several inorganic chemical compounds (heavy metals, pesticides, fertilizers, etc.), and their removal is essential for environmental safety. Atmospheric concentration greenhouse gas (GHGs) such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are at their peak concentration and resulting in accelerated global warming. The problem of contamination in water resources, soil, and the atmosphere can be balanced through aquatic macrophytes Azolla. Agricultural soil fertility and ammonia volatilization can be managed through the application of Azolla in rice. The emission of GHGs from the agricultural system can also be checked through the Azolla application, special in the flooded rice agroecosystem. The present review highlights the Azolla promising approach in environmental remediation.

Keywords: Azolla; Agriculture; Rice; Global warming; Soil fertility.

1. Introduction
Population explosion, urbanization, industrialization, and modernization of agricultural system in the last few decades have added enormous pollutants in different spheres of the environment. Excessive application of fertilizers and irrigation with water contaminated from the industrial effluent result in agricultural soil pollution. The untreated industrial effluent of electroplating, steel-iron, paper-pulp, petroleum, textile, lathers, pesticide, pharmaceutical, paint, etc., industries polluted soil, and water resources. The untreated waste affects the food chain and result in human health risks. This industrial effluent as sources of several inorganic and organic pollutant and required economical removal approach. Removal of toxic pollutants from industrial wastewater through tertiary treatments approach can be achieved. Conventional approach such as electro coagulation is widely used for the wastewater treatment (Kumar and Sharma, 2019; Kumar et al., 2022)however production of secondary pollutants and high energy demand make it non-economical process (Che et al., 2020). Chemical precipitation, coagulation-flocculation, chemical oxidation and reduction, ultra filtration, reverse osmosis, ion exchange ,and advanced oxidation processes can also use for the treatment of wastewater but economic feasibility is challenge for the developing and non-developed countries. Therefore, there is need for low cost and environmentally friendly approach for the treatment of wastewater. Biological treatment approach such as phytore mediation is environment friendly and low-cost approach for the wastewater treatment. Phytoremediation can used for the removal of pesticides, organic pollutants, heavy metals, dyes, etc., from both contaminated water and soil(Mani et al., 2007; Nandakumar et al., 2019). Azolla can be used for the treatment of industrial wastewater and the treated wastewater can be used in irrigation. Azolla has great potential in wastewater treatment and it widely used as organic fertilizer in agricultural soil. This study we reviewed the role of Azolla in the agro ecosystem.

2. Perspective of Azolla in agricultural system
Apart from phytoremediation property, Azolla have nitrogen fixing capacity and therefore it is widely exploited as biofertilizer in rice fields(Kollah et al., 2016; Malyan et al., 2016; Pabby et al., 2003).

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Nitrogen fixing capacity is affected by several biotic and abiotic factors and Sood et al., (2012) quoted that heavy metals such as Zn, Ni and Cd inhibited or suppressed the nitrogen fixation potential of Azolla.Leaves of Azolla consist of chlorophylls for the and a colorless lobe to supply buoyancy. Nitrogenase enzyme is responsible for nitrogen in *Azolla-Anabaena* association(Yadav et al., 2021). Azolla is used as biofertilizers in India(Bharali et al., 2021; Bharati et al., 2000; Malyan et al., 2021; Ramessh et al., 2022), Bangladesh(Ali et al., 2012), Japan(Ali et al., 2015; Kimani et al., 2020), China(Xu et al., 2017) , Vietnam, Italy(Bocchi and Malgioglio, 2010), Indonesia (Mujiyo et al., 2016) and other rice growing countries. Weed affect the economical yield of rice and application of Azolla significantly reduced the weed problem which results in higher yield. Thick interconnect mat of Azolla in flooded rice inhibitor the growth of emerging weed(Prabakaran et al., 2022). Azolla have 5% of nitrogen, 0.5% of phosphorus, 0.65% of magnesium, etc. (Fig. 1) and such composition of nutrient make it respectable organic manure. Application of Azolla and its extract as green manure improve soil salinity buffer capacity and result in higher rice yield (Abou Hussien et al., 2020; Fagodiya et al., 2022; Ibrahim, 2021). Application of Azolla as biofertilizer has several advantages over chemical fertilizer (Table 1).

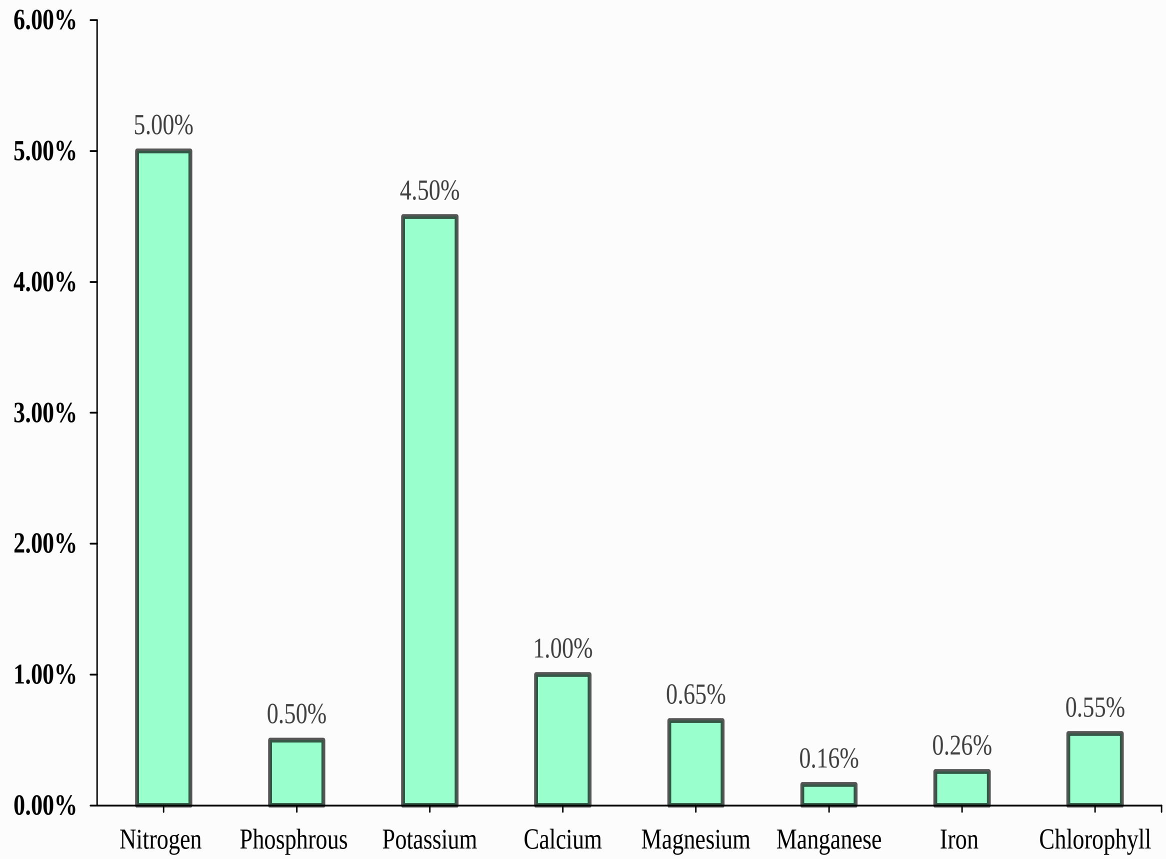

Fig. 1 Economical composition of Azolla (Source: Dayal et al., 2022)

Table 1 General advantages of Azolla

S. No	Advantages	References
01	Low cost or inexpensive: Fix atmospheric nitrogen in presence of sunlight and water	(Kollah et al., 2016; Marzouk et al., 2023)(Herath and Yapa, 2023)
02	Environment friendly: No inorganic pollutant as it nature-based product	(Bhuvaneshwari and Singh, 2015; Marzouk et al., 2023)
03	Have vitamins, minerals and amino acids	(Kollah et al., 2016; Riaz et al., 2022)
04	Improve soil fertility by adding organic matter in soil after decay	(Bhuvaneshwari and Singh, 2015; Marzouk et al., 2023; Shin et al., 2021; Singh and Singh, 1987)
05	Help in carbon sequestration	(Bharali et al., 2021; Hamdan and Houri, 2022; Kumar et al., 2023)
06	Reducesmethane emission from rice	(Ali et al., 2015; Bharati et al., 2000; Malyan et al., 2021; Yang et al., 2019)
07	Weed management	(Marzouk et al., 2023; Prabakaran et al., 2022; Shin et al., 2021; Sree et al., 2023)
08	Food supplement	(Kollah et al., 2016; Li et al., 2020; Nham Tran et al., 2020)
09	Bioremediation	(Al-Baldawi et al., 2018; Annisa et al., 2021; Carlozzi and Padovani, 2016; Eimoori et al., 2020; Naghipour et al., 2018; Prabakaran et al., 2022; Sivakumar and Nouri, 2015)

2.1 Methane mitigation from rice through Azolla

Role of Azolla in GHG mitigation from rice fields is reported in Indian and other rice growing countries. Methane (CH_4) is a potent GHG gas emitted which is emitted from lowland and irrigated rice. Malyan et al. (2021, 2019) reported the CH_4 mitigation through Azolla in irrigated rice in India. In two-year field experiment at Indian Agricultural Research Institute, New Delhi, India, in combination of Azolla were applied with inorganic nitrogen fertilizers to provide 120 kg N ha^{-1} (urea 90 kg N, Azolla, 30 kg N). The cumulative CH4 emission was higher in urea (10 kg N ha-1) and Azolla +plus urea (30 kg N –Azolla + 90 kg N-urea) reduced emission by 9.62% as over urea without effect the economical rice production (Malyan et al., 2021). In other study, Bharati et al. (2000) also reported that similar finding in Cuttack, India and reported the cumulative CH_4 emission up to 31.9% as over urea treatment through Azolla dual cropping in rice. Significant cumulative CH_4 emission mitigation through Azolla application is also reported in Bangladesh by Ali et al. (2012, 2015) and observed up to 11.24% of cumulative reduction in CH4 emission as over urea. Role of Azolla in CH_4 mitigation is also reported by Xu et al. (2017) in Hunan Province of China. In pot study, 34.66% of the CH4 mitigation through Azolla application was reported by Kimani et al. (2018) in Japan. In flooded rice, application of Azolla release dissolved oxygen in flooded water which enhanced the soil redox potential. The higher soil redox potential suppress the methanogens activity and result in lower CH_4 emission (Malyan, 2017; Malyan et al., 2020). On the other hand the higher dissolved oxygen in flooded water of rice enhances the methanotrophs population which result in higher methane oxidation and result in lower CH4 flux (Fagodiya et al., 2022; Medhi et al., 2022).

2.2 Regulating in soil fertility and ammonia volatilization through Azolla

Soil fertility of the soil can be improve through Azolla (Al-Sayed et al., 2022; Marzouk et al., 2023; Subedi and Shrestha, 2015). Subedi and Shrestha, (2015) quoted that the application of Azolla improve the soil structure, and chemical properties. The application of Azolla improve the nitrogen use efficiency in lowland rice (De Macale and Vlek, 2004). Azolla cover in flooded rice reduce the ammonia volatilization which result in lower nitrogen loss and higher nitrogen efficacy (De Macale and Vlek, 2004). Yang et al. (2020) observed that the application of Azolla in combination of urease inhibitor reduced ammonia loss up to 55.4% in rice. Azolla cover in flooded rice water prevents the rapid increases temperature and pH and absorbed the ammonium ion which results in lower ammonia volatilization. Application of Azolla in transplanted rice increases the soil organic matter in both dry and wet season and higher organic matter in soil enhanced the soil fertility (Singh and Singh, 1987).

Conclusion

Azolla is aquatic fern through which major problems of the rice agro-ecosystem can be combat. The application of Azolla as biofertilizer is economic feasibility. Generally, Azolla fix 25-30 kg N ha^{-1} per season in rice and its application can reduce the demand of inorganic fertilizer such as urea. The application of Azolla reduced weed problem as methane emission in rice agro-ecosystem. Cover of Azolla in rice helps in regulating flooded water temperature and pH. Azolla cover also mitigate the ammonia volatilization and enhances the nitrogen use efficacy. This study suggested that the Azolla is significant resources in rice agro-ecosystem.

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