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Symbiotic Blue Green Algae (Azolla): A Potential Bio fertilizer for Paddy Rice Production in Fogera Plain, Northwestern Ethiopia

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Abstract

A field experiment was carried out in Fogera plain, where lowland rice is widely grown, to assess the adaptability and yield of Azzola strains and to determine the level of nitrogen they generate in 2005 and 2006. A year earlier, 2004, the two Azolla strains (*Azolla filiculoides* and *Azolla microphylla*) were introduced from India. They were maintained and multiplied in plastic containers at Adet in a greenhouse and then inoculated into concrete tanks for testing their adaptability. Both strains were well adapted to Adet condition. The actual experiment was laid out in a randomized complete block design replicated three times. In the summer season, *Azolla filiculoides* gave an average of 48 tons/ha (range: 42-56.4 tons) and *Azolla microphylla* yielded 40 tons/ha fresh biomass (range: 30-45 tons). In autumn and winter seasons, biomass production was reduced because of fluctuating temperatures. An average of 54.4 t ha^{-1} of Azolla fresh biomass was harvested at Fogera. Maximum plant height, number of tillers, straw yield and grain yield of rice was recorded on the treatment that was planted by using 64 kg N + 20 kg P ha^{-1} followed by *Azolla filiculoides* + 20 kg P ha^{-1}, 32 kg N + 10 kg P ha^{-1}. Inoculation of Azzola by incorporating once into the soil has increased rice yield by 911 kg ha^{-1} (19%) on *Azolla filiculoides* plots and 721 kg ha^{-1} (15%) on *Azolla microphylla* plots. However, there was temperature fluctuation and colonization of Azolla roots by algae. Multiplication and maintenance of Azolla needs special attention. It also needs continuous watering to a depth of 5 -10 cm and P fertilizer application, thus, irrigation facility and alternate P sources are vital. Azolla gives a lot of biomass and it is easy to manage and establish, which means that it is logical and cost-effective to use it as biofertilizer for paddy rice. Its effect on high value and perennial crops may be the subject of further research.

Keywords: Azolla, biofertilizer, fresh biomass, nitrogen, rice, symbiotic

1. Introduction

Nitrogen is the key element required for plant growth and productivity. It is abundant and constitutes 78% of the atmosphere, but cannot be utilized by plants as such and has to be converted to nitrates or ammonium form either by chemical or biological processes (Singh, 1998; Banu *et al.*, 2003). Chemical synthesis of nitrogen by industrial means is energy intensive and expensive. However, the same process can be carried out by certain species of bacteria such as cyanobacteria, which are equipped with the appropriate enzymes. Most of the cyanobacteria exist under free living conditions but some are found in symbiotic association with lower plants like water fern Azolla (Singh, 1998).

Azolla partners blue green algae inside its lobes and is capable of harvesting atmospheric nitrogen. Due to this invisible partnership, the fern multiplies very fast. The symbiotic association of the algae aids in the creation of a large amount of biomass on the surface of the water. In Azolla-anabaena symbiosis, the fern is a macro symbiont which gives protective environment and nutrients to the blue green algae (the micro symbiont) which in turn gives nitrogen and other growth hormones to the fern for its growth and multiplication. Both partners harvest solar energy via photosynthesis and the total nitrogen requirement can be supplied by the assimilation of N fixed by anabaena. Each leaf of Azolla has the potential of harboring 75 thousand anabaena cells containing 3 to 3.5% nitrogen (www.ineedcoffee.com/06 /azolla/). The beauty of this fern is that it is quite hardy and during favorable environmental conditions it multiplies exponentially. The algal symbiont is closely associated with all stages of the fern's development and resides in the cavities formed in the dorsal lobe of the fern. Rapid multiplication of the fern takes place in summer months. Azolla lives on the water surface of rice fields harmoniously under the canopy of rice plants without affecting the growth of rice (Gevrek, 1999), and on small ponds, canals, and rivers (Ferentinos *et al*., 2002; Dhar *et al*., 2003). Generally, it multiplies vegetatively and often sexually. Its size is 1- 5 cm. Azolla has high protein content of approximately 23-37% of the dry biomass. Hence, it can also be used as, feed supplement with other low protein rations, feed for fish, pigs, ducks, chicken and cattle that like to eat it fresh as well as dried and used in salads and sandwiches, just as alfalfa and bean sprouts are used (Gevrek, 1999; Ferentinos *et al*., 2002).

Azolla is distributed worldwide. Seven species are recognized in temperate and tropics viz. *Azolla filiculoides, A. rubra, A. caroliniana, A. mexicana, A. microphylla, A. pinnata* and *A. nilotica* (Dhar *et al.*, 2003). All these species have anabaena as symbiont in leaves (Singh, 1998).

The high nitrogen fixing ability, rapid growth, high biomass accumulation and N content determines the potential of Azolla as fertilizer for increasing rice yield under low cost rice production technology. Biological nitrogen fixation through *Azolla anabaena* complex is considered as potential biological system for increasing rice yield at comparatively low cost (Singh, 1998). According to Kikuchi *et al.* (1984), maximum biomass production ranged from 0.4 to 5.2 t dry matter ha^{-1} (average = 2.1 t ha^{-1}); and the N content ranged from 40-146 kg ha^{-1} with an average of 70 kg N ha^{-1}.

Azolla derives more than 80% of its N from Nitrogen fixation in the field (Giller, 2001). Annual N production rates by Azolla can be as high as 500 kg N ha^{-1} (for *A. pinnata*) to 1200 kg N ha^{-1} (for *A. filiculoides*) with average of 1000 kg N ha^{-1} yr^{-1} with daily production rates of 0.4 - 3.6 kg ha^{-1} day^{-1} with average of 2 kg N ha^{-1} day^{-1} (Kikuchi *et al*., 1984). Azolla grown as an intercrop with rice can accumulate 40-170 kg N ha^{-1} (average 70 kg N ha^{-1}) (Kikuchi *et al*., 1984). Singh (1979) in Gevrek (1999) reported that the mineral nutrient composition inside the plant body of *A. pinnata* was Nitrogen 4-5%; phosphorus 0.5-0.9%; potassium 2-4.5%; calcium 0.4-4 %; magnesium 0.5-0.65%; iron 0.06-0.26%; manganese 0.11-0.16% and crude protein 24-30% on dry matter basis. Gevrek and Yagmur (1997), also recorded the chemical composition of *A. mexicana* as N 3.92%; P 0.52%; K 1.25%; Ca 4.3%; Mg 1.10%; Na 1.08%; Zn 0.1%; Mn 0.3% and etc on dry matter basis. This indicates that Azolla has higher rate of nitrogen than compost (0.5 – 0.9% N) and animal manure.

Losses of Azolla N were found to be small (0-11%) in comparison to the loss from an equivalent amount of urea fertilizer (30%) which was probably due to direct volatilization of ammonia to the atmosphere (Watanabe and Berja, 1983). Giller (2001) observed that the pH of the flood water was reduced by 2 pH units due to the presence of mat of Azolla on its surface and resulted in the reduction of N losses by ammonia volatilization and increased the recovery of fertilizer N applied as urea up to 60%. When Azolla was incorporated into the soil, overall fertilizer losses were reduced by 35-55% (Kumarasighe and Eskew, 1993). Biological N_2 fixation through *Azolla anabaena* complex is considered a potential biological system for increasing rice yield at comparatively low cost (Khan, 1988; Main, 1993; Singh, 1998). Recently, Azolla has been used as biofertilizer in many countries in the world viz. China, Vietnam, India, North America, Thailand, Philippines, Korea, Srilanka, Bangladesh, Nepal, West Africa and etc (Khan, 1988; Dhar *et al*., 2003). Some of these countries use Azolla as one of the substitutes to commercial fertilizer. A report made by Gevrek (1999) revealed that Azolla is used in more than a million hectares of rice land in China and in more than 400 thousand hectars in Viet Nam.

Low-land rice is a recent introduction to Ethiopia and has received special attention at Fogera plain and it is well adopted by farmers. According to Fogera Office of Rural and Agricultural Development, its area coverage has increased from a mere 80 ha to 64 hundred ha within less than a decade (1996-2004) with yields not exceeding 3.5 t ha^{-1}. However, its productivity constantly declined from time to time due to continuous cereal to cereal cultivation and nutrient depletion and farmers' failure to use chemical fertilizer due to increasing price (Gezahegn and Tekalign, 1995).

Azolla can be used as a biological substitute for the rather expensive artificial fertilizers. Azolla is converted into compost to be used as fertilizer for dryland crops and vegetables (Singh, 1998). In other countries, rice yield has been increased by 1,470 kg (112%) over the control when one layer of 60 kg N $ha^{-1}$of *A. filiculoides* was incorporated into the paddy soil and further increased by 2700 kg ha^{-1} (216%) by incorporating one layer and then growing Azolla as dual crop with rice (Talley *et al*,. 1977). Since Azolla is a low cost nitrogen source, ecologically friendly, easy for management and used as nitrogen fertilizer source in different countries in the world, introduction and use of this cheap and ecologically friendly N source to our system is vital to increase rice yield. Hence, this work was initiated with the objective of introducing Azolla strains and generating information on their N contribution to the newly introduced paddy rice at Fogera plain.

2. Materials and Methods

2.1 Experimental Procedure

Culturing and maintenance

Two Azolla strains namely, *Azolla filiculoides* and *Azolla microphylla* were introduced from India in 2004 and were maintained in Addis Ababa at the National Soils Research Center greenhouse in a nutrient media and were brought to Adet Agricultural Research Center to maintain and test their adaptability. Labeled plastic containers were filled with 5 kg of forest soil and tap water was added at a depth of 10 cm and left overnight to let the suspended materials settle down. To maintain the mother culture, fresh and healthy Azolla fronds were inoculated to the containers and water was maintained to $\geq$ 5 cm depth every day. A pinch of TSP was added initially and when the deficiency symptom was seen to each container. There was no insect problem in the plastic containers. Both strains multiplied very well and covered the surface of the containers in the greenhouse within three weeks.

After enough biomass of both strains was attained, two concrete tanks of a dimension 4 m × 1.5 m × 0.45 m were constructed and filled with forest soil at a rate of 5 kg /m^2 (i.e., 30 kg of forest soil per tank) and filled with tap water at a depth of 10 cm and left overnight to let the suspended materials settle down. The next day, fresh *Azolla filiculoides* was added to one tank and *Azolla microphylla* to the other tank at a rate of 1 kg per tank. The water level was kept to a depth of $\geq$ 5 cm every day; 87 g TSP (40 gm P_2O_5) was applied to each tank initially and when deficiency symptoms were observed.

The adaptability of the strains to the new environment was studied based on the biomass produced, phenotypical appearance at different weather conditions, occurrence of disease and insect pests. Two additional concrete tanks of a size 5 × 10 m^2 were constructed for multiplication of Azolla for the actual field experiment (to produce enough biomass) following the same procedure, in which 250 kg of forest soil was added to each tank and the strains were inoculated and the water level was maintained to 5-10 cm depth every day. Two third of the Azolla mat was collected every two weeks from each container and tank leaving one third for further multiplication and the collected mat was weighed, sun dried and stored.

Field experiment

The field experiment was conducted in 2005 and 2006 at Fogera plain where paddy rice is widely produced. It was laid out in a randomized complete block design with three replications. The experimental site of size 13 m × 34 m was selected each year and prepared as per the farmers' practice and divided to replications and experimental plots of 2 m × 3 m. The distance between plots and blocks was 2 m each. The plots were leveled and rows at a spacing of 20 cm were prepared and fertilizer was applied to rows of respective plots evenly at a rate of 64 kg N ha^{-1} plus 20 kg P ha^{-1}, 32 kg N ha^{-1} plus 10 kg P ha^{-1}, 20 kg P ha^{-1} plus 10 kg P ha^{-1} then mixed with the soil and rice variety X-Jigna was sown at a rate of 80 kg ha^{-1} in rows with 20 cm spacing between rows. Split application of N was practiced, i.e., half of N and all P were applied initially and the split was applied at flowering during Azolla incorporation. Urea served as source of N and TSP for P. After sowing, ridges were made for each plot to collect water which could float the Azolla strains and then the strains were inoculated to their respective plots at a rate of 1 kg fresh biomass after the field was flooded with water. The strains were incorporated to the soil in a plot by draining the water after producing enough biomass that forms a thick mat.

The experiment had the following treatments:

1. Control
2. 64 kg N ha^{-1} + 20 kg P ha^{-1}
3. 32 kg N ha^{-1} + 10 kg P ha^{-1}
4. *Azolla filiculoides* + 20 kg P ha^{-1}
5. *Azolla microphylla* + 20 kg P ha^{-1}
6. *Azolla filiculoides* + 10 kg P ha^{-1}
7. *Azolla microphylla* +10 kg P ha^{-1}
8. *Azolla filiculoides*
9. *Azolla microphylla*

2.2 Data Collection

Five representative plants were randomly selected from each plot and the number of tillers was counted and the average number was recorded. Similarly, the average plant height for the five randomly selected plants per plot was measured using a meter scale. Fresh biomass of Azolla was measured and recorded by taking a mat of the azolla on a 1 m × 1 m area. A quadrant was used in defining the sampling area. It was then sun dried and the corresponding dry weight was taken.

Among the 10 rows of rice per plot, eight central rows were harvested from each plot and grains and straws were separated to measure straw and grain yield per plot. The grain yield was recorded after adjusting the moisture to 12.5% and expressed as kg per hectare. The straws separated from grains were sun dried and weighed to determine the straw yield in kg plot^{-1}.

3. Results and Discussion

Both strains were well adapted to Adet in a greenhouse and outdoor in concrete tanks. The strains started multiplying within two days and covered the whole surface of the containers forming a thick mat within three weeks after inoculation (Fig. 1). The starter inocula were very small in amount and hence the multiplied strains were inoculated to other containers to achieve enough biomass for further activities (Fig. 2a).

Fig. 1. Mother culture of *A. filiculoides* (left) and *A. microphylla* (right) in the greenhouse at Adet

After enough biomass was produced from the plastic containers, both strains were inoculated to the outdoor concrete tanks at a rate of 1 kg fresh biomass per tank (Fig. 2b). The strains started multiplying and covered the surface of the tanks after three weeks. After first harvest, the strains repeatedly covered the surface of the tanks forming thick mat every two weeks (Fig. 2c). The fern is light green in color until the micro symbiont (*Anabaena azollae*) makes association with and turns it deep green after association. The blue green algae forms series of oval rings on the dorsal lobe of each leaf of the fern as seen under microscope and each leaf of Azolla has the potential of harboring 75 thousand anabaena cells that are excellent nitrogen fixers (www.ineedcoffee.com/06/azolla/). From June to September, both strains performed well; they were deep green and formed thick mat (Fig. 2).

a b c

Fig. 2. Performance of *A. filiculoides* and *A. microphylla* in the greenhouse (a) and in concretetanks, (b) during June – October (c) thick mat of azolla

Anabaena filiculoides performed relatively better under low temperature (i.e., October to January) and poorly from February to April, when temperatures were high. In contrast, *A. microphylla* tolerated relatively high temperature and performed better from February to April and poorly performed from October to January. Similar results have been reported earlier by FAO (1982).

The biomass produced by both strains during these seasons is indicated in Table 1. Both strains turned brown (Fig. 3a) when exposed to high temperature or low temperature and/or during maturity (Fig. 3b) and turned green to slightly brown otherwise. P deficiency was associated with pinkish color which can be corrected by applying P from sources such as TSP. However, both strains may poorly perform if the temperature is below 10^{O}C or above 35 ^{O}C. Therefore, partial shade is needed for their better performance.

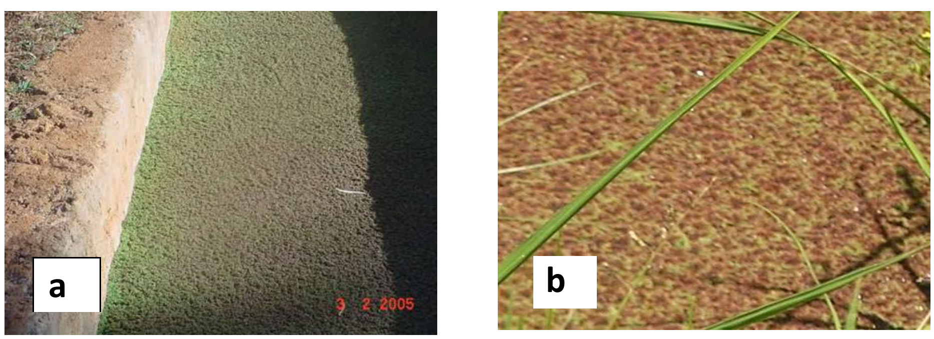

Fig. 3. Azolla turned brown during temperature fluctuation (a) and during maturity (b)

Growth of algae was a common problem from October to April and seriously affected both strains. The reason was that we added excess P into the tanks, which caused excess algal growth and we failed to remove it from the tanks manually. The lesson was that excess P should not be applied and optimum amount should be applied in split. The objective of using P is ensuring maintenance.

The field experiment that was conducted in Fogera showed that both strains adapted well, multiplied and covered the plots within two weeks. In 40 days after inoculation, the fern formed a thick mat (Fig. 4) and produced 54.4 t ha^{-1} fresh biomass. According to the literature, fresh biomass produced by Azolla ranges from 10 to 20 t ha^{-1} (Singh, 1998), an amount much lower than the present results. Insect and disease problems were not observed on both strains at all locations. The relatively high fresh biomass produced in Ethiopia indicates that Azolla can adapt and perform well in this country and hence may serve as a source of nitrogen and other macro and micro nutrients for rice and other high value crops.

The control gave the lowest mean plant height followed by *A. microphylla* + 10 kg P ha^{-1}. The height of rice plants grown with *Azolla filiculoides* alone and *A. filiculoides* with full recommended P was more or less the same and considerably high. Both strains increased plant height more significantly than the control did (Table 2).

A significant difference in the number of tillers was observed among some treatments (Table 3). The maximum number of tillers was recorded by full recommended NP followed by half recommended NP (32 kg N ha^{-1} + 10 kg P ha^{-1}), *A. filiculoides* alone, *A. microphylla* alone and *A. filiculoides* + 20 kg P ha^{-1}. Both strains significantly ($P<0.05$) increased the number of tillers per plant over the control.

a b

Fig. 4. Thick mat of Azolla produced in a plot (a) and in a space between blocks (b) in Fogera Plain

Table 1. Average fresh biomass produced by two Azolla strains in different seasons

Season	Fresh biomass (t ha^{-1})		Remark
	A. filiculoides	*A. microphylla*	
May - Sep.	48	40	*A. filiculoides* gave a maximum biomass of 56.4 t ha^{-1} and *A. microphylla* gave 45 t ha^{-1}
Oct. - Jan.	30	11	*A. filiculoides* performed well but it turned cloudy and pinkish as temperatures dropped; also they did not perform as good from May to September
Feb. - April	14	32	*A. microphylla* performed well but it turned brown as temperature rose and did not perform as good from May to Sept

Table 2. Effect of Azolla on plant height at Fogera in 2005 and 2006

Treatment	Mean plant height (cm)		
	2005	2006	Combined
Control	95.30	95.00	95.15 d
64 kg N + 20 kg P ha^{-1}	107.27	102.20	104.70 a
32 kg N + 10 kg P ha^{-1}	99.50	98.83	99.17 c
Azolla filiculoides + 20 kg P ha^{-1}	103.70	100.70	102.20 b
Azolla microphylla + 20 kg P ha^{-1}	101.53	97.30	99.42 c
Azolla filiculoides + 10 kg P ha^{-1}	101.90	96.30	99.10 c
Azolla microphylla + 10 kg P ha^{-1}	99.53	93.03	96.28 d
Azolla filiculoides	101.63	100.70	101.20 b
Azolla microphylla^{-1}	100.47	96.93	98.70 c
LSD (0.05)	1.76	1.69	1.66
C.V (%)	1.01	1.00	1.00

Table 3. Effect of Azolla on number of tillers of rice at Fogera during 2005 and 2006

Treatment	Mean number of tillers per plant		
	2005	2006	Combined
Control	9.67	8.33	9.00 c
64 kg N + 20 kg P ha^{-1}	15.00	13.00	14.00 a
32 kg N + 10 kg P ha^{-1}	12.00	11.33	11.67 b
Azolla filiculoides + 20 kg P ha^{-1}	11.00	10.00	10.33 bc
Azolla microphylla + 20 kg P ha^{-1}	10.67	9.33	10.17 bc
Azolla filiculoides + 10 kg P ha^{-1}	11.00	8.67	9.67 c
Azolla microphylla + 10 kg P ha^{-1}	10.67	9.00	10.00 bc
Azolla filiculoides	11.67	9.67	10.50 bc
Azolla microphylla^{-1}	11.33	9.00	10.33 bc
LSD (0.05)	2.55	1.25	1.93
C.V (%)	12.86	7.37	10.91

Recommended NP gave the maximum straw yield followed by half recommended NP combined over years; whereas straw yield of other treatments did not significantly differ from the control (P<0.05) (Table 4). However, straw yield from treatments *A. microphylla* + 20 kg P ha^{-1}, *A. filiculoides* + 20 kg P ha^{-1}, *A. microphylla* + 10 kg P ha^{-1}, *A. filiculoides* + 10 kg P $ha^{-1}$and *A. filiculoides* alone (i.e., without P) recorded equal straw yield with half recommended NP. However, the straw yield due to these combinations was not significantly different from the control and *A. microphylla* alone.

Table 4. Effect of Azolla on straw yield of rice in Fogera in 2005 and 2006

Treatments	Mean straw yield (kg ha^{-1})		
	2005	2006	Combined
Control	7417 c	7359 g	7388 c
64 kg N + 20 kg P ha^{-1}	10132 a	9035 a	9584 a
32 kg N + 10 kg P ha^{-1}	8931 ab	8357 b	8644 ab
Azolla filiculoides + 20 kg P ha^{-1}	8396 bc	8063 c	8230 bc
Azolla microphylla + 20 kg P ha^{-1}	8757 abc	7799 de	8278 bc
Azolla filiculoides + 10 kg P ha^{-1}	8354 bc	7674 e	8014 bc
Azolla microphylla + 10 kg P ha^{-1}	8688 bc	7514 f	8101 bc
Azolla filiculoides	7444 c	7924 cd	7684 bc
Azolla microphylla^{-1}	7708 bc	7480 fg	7594 c
LSD (0.05)	1430	148	1017
C.V (%)	10.20	1.13	7.48

Grain yield significantly varied among treatments (Table 5). The combined analysis showed that recommended NP fertilizer gave the maximum grain yield of 6.2 t ha^{-1} followed by half recommended NP fertilizer with grain yield of 5.9 and *A. filiculoides* + 20 kg P ha^{-1} with grain yield of 5.8 t ha^{-1}. All treatments gave significantly more grain yield than the control. Grain yield increment due to *A. filiculoides* + 20 kg P ha^{-1} was as much as the one obtained from the half recommended NP, which was followed by *A. filiculoides* alone. *A. filiculoides* alone gave significantly more grain yield than *A. microphylla* alone ($P<0.05$). However, *A. microphylla* with and without P gave significantly more grain yield than the control. *A. filiculoides* without incorporating P to the soil once has increased rice yield by 911 kg ha^{-1} (19%) over the control and *A. microphylla* by 721 kg ha^{-1} (15%).

Table 5. Effects of Azolla on grain yield of rice in Fogera in 2005 and 2006

Treatment	Mean grain yield (kg ha^{-1})		
	2005	2006	Combined
Control	4812 e	4932 f	4872 f
64 kg N + 20 kg P ha^{-1}	6167 a	6219 a	6193 a
32 kg N + 10 kg P ha^{-1}	6041 b	5826 b	5934 b
Azolla filiculoides + 20 kg P ha^{-1}	5937 bc	5758 b	5848 bc
Azolla microphylla + 20 kg P ha^{-1}	5791 d	5603 cd	5697 de
Azolla filiculoides + 10 kg P ha^{-1}	5812 d	5555 de	5683 de
Azolla microphylla + 10 kg P ha^{-1}	5749 d	5473 e	5611 e
Azolla filiculoides	5840 cd	5726 bc	5783 cd
Azolla microphylla^{-1}	5729 d	5458 e	5593 e
LSD (0.05)	117	125	121
C.V (%)	1.22	1.28	1.28

In general, inoculation of *A. filiculoides and A. microphylla* with and without P had significant effect on most parameters measured over the control. *A. filiculoides* with 20 kg P ha^{-1} and half recommended NP were more or less similar in most parameters. *A. filiculoides* alone and *A. filiculoides* with 20 kg P ha^{-1} affected grain yield of rice combined over years more or less equally.

Azolla is rich in major nutrients such as N, P, K and S and micro nutrients such as Fe, Zn and others. It is a recycling source of P, S and other nutrients to rice and hence the increase in grain yield and other yield parameters may be due to this fact (Singh, 1979; Main, 1993). Talley *et al.* (1977) reported that rice yield was increased by 112% (1470 kg) over the control by incorporating *A. filiculoides* once (at the rate of 60 kg ha^{-1}) and by 216% (2700 kg ha^{-1}) by incorporating once and then growing Azolla as a dual crop with rice. In China, azolla is reported to have increased rice yield that ranges between 0.4 and 158% with an average of 18.6% (Lumpkin and Plunknet, 1980).

4. Conclusion and Recommendation

From the results of the study, it is possible to conclude that Azolla should be used as a biofertilizer for rice production in Ethiopia since it produces high biomass, is easy to manage and establish, increases the availability of macro and micronutrients (it scavenges K and recycles P and S), improves soil physical and chemical properties and fertilizer use efficiency, increases crop yield by 15-19% (by one incorporation) in Ethiopia and releases plant growth hormones and vitamins and does not attract rice pests.

Drawbacks of Azolla include requirements of nurseries for multiplication, land for production, continuous watering and more labor for incorporating and watering, irrigation facilities, the need for the rice crop to be grown in rows rather than the farmers' usual practice of broadcasting in Fogera plain. Furthermore, temperature fluctuations may make difficult to establish Azolla in the dry season, or it may fail to compete with other ordinary algae, it requires high P fertilizer for multiplication and may turn to be a weed itself in irrigation channels. Any recommendation package may have to address these issues.

From the results of the experiment, it is possible to recommend the following for scaling up of the technology: Simple multiplication tanks should be constructed near places of steady water supply such as near irrigation schemes or rivers to maintain the strains during the dry seasons. Farmers should also be trained on how to manage, maintain and use Azolla as an alternative N fertilizer source. Effects of azolla on high value crops (vegetables and fruit crops) should also be investigated.

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