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Azolla Fern in Mwea Irrigation Scheme and Its Potential Nitrogen Contribution in Paddy Rice Production

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Abstract

Azolla fern is invasive in Mwea Irrigation Scheme in Kenya and its management in paddy rice fields is a challenge to farmers. A survey was undertaken to establish farmer's knowledge and potential nitrogen contribution by *Azolla* in the paddies. The Scheme was stratified into seven sections and a questionnaire administered to 250 farmers. Data were collected on awareness levels, source, trend of infestation, abundance, fertilizer regimes and management practices. Five farms from each of the sections were also sampled for *Azolla* coverage and tissue N levels analyzed. Survey data were analyzed using SPSS software and interpreted using descriptive statistics. Biomass sampling data were analyzed using SASS and means separated using the least significant differences at $P \leq 0.05$.

The results demonstrated that *Azolla* has infested nearly all the paddy farms in Mwea. *Azolla* invasion occurred more than 10 years ago and coverage per unit area was on a decline and stood at 25%. Water shortage and herbicide use were the main reasons associated with this trend. *Azolla* is conspicuously noticed at transplanting and weeding times. The presence of *Azolla* in Mwea is enhanced by widespread use of P and K fertilizers and continuous paddy cropping, thus providing a suitable environment for *Azolla* growth. *Azolla* was reported to enhance soil fertility, rice yield and yield components. The maximum *Azolla* biomass coverage was 14.92 t/ha, with a potential nitrogen contribution of 37.6 kg N/ha. *Azolla* is invasive in Mwea, widespread, beneficial to paddies and with high potential N contribution.

Keywords: *Azolla* invasion, Mwea paddies, nitrogen contribution

1. Introduction

Azolla fern has a symbiotic association with a cyanobacterium, *Anabaena azollae*, through which it fixes nitrogen (Carrapico et al., 2002). The nitrogen fixing association is beneficial in rice production system (Armstrong, 1997). The nitrogen fixing ability has made been extensively used as a bio-fertilizer over the years, especially in the Asian continent (Carrapico et al., 1991). The bio-fertilizer potential of *Azolla* has also been exploited in rice cultivation systems in Italy (Milicia & Favilli, 1992). In Kenya, *Azolla* exists in Mwea, Ahero, West Kano, Bunyala, Taveta and TARDA rice Irrigation Schemes. At Ahero Irrigation Scheme, the positive nitrogen potential of the native species *Azolla nilotica,* was reported in 1982 and 1987 (AIRS, report no. 34 and 57). In Mwea Irrigation Scheme, *Azolla* species *Azolla filiculoides* is invasive (Oyange, 2019). Farmers have christened it "Acquired Immuno-Deficiency Syndrome" due to a fast growth rate and difficulty in management.

Azolla is native to the tropic and temperate areas of the world (Campbell, 2011). However, it has spread worldwide due to human activities (Carapico et al., 2000). The introduced species have in some places eliminated existing ones (Szczęśniak et al., 2009). Findings by McConnachie et al. (2004) have shown that new world species have invaded South, Central, East Africa regions including Kenya. In Ahero-Kenya, *Azolla nilotica* species was reported in 1981 (AIRS Report, No. 22). However, this species is no longer in existence in Ahero but a new unidentified one is invasive in the Scheme. In Taveta and Tana River Development Authority Irrigation Schemes, a species similar to *Azolla nilotica* has also been identified (Oyange, 2019). Within Mwea

Irrigation Scheme paddies, a species closely linked to *Azolla filiculoides* is in existence. Its source is unknown and farmers have in the past struggled to control it.

Azolla growth and multiplication is affected by environmental conditions; water availability, temperature, pH and P content (Lumpkin, 1985). According to Wanjogu et al. (1992), 60 Kg P_2O_5 per ha^{-1} plus manure is recommended for paddy rice cultivation in Mwea. Majority of the farmers apply this amount of P and undertake double cropping which ensures continuous flooding of paddies thus providing a suitable environment for *Azolla* growth. In addition, farmers in Mwea rotovate flood and fallow their fields 3-4 months prior to transplanting (RiceMAPP, 2012). These practices can enhance *Azolla* multiplication and spread. The average temperatures of 22 °C and pH of 6.5, which are experienced in Mwea, are also suitable for *Azolla* growth (Wong & Vu, 1987). Quintero et al. (1993) reported that temperature affects relative growth rate, chlorophyll content and nitrogen fixation of plants.

Estimates of the amounts of nitrogen fixed by *Azolla* in paddy fields are varied but can be up to 1000 kg N ha^{-1} (IRRI, 1990). Ferentinos et al. (2002) reported that *Azolla anabaena* complex can fix up to 390 tons N ha^{-1}. Apart from nitrogen fixation, *Azolla* multiplies rapidly and doubles its biomass within 7-10 days (Campbell, 2011). It can therefore attain a biomass coverage of up to 5 kg m^{-2}, which is capable of shielding up to 10% light (Yanni et al., 1994). This is advantageous in controlling some aquatic weeds (Scagel et al., 1966). The fast rate of biomass accumulation, although advantageous, can cause mechanical obstruction, impede water flow and clog irrigation canals (Scagel et al., 1966). With the current global warming and climate change, increase in temperatures and reduced water resources is a reality (Bauckland et al., 2008). This supposes a future risk of reduction in *Azolla* growth and spread. The study sought to establish the level of awareness, extent of infestation, the management strategies and the potential nitrogen contribution of *Azolla* in the Mwea paddies during the period of 2016 and 2017 long and short rains.

2. Materials and Methods

2.1 Site Description

The study was conducted in Mwea Irrigation Scheme, during the year 2016. Mwea Irrigation Scheme is located about 100 km East of Nairobi, along Nairobi-Meru road at an altitude of 1159 metres above the sea levels, 0°37′S and 37°27′E. The climate is tropical within agro-ecological zones Lower Midland 3 and Lower Midland 4. Rainfall pattern is bimodal with annual mean of about 930 mm with average temperature of 22 °C. The scheme is approximately 8,000 hectares and is subdivided into seven sections namely: Mwea (M), Tebere (T), Thiba (H), Wamumu (W), Karaba (K), Ndekia and Mutithi/Curukia (Figure 1). Irrigation water is sourced from two rivers; Thiba and Nyamindi.

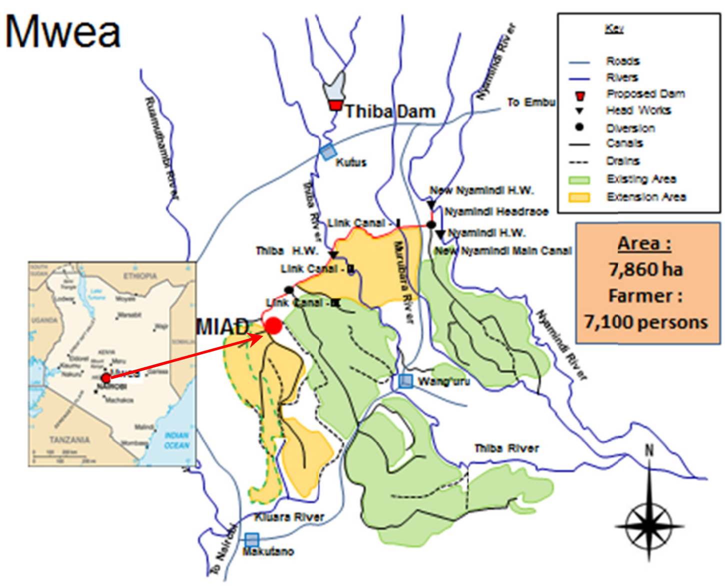

Figure 1. A map showing Mwea Irrigation Scheme in Kenya (Source: NIB)

2.2 Experimental Design and Sampling

The survey was conducted within the seven sections of Mwea Irrigation Scheme namely: Mwea, Tebere, Thiba, Wamumu, Karaba, Ndekia and Mutithi/Curukia, with 6,049 households. The study used stratified sampling design, and 40 farmers each from the seven sections of the scheme were randomly selected from the Irrigation Water Users Association list and questionnaire administered to obtain data on *Azolla* awareness, infestation trend, sources, management and perception. The questionnaires were pre-tested with 20 farmers in Thiba section of the scheme; to assess its clarity to the respondents. Stratified sampling technique was used to sample a total of 250 farmers who were interviewed out of the 280 targeted to achieve a minimum of 10% statistical requirement (Orodho, 2005). Both qualitative and quantitative modes of inquiry were used. Secondary data was collected though literature review while primary data by in-depth interviews with the respondents.

In addition to the survey, a sample of 100g fresh *Azolla* biomass and 500 ml of water were collected from the irrigation canals of each of the seven sections for plant tissue nutrient (N, P and K) and irrigation water quality (N, P, K, and pH) analysis. Collected fresh biomass was oven dried to a constant weight in the laboratory at 100 ^{o}C for 24 hours and dry weight determined (Faichney & White, 1983). About 5g of *Azolla* dry matter was then used to determine the nitrogen content using Kjeldahl's method (Kjeldahl, 1883), P content by calorimetric method (Barton, 1948) and K content by flame photometry method (Schollenberger & Simon, 1945). From the irrigation water samples, N content was analysed using the procedure by Kjeldahl (Kjeldahl, 1883), P content by orthophosphate method (Jackson, 1958), K content by atomic absorption method (Fishman, 1965) and pH by glass electrode method (Jackson, 1958). From each of the seven sections of the scheme, five farms were randomly selected, and *Azolla* biomass per unit area measured by sampling three (3) 1 m^2 unit areas. The potential nitrogen contribution per unit area was then calculated by multiplying the average dry mater weight per unit area x% tissue N.

2.3 Data Analysis

Survey data was analysed using SPSS version 20 and Chi square test done to determine relationship between variables. Data for ttissue nutrient, irrigation water quality and potential nitrogen contribution data were analysed using SAS software and means separated using the least significant difference (LSD) test at $p \leq 0.05$. Regression analysis was conducted to determine the relationship between *Azolla* tissue nutrient and irrigation water quality.

3. Results

3.1 Azolla Infestation in Mwea Irrigation Scheme Paddies

Nearly 100% of the respondents were aware of the presence of *Azolla* in Mwea Irrigation Scheme. The fern was reported to have infested an average of 97% of the farms within Mwea Irrigation Scheme. The percentage of farmers whose farms had been infested by *Azolla* ranged from 94% (Wamumu) to 100% (Ndekia) as shown in Table 1. There was no significant relationship ($P > 0.05$) between awareness and the various sections of the Scheme as shown by the Chi test.

Table 1. Percentage of farmers having seen *Azolla* in their paddy fields in Mwea Irrigation Scheme

Section	Yes (%)	No (%)	Total (%)
Tebere	96	4	100
Thiba	95	5	100
Mwea	97	3	100
Wamumu	94	6	100
Karaba	97	3	100
Ndekia	100	0	100
Mutithi/Curukia	100	0	100
Average	**97**	**2.8**	**100**
$x^2(6) = 1.71$, P = 0.983			

3.2 Azolla Invasion in Mwea Irrigation Scheme

Azolla infestation in Mwea Irrigation Scheme was first noticed more than 10 years ago within Thiba, Wamumu, Karaba, Tebere and Mwea sections by 31.7, 25, 25, 17 and 6.7% of the respondents respectively (Table 2). In

Ndekia and Mutithi/Curukia, infestation was first noticed within the last 5-10 years. The time of infestation had a significant (P = 0.022) relationship with the various sections of the scheme (Table 2).

Table 2. Time of *Azolla* invasion in various sections of Mwea Irrigation Scheme (% respondents)

Section	No idea	< 5 years ago	5-10 years ago	> 10 years ago
Tebere	4.3	31.9	46.8	17.0
Thiba	0.0	31.7	36.6	31.7
Mwea	13.3	53.3	26.7	6.7
Wamumu	12.5	25.0	37.5	25.0
Karaba	3.1	18.8	53.1	25.0
Ndekia	0.0	75.0	25.0	0.0
Mutithi/Curukia	0.0	62.5	37.5	0.0
Average	**4.7**	**42.6**	**37.6**	**15.1**
$x^2(18) = 32.0$, P = 0.022				

3.3 Trend of Azolla Infestation in Mwea Irrigation Scheme

Azolla infestation has been on the decline according to 71% of the respondents (Tables 3 and 4).The trend of coverage was however reported to be on the increase in Mutithi/Curukia. More than 10 year ago, about 48% of the farms had more than 50% *Azolla* coverage compared with 14% (5-10 years ago) and 12% currently. The trend of coverage had significant (P < 0.05) relationship with the period of infestation. It was however not related to the sections (P> 0.05) and the unit coverage (P > 0.05) (Tables 3, 4 and 5).

Table 3. Trends of *Azolla* coverage in Mwea irrigation Scheme (% of respondents)

Period	No idea	Increasing	Decreasing
< 5 years ago	15.0	17.5	67.5
5-10 years ago	7.9	28.9	63.2
> 10 years ago	2.6	14.5	82.9
Average	**8.5**	**20.3**	**71.2**
$x^2(6) = 59.7$, P = 0.000			

Table 4. Trends of *Azolla* coverage in Mwea Irrigation Scheme (% respondents)

Section	No idea	Increasing	Decreasing
Tebere	8.5	19.1	72.3
Thiba	7.3	9.8	82.9
Mwea	10.0	20.0	70.0
Wamumu	9.4	31.3	59.4
Karaba	3.1	21.9	75.0
Ndekia	0.0	0.0	100.0
Mutithi/Curukia	12.5	50.0	37.5
Average	**7.7%**	**20.6%**	**71.6%**
$x^2(12) = 13.4$, P = 0.54			

Table 5. *Azolla* coverage per unit area in Mwea Irrigation Scheme (% respondents)

Period	Nil	< 25% coverage	25-50% coverage	> 50% coverage
2016 (currently)	29.0	48.9	9.7	12.4
5-10 years ago	7.3	31.8	46.9	14.0
>10 years ago	19.4	20.9	11.6	48.1
Average	**18.6**	**33.9**	**22.7**	**24.8**
$x^2(9) = 11.9$, P = 0.022				

3.4 Major Reasons for Declining Levels of Azolla Biomass in Paddy Fields

The reduction in *Azolla* levels in the paddies was attributed mainly to increased water shortage and herbicide use. A large percentage (21.9%) of farmers from Karaba section of the scheme had no idea of the reason for reduced levels of *Azolla* biomass in the paddy fields. There was no significant (P > 0.05) relationship between the reasons and the various sections of the scheme (Table 6).

Table 6. Reasons for reduction in *Azolla* biomass coverage in Mwea Irrigation Scheme paddies (% respondents)

Section	Water shortage	No idea	Soil fertility	Herbicide	Drying after cropping	Others
Tebere	68.1	6.4	0.0	14.9	6.4	4.3
Thiba	82.9	2.4	4.9	7.3	0.0	2.4
Mwea	76.7	3.3	0.0	16.7	0.0	3.3
Wamumu	71.9	3.1	0.0	15.6	9.4	9.4
Karaba	75.0	21.9	3.1	0.0	0.0	0.0
Ndekia	100.0	0.0	0.0	0.0	0.0	0.0
MC	100.0	0.0	0.0	0.0	0.0	0.0
Average	**82.1**	**5.3**	**1.1**	**7.8**	**2.3**	**1.4**
$x^2(42) = 53.6$, P = 1.08						

Note. MC = Mutithi/Curukia ; Others = weeding, manual removal.

3.5 Irrigation Water Availability in Mwea Irrigation Scheme

Irrigation water availability was reported to be generally poor in Karaba, Ndekia and Mutithi/Curukia (Table 7). However, in Thiba and Tebere sections of the scheme, about 51% and 47% of the respondents, respectively, reported that the water situation ranged from good to very good. The water availability had significant (P < 0.05) relationship with the various sections of the scheme (Table 7).

Table 7. Irrigation water availability in various sections of Mwea Irrigation Scheme (% respondents)

Section	Poor	Good	Very good	Others
Tebere	8.5	36.2	10.6	44.7
Thiba	17.1	43.9	7.3	31.7
Mwea	6.7	23.3	3.3	66.7
Wamumu	0.0	0.0	0.0	100.0
Karaba	71.9	21.9	3.1	3.1
Ndekia	0.5	25.0	0.0	25.0
Mutithi/Curukia	62.5	12.5	0.0	25.0
Average	**22.2**	**26.3**	**5.2**	**46.4**
$x^2(18) = 118$, P = 0.000				

3.6 Source of Azolla in Mwea Irrigation Scheme paddies

About 83% of the respondents reported that irrigation water was the main source of *Azolla* infestation followed by Quelea quelea (1.1%) and Air (0.7%) as shown in Table 8. On average, 13.2% of the respondents were not aware of the source of *Azolla* infestation. Ndekia section had the highest percentage of respondents not aware of *Azolla* infestation (50%). There was no significant (P > 0.05) relationship between the sources of infestation and the various sections of the scheme (Table 8).

Table 8. Sources of *Azolla* infestation in Mwea Irrigation Scheme (% respondents)

Section	Water	Birds	Air	No idea	Others	Machines
Tebere	83.0	0.0	0.0	11.0	2.0	0.0
Thiba	88.0	2.0	0.0	10.0	0.0	0.0
Mwea	77.0	3.0	3.0	10.0	0.0	3.0
Wamumu	78.0	3.0	0.0	19.0	0.0	0.0
Karaba	84.0	0.0	0.0	16.0	0.0	0.0
Ndekia	50.0	0.0	0.0	50.0	0.0	0.0
Mutithi/Curukia	63.0	0.0	13.0	13.0	0.0	0.0
Average	82,5	1.1	0.7	13.2	0.3	0.4
$x^2(36) = 39.5$, $P = 0.32$						

3.7 Peak Periods of Azolla Infestation

Azolla was reported to be most abundant at rice transplanting and weeding stages by 42% and 49.8% of the respondents respectively (Table 9). In Ndekia, Karaba and Mwea sections of the scheme, prevalence was reported to be at weeding stage while in Tebere and Thiba prevalence was at transplanting stage of rice. Equal proportion of respondents in Wamumu section (40.6%), reported equal prevalence at both transplanting and weeding stages of rice. The relationship between peak times of infestation and the Sections of the scheme was significant ($P < 0.05$).

Table 9. Peak periods of *Azolla* infestation in Mwea Irrigation Scheme (% respondents)

Section	Transplanting time	Weeding time	Heading time	No idea
Tebere	72.3	19.1	2.1	6.4
Thiba	65.9	26.8	0.0	7.3
Mwea	40.0	46.7	6.7	6.7
Wamumu	40.6	40.6	6.3	12.5
Karaba	31.3	65.6	3.1	0.0
Ndekia	0.0	100.0	0.0	0.0
Average	**41.7**	**49.8**	**3.0**	**5.5**
$x^2(18) = 39.2$, $P = 0.03$				

3.8 Herbicide Use in Rice Production

The types of herbicides used by farmers in Mwea paddies and the frequency of application are shown in Tables 1.10 and 1.11. Use of herbicides for weed control in Mwea Irrigation Scheme was noted to be prevalent with about 95% of the respondents using herbicides for weed control. Out of these, about 54% used glyphosate based pre-plant herbicides while 31% applied 2,4-D based post-emergent selective herbicides. Only 13% were reported to be using both pre-plant and post-emergent herbicides. Ndekia and Mwea sections of the scheme reported the highest use of pre-plant herbicides at 75% and 63% respectively. The use of post emergent herbicides was highest in Wamumu section (41%).

Out of the 95% respondents who confirmed using herbicides, majority (71%) used it but not always. Comparatively, Wamumu section of the scheme reported the highest number of farmers (43%) who always used herbicides. In this section of the scheme, a comparatively higher proportion of farmers (40.6%) used post-emergent herbicides compared with 13.3% in Mwea section. The type of herbicides and the frequency of use had no significant ($P > 0.05$) relationship with the sections of the scheme (Tables 10 and 11).

Table 10. Types of herbicide used by farmers in Mwea Irrigation Scheme (% respondents)

Section	Pre-plant herbicide	Post-emergent herbicide	Pre-plant+Post-emergent	No idea
Tebere	44.7	36.2	12.8	6.4
Thiba	58.5	26.8	12.2	2.4
Mwea	63.3	13.3	10.0	13.3
Wamumu	50.0	40.6	3.1	6.3
Karaba	50.0	37.5	6.3	6.3
Ndekia	75.0	25.0	0.0	0.0
Mutithi/Curukia	37.5	37.5	25.0	0.0
Average	**54.1**	**31.0**	**9.9**	**5.0**
$x^2(12) = 12.5, P = 0.41$				

Table 11. Frequency of herbicide use by farmers in Mwea Irrigation Scheme (% respondents)

Section	Sometimes	Always	Never
Tebere	68.1	27.7	4.3
Thiba	73.2	24.4	2.4
Mwea	78.6	14.3	7.1
Wamumu	53.1	43.8	3.1
Karaba	80.6	12.9	6.5
Ndekia	100.0	0.0	0.0
Mutithi/Curukia	75.0	25.0	0.0
Average	**75.5**	**21.2**	**3.3**
$x^2(12) = 39.20, P = 0.34$			

3.9 Fertilizer Regimes

In Mwea, farmers use both manure and inorganic fertilizers to supply nutrients required by rice plant. About 46% of the respondents reported using triple superphosphate+ muriate of potash (as basal) followed by sulphate of ammonia (as a top-dress). This was followed by 22.7% of the respondents using triple super phosphate + Muriate of potash + manure (as basal), followed by sulphate of ammonia (as top-dress). Relatively a high percentage of farmers (21.8%) was reported to be using other recommended practices of basal fertilizer application and a top-dress. There was a significant ($P < 0.05$) relationship between fertilizer regimes and various sections of the scheme (Table 12).

Table 12. Types of fertilizers used in Mwea Irrigation Scheme (% respondents)

Section	TSP/DAP+MOP+SA	TSP/DAP+MOPSA+Manure	TSP/DAP+SA	17/23+SA+Manure	17/23+SA	Others
Tebere	6.4	4.3	0.0	2.1	8.5	78.8
Thiba	61.0	24.4	7.3	0.0	0.0	7.3
Mwea	50.0	33.3	3.3	3.3	0.0	10.0
Wamumu	34.4	43.8	18.8	0.0	0.0	3.1
Karaba	68.8	28.1	0.0	0.0	0.0	3.1
Ndekia	25.0	25.0	25.0	0.0	0.0	25.0
Mutithi/Curukia	75.0	0.0	0.0	0.0	0.0	25.0
Average	42.8	23.7	7.8	0.8	1.2	21.8
$x^2(108) = 234.9, P = 0.00$						

Note. Application rates for TSP, DAP, MOP, 17:17:10, 23:23:0 = 2.5 bags ha^{-1}; SA = 5 bags ha^{-1}; Manure = 5 tons ha^{-1}.

3.10 Cropping Systems and Rice Yields

There are four cropping systems in Mwea Irrigation Scheme namely: rice-ratoon, rice-ratoon-rice, rice-rice and rice fallow (Table 13). It was estimated that rice-rice system (double cropping) and rice once (single cropping) yielded 28.5 and 23 bags per acre respectively. The cropping system had no significant (P > 0.05) relationship with the yields (Table 13).

Table 13. Rice yields in different rice cropping systems in Mwea Irrigation Scheme (% respondents)

	20-23 bags/acre	24-26 bags/acre	27-30 bags/acre
Rice-ratoon	14.5	26.7	58.8
Rice-ratoon-Rice	7.1	42.9	50.0
Rice-fallow	0.0	33.3	66.7
Rice-Rice	0.0	0.0	100.0
$x^2(8) = 6.7$, P = 0.57			

Note. There were no yields of less than 20 bags or more than 30 bags per acre.

3.11 Farm Productivity and Effect of Azolla on Soil Fertility and Yield

The survey showed that majority (43%) of the farmers obtained an average of 28.5 bags of paddy per acre, 30% got 25 bags per acre while the rest harvested an average of 21 bags of paddy per acre (Table 14). A high proportion of the respondents from Thiba (70.7%) followed by Karaba (60%) and Tebere (55.6%), obtained an average of 28 bags of paddy per acre compared to Ndekia which had 22 bags of paddy per acre.

Majority of the respondents (77%) reported that *Azolla* was beneficial, increased soil fertility and consequently rice crop yields (Tables 15 and 16). However, 12.5% reported that it reduced yields while 2.5% had no idea. Thiba section of the scheme had 90.2% of the respondents who were knowledgeable about the benefits of *Azolla*, Tebere 83% and Mutithi/Curukia (out-growers section) at 62%. About 13% of the respondents indicated that *Azolla* reduced crop yields. The level of education affected knowledge of the beneficial effects of *Azolla* on yield. About 77% of those with college education reported that *Azolla* caused an increased effect on yield compared with 70% and 48%, with secondary and primary education respectively. The relationship between paddy rice yields and the various sections of the scheme was significant (P < 0.05). However, farmers' perception of the effect of *Azolla* on soil fertility and paddy yields had no significant (P > 0.05) relationship with the various sections of the scheme. The level of education also had no significant (P > 0.05) relationship with the perception of Azolla on yield (Table 17).

Table 14. Average rice yields in Mwea Irrigation Scheme (% respondents)

Section	21 bags/acre	25 bags/acre	28.5 bags/acre
Tebere	6.7	37.8	55.6
Thiba	14.6	14.6	70.7
Mwea	14.3	42.9	42.9
Wamumu	3.1	25.0	71.9
Karaba	6.7	33.3	60.0
Ndekia	100.0	0.0	0.0
Mutithi/Curukia	42.9	57.1	0.0
Average	**26.9**	**30.1**	**43.0**
$x^2(12) = 53.4$, P = 0.000			

Table 15. Farmers perception about effects of *Azolla* on soil fertility in Mwea Irrigation Scheme (% respondents)

Section	Increases	Reduces	No effect	Don't know
Tebere	72.1	7.0	4.7	16.3
Thiba	86.5	10.8	2.7	0.0
Mwea	77.8	11.1	3.7	7.4
Wamumu	100.0	0.0	0.0	0.0
Karaba	71.4	3.6	3.6	21.4
Ndekia	100.0	0.0	0.0	0.0
Mutithi/Curukia	85.7	14.3	0.0	0.0
Average	84.9	6.7	2.1	6.4
$x^2(18) = 24.0$, P = 0.16				

Table 16. Farmer's perception of *Azolla* as increasing rice yields in Mwea Irrigation Scheme (% respondents)

Section	Increases	Reduces	No idea
Tebere	83.0	4.3	12.8
Thiba	90.2	0.0	9.8
Mwea	80.0	3.3	16.7
Wamumu	80.0	3.3	16.7
Karaba	75.0	0.0	25.0
Ndekia	75.0	25.0	0.0
Mutithi/Curukia	62.5	12.5	25.0
Average	**78.0**	**6.9**	**15.1**
$x^2(18) = 28.0$, P = 0.06			

Table 17. Perception of the effect of *Azolla* on yield in Mwea Irrigation Scheme, based on level of education (% respondents)

Education level	Increases	Reduces	No effect	Don't know	Total
Primary education	48.6	17.1	22.9	11.4	100.0
Secondary education	70.1	8.4	13.1	8.4	100.0
College education	76.5	17.6	0.0	5.9	100.0
Others	50.0	25.0	25.0	0.0	100.0
Average	**65.6**	**11.7**	**14.1**	**8.6**	**100.0**
$x^2(9) = 10.9$, P = 0.29					

Note. Others = not educated.

3.12 Management of Azolla

The management strategies of *Azolla* in Mwea paddies at transplanting and weeding, involved water drainage (to cause desiccation and death) and incorporation of *Azolla* in the soil (Table 18). At transplanting, water drainage was common while at weeding, incorporation in the soil together with weeds was practiced. About 76.1% of the respondents' drained water at transplanting, 16.6% drained at weeding, while 41.6% of the respondents incorporated *Azolla* in the soils at weeding. At other times, about 28% of the respondents collected and threw away *Azolla* from the paddy fields.

Table 18. Management of *Azolla* in Mwea Irrigation Scheme paddies (% respondents)

	Drain water	Incorporate	Throw away	Do nothing	Use herbicides
Transplanting	76.1	9.7	0.8	2.6	10.8
Weeding	18.5	41.6	0.8	39.8	1.3
Other times	16.6	6.6	28.2	4.87	0.0

Note. Others times = Fertilizer application, pest and disease control, bird scaring.

3.14 Nitrogen, Phosphorus and Potasium Content of Azolla Accessions

Nitrogen, phosphorus and potassium contents, on a dry weight basis of *Azolla* from various sections of Mwea ranged from 2.0% to 3.4%, 0.20-0.40% and 0.24-1.35% respectively. *Azolla* collected from Tebere and MC sections had significantly lower N content than the rest of the sections. Samples from Mwea, Wamumu and Ndekia sections had significantly the highest P content compared to samples collected from other sections, while Karaba samples had significantly the least P content. *Azolla* samples from Ndekia and Wamumu had significantly the highest and the least content of K respectively (Table 19).

Table 19. Tissue N, P and K contents of *Azolla* from different sections of Mwea Irrigation Scheme in 2016

Accession	%/N	%/P	%/K
Mwea	2.40	0.40	0.7
Thiba	2.60	0.26	0.83
Wamumu	2.50	0.40	0.24
Tebere	2.00	0.29	0.67
Karaba	2.30	0.20	0.68
Ndekia	3.40	0.40	1.35
Mutithi/curukia	2.00	0.36	1.06
Mean	**2.5**	**3552.0**	**0.80**
P-value	**<0.000**	**0.0001**	**0.0001**
LSD (0.05)	**0.2**	**248.4**	**0.27**
CV (%)	**3.4**	**2.9**	**13.6**

3.15 Irrigation Water Quality

The level of N, P, K and pH in the irrigation water averaged 9.6 ppm, 0.8 ppm, 4.4 ppm, and 6.6 respectively (Table 20). Generally, the highest N, P, K and pH levels were from Tebere, Wamumu, Ndekia and Karaba samples respectively. Mutithi/curukia water samples had significantly the highest Cl (12.2 meq/l) and Ec levels (1.0 ds/m). The N, pH, Cl and Ec levels were within acceptable limits based on FAO standards (Ayers and Westcot, 1985).

Table 20. Irrigation water quality from sections of Mwea Irrigation scheme

Accession	N (ppm)	P (ppm)	K (ppm)	pH	Cl meq/l	Ec250 ds/m
Mwea	9.2	0.6	4.4	6.9	7.4	0.6
Thiba	6.7	0.4	5.2	6.5	5.9	0.7
Wamumu	11.3	1.1	4.0	6.3	7.6	6.4
Tebere	12.2	0.7	45	6.3	8.3	0.5
Karaba	11.0	1.0	3.4	7.8	9.0	0.5
Ndekia	8.2	0.5	6.4	5.9	8.3	0.5
Mutithi/curukia	8.9	1.0	3.5	6.8	12.2	1.0
Mean	**9.6**	**0.8**	**4.5**	**6.6**	**8.1**	**0.6**
P-value	**0.0003**	**0.002**	**0.87**	**0.15**	**0.00001**	**0.28**
LSD (0.05)	**1.2**	**0.2**	**NS**	**NS**	**0.67**	**NS**
CV (%)	**5.0**	**10.2**	**21.4**	**5.8**	**3.4**	**15,4**

3.16 Linear Regresion Relationship Between Azolla Tissue N, P, K and Irrigation Water N, P and K in Mwea Irrigation Scheme

Linear regression analysis showed a strong positive and significant linear relationship between *Azolla* tissue N and irrigation water N (r = 0.82), a weak negative and non-significant relationship between tissue P and irrigation water P (r = 0.24) and a non-significant positive relationship between tissue K and irrigation water K (r = 0.43).

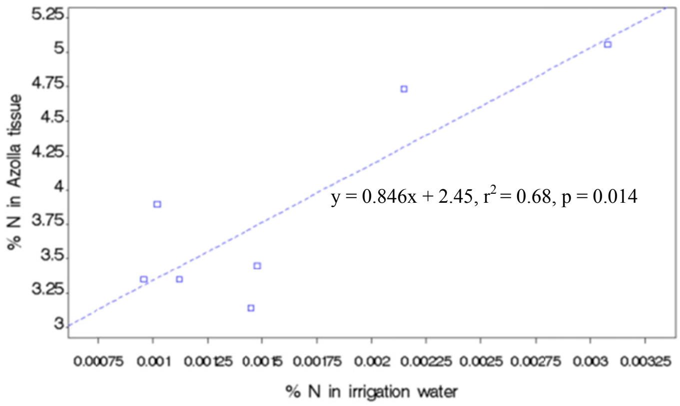

Figure 2. Linear regression relationship between *Azolla* tissue N and irrigation water in Mwea Irrigation Scheme

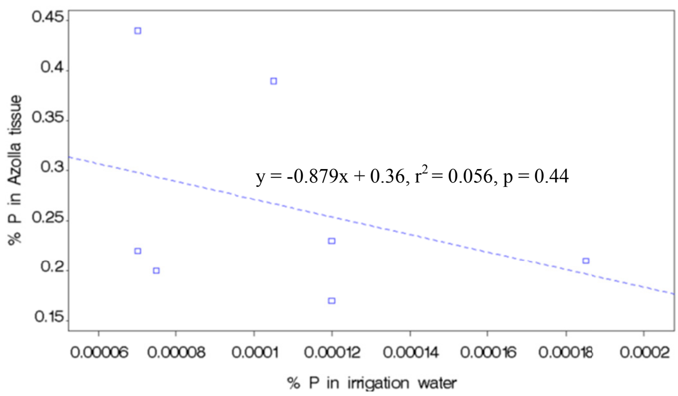

Figure 3. Linear regression relationship between *Azolla* tissue P and irrigation water P in Mwea Irrigation Scheme

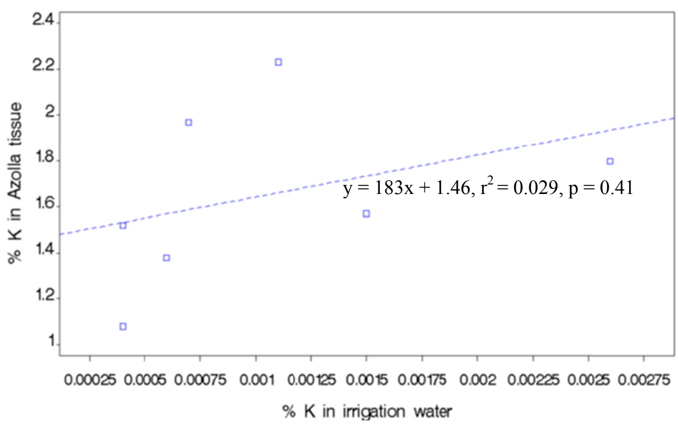

Figure 4. Linear regression relationship between *Azolla* plant tissue K and irrigation water K

3.17 Azolla biomass Levels and Potential N Contribution in Mwea Paddies

Azolla infestation level and the potential nitrogen contribution in Mwea Paddies are shown in Table 21. *Azolla* biomass production averaged 8,555.7 kg/ha and 286.9 kg/ha during the first and second season respectively. Ndekia section had significantly the highest biomass levels of 19,303 kg/ha followed by Tebere (14,725 kg/ha). The average potential N contribution by *Azolla* was about 11 kg N/ha and 0.4 kg N /ha during the first and second season respectively. *Azolla* in Ndekia section had the highest potential N (32.8.1 Kg N/ha) contribution followed by Thiba section (19.1 Kg N/ha). The second season was occasioned by lack of irrigation water due to low rainfall on the Thiba and Nyamindi river sources in Mount Kenya region.

Table 21. *Azolla* infestation levels and potential N contribution in paddies at Mwea Irrigation Scheme

Section	*Azolla* coverage (kg/ha)	Potential N (kg/ha)
Season 1		
Mwea	7251.0	8.7
Thiba	14725.0	19.1
Tebere	5344.0	5.3
Wamumu	9125.0	11.4
Karaba	2576.0	3.0
Ndekia	19303.0	32.8
Mutithi/curukia	3666.0	3.7
Mean	**8855.7**	**11.1**
P-value	**< 0.0001**	**< 0.0001**
LSD (0.05)	**4445.2**	**6.8**
CV (%)	**42.8**	**47.8**
Season 2		
Mwea	483.0	0.6
Thiba	920.7	1.2
Tebere	230.7	0.2
Wamumu	271.3	0.3
Karaba	6.7	0.0
Ndekia	83.3	0.1
Mutithi/curukia	0.0	0.0
Mean	**286.9**	**0.4**
P-value	**0.081**	**0.049**
LSD (0.05)	**646.0**	**0.8**
CV (%)	**172.5**	**168.0**

4. Discussion

Results of the survey indicated that Mwea Irrigation Scheme is infested with *Azolla* fern and on average 97% of the farmers were aware of it. Presence of native *Azolla* species had been reported in Ahero (AIRS Report, No. 42) while Henderson (2002) and McConnachie et al. (2004) reported the invasion of East Africa region by new world species. Majority of the participants had seen *Azolla* in their farms Mwea in Irrigation Scheme. Citing of *Azolla* infestation was first reported in Mwea, Thiba and Tebere sections of the Scheme. These sections are located on the upper parts of the scheme with reliable irrigation water. Presence in Ndekia and Mutithi curukia later during the period is due to the fact that these are out-growers sections, which were brought into rice production after 1998 (Washington-Ottombere & Evans, 2019). This also explains the significant relationship between the sections and irrigation water supply.

Prevalence of *Azolla* was reported at weeding and transplanting. This may be attributed to the predominant farmers' practice of land rotovation, followed by a two-month fallow flooding of paddies. Rice-MAPP (2012) reported this practice in a baseline survey. Flooded paddies are known to provide a good environment for growth of *Azolla* (Bochi & Maglioglio, 2010).

Azolla biomass level per unit area was reported to be on a decline. More than 10 years ago coverage was more than 50% in an acre and in 2016, it was less than 25% in an acre. The decline in *Azolla* biomass levels per unit area over the years can partly be attributed to inadequate irrigation water availability and frequent herbicide use. Nearly 80% of the respondents reported poor water availability especially in Karaba and Mutithi/Curukia. Karaba is located on the tail part of the scheme, thus being the last section to be supplied with irrigation water. Mutithi/Curukia on the other hand, is an out-growers' section that lacks irrigation infrastructure and normally relies on drainage canals for its supply. Water inadequacy is hence experienced in these areas. The strain on existing water resources has led to the National Irrigation Board implementing a water rationing program to enable all rice farmers in Mwea to cultivate rice (JICA, 2014). *Azolla* is an aquatic fern and lack of water exposes the weed to desiccation and death (Bhuvaneshari & Kumar, 2015). This therefore explains the significant relationship between the various sections and abundance of *Azolla*.

The use of herbicides in Mwea Irrigation Scheme is high. More than 90% of the respondents reported using herbicides. Out of these, 31% used post emergent herbicides while 51% used pre-emergent herbicides. Application of post emergent herbicides is normally done within 14 days after transplanting. This is the time period for weeding, which has been coincidentally, reported to also have abundant *Azolla* biomass. Elsewhere, use of herbicides has been reported to reduce *Azolla* population (Roncoroni, 2011; Ivens, 1987). In Wamumu section of the scheme, the relatively high usage of herbicides compared to other sections, may partly be a contributory factor to the comparatively low *Azolla* coverage reported in this section. Comparatively, there were high levels of *Azolla* infestation in Ndekia, Thiba and Tebere sections of the scheme. This can be associated with the location of the respective sections within reliable water supply which enables farmers to practice predominantly rice-rice and rice-ratoon-rice cropping systems. These systems ensure continuous flooding of fields and enhanced *Azolla* growth. Sadeghi et al. (2013) reported that water availability for *Azolla* growth is very important. Continuous cropping is also associated with more frequent P-fertilizer application, which is important for *Azolla* growth. Field analysis showed P levels of about 10.0 ppm which is equivalent to about 23 kg P_2O_5 per ha (Oyange, 2019).

The common management strategies for *Azolla* by most farmers (75%) included water drainage at transplanting and incorporation of *Azolla* into the soil at weeding, to facilitate transplanting and effective weed control respectively. Although the strategy was applied, *Azolla* continues to infest other parts of Mwea. Uses of herbicides have been recommended, but with utmost care (Cilliers et al., 2003). Biological control using weevils (*Stenopelmus rufinasus*) has been reported to be effective in South Africa (Hill & Cilliers, 1999). However, Hussner (2010) reported that *Azolla* lacks proper and effective control strategies.

The general perception of farmers about *Azolla* was positive. More than 70% of farmers concurred that *Azolla* increases soil fertility, tiller numbers and paddy yields. This is in concurrence with reported findings by Ferentinos et al. (2002) that *Azolla* improves soil quality through soil nitrogen supply. During the survey period, *Azolla* tissue N% on a dry weight basis was found to be between 2.4 and 3.4%. The amounts are closer to the reported range of 4-5% by Watanabe and Berja (1983). There was a significant positive relationship between *Azolla* tissue N and irrigation water N. This suggests that flood water N increases *Azolla* tissue N. It is in conformity with reported findings of Sah et al. (1989) that increase of N in growth media increased *Azolla* tissue N.

The maximum potential nitrogen contribution was 32.8 kg N/ha which is about 45% of the recommended rice crop paddy N requirement. In the second season, there were no significant differences partly due to long and prolonged drought, which made paddies to dry and caused death of existing *Azolla* biomass. The potential N contribution of 45% of the crop requirement therefore implies that *Azolla* is beneficial to rice crop production. Farmers in Mwea can therefore benefit from reduced cost of production by exploiting integrated *Azolla* use in paddy rice production system.

5. Conclusion

Azolla fern has infested Mwea Irrigation Scheme and it is well known to farmers. Its level of infestation is high although per unit area occupation is on a declining trend due to drought. Farmers in Mwea have appreciated the positive effect of *Azolla* on paddy rice production although they lack a good management strategy for it. In Mwea Irrigation Scheme, *Azolla* infestation has positively complemented the soil nutrient status thus reducing inorganic fertilizer requirements.

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