Kerala State Council For Science, Technology & Environment Science Research Scheme

Productivity enhancement in rice through promoting zinc nutrition using mycorrhizal symbiosis in Kuttanad soils

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Introduction

Kuttanad region of Kerala is a unique agricultural area lying 0.6 to 2.2 m below mean sea level and it is considered as the rice bowl of Kerala producing nearly 30 per cent of states rice output. The paddy fields in Kuttanad are wetlands reclaimed from the Vembanad lake and are classified into Kayal, Karappadom and Kari lands. The land area of Kuttanad is divided into a large number of padasekharams surrounded by broad man made bunds of mud or rubbles.The different padasekharams are separated from one another by canals and rivers.Rice is grown in these padasekharams after pumping out water into the adjoining water ways.

Kuttanad soil condition is highly specific to the dynamic soil nutrient changes that in turn affect the productivity of the crop .Unprecedented floods, soil problems like salinity, acidity and precipitation of mineral salts like Fe, Al etc bring about considerable damage and yield loss to rice crop in addition to the biotic stress.Iron toxicity is one of the major yield-limiting factors in lowlands by inhibiting plant growth,and root development, which influences uptake and retention of nutrients.Applying plant nutrients that are deficient, like P, K, Ca, Mg and Zn, may play an important role in the management of iron toxicity .Scientific recommendations have been standardised for all these nutrients.But as far as Zinc is concerned being a micronutrient blanket application is not possible and it is not practically possible to suggest farmers to go for soil testing before each crop.Previous experiments conducted at Kuttanad have indicated not only the high residual effect of soil Zinc but also its low mobility(KAU,2011). Arbuscular mycorrhizal fungi are known to improve the availability of nutrients especially phosphorus,moving them to the root surface by diffusion(Jakobsen et al., 1992). It is also reported that mycorrhizal symbiosis enhances absorption of relatively immobile micronutrients such as Zn and Cu (Ryan and Angus, 2003). Accordingly, absorption area is important parameter influencing bioavailability of Zn (Hacisalihoglu and Kochian,2003). Therefore, an increased absorption surface as a result of arbuscular mycorrhizal colonization may be of particular importance for Zn uptake. Very little research has been undertaken to study the significance of mycorrhizal symbiosis in Zinc nutrition in rice but no such work is yet reported in wetlands. This project is proposed to explore the capacity of AMF to tap the nutrients like Zn and P in iron toxic soils thereby improving the growth ,productivity and profitabilityof lowland rice in an ecofriendly and sustainable manner.

Materials and Methods

Location: Wetlands at Regional Agricultural Research Station, Kumarakom.

Design: Randomized Complete Block design

Replication: 3

Plot size: 25 m^2

Number of treatments: 9

The details of treatments are furnished below

T1 - Control

T2 - Recommended dose of nutrients - Lime @ 600 kg ha^{-1}; FYM @5t/ha; NPK @ 90:45:45 kg/ha

T3 - T2 + Sowing seeds coated with AMF @ 1kg for 1 acre seeds (32 kg) + Soil application @ 1 kg AMF in 1t of FYM for 1 acre.

T4 - T2 + Zn as $ZnSO_4$ @ 10 kg ha^{-1} once during the cropping season

T5 - T2 + Zn as $ZnSO_4$ @ 20 kg ha^{-1} once during the cropping season

T6 - T4 + Sowing seeds coated with AMF @ 1kg for 1 acre seeds (32 kg) + Soil application @ 1 kg AMF in 1t of FYM for 1 acre.

T7 - T5 + Sowing seeds coated with AMF @ 1kg for 1 acre seeds (32 kg) + Soil application @ 1 kg AMF in 1t of FYM for 1 acre.

T8 - T3+ Foliar application of Zn at the POP rate

T9 - T3 + Half the recommended dose of P and K

The experiment has been laid out in paddy fields under direct sown condition during first year (June 2014) and next two years (June 2015 and 2016)under both direct sown and transplanted situation. Seeds of wetland rice (*Oryza sativa* L.) variety Uma (MO.16) suited to Kuttanad soils and extensively cultivated with 120 days duration was sown. The seeds were soaked in water for 24 h and then allowed to germinate in warm, moist condition. These pre germinated seeds were used for sowing with and without AMF treatment in direct sown rice. Mat nursery was raised to produce rice seedlings for transplanting.AMF mixed with farmyard manure was applied in the mat nursery before sowing .Soil application of AMF was imposed one month after sowing/ transplanting. All other management practices were followed as per Package of Practices Recommendations "Crops" (KAU, 2016).

Plants were sampled from the plot at active tillering stage (30 DAS), panicle initiation (70 DAS) and at harvest. Three replicate plots were sampled for each treatment at each sampling time. Biometric observations, yield and yield attributing characters, soil and plant nutrient statuses at different stages of growth were recorded. The data were statistically analyzed using the ANOVA technique and results drawn.

Experimental setup

RESULTS

DIRECT RICE – YEAR I

The experiment has been laid out in direct seeded rice plots of Kuttanad during Virippu season. Biometric observations and yield data were recorded as per the treatments. Soil and plant nutrient analysis were completed. Microbial observations were also observed at regular intervals. Statistical analysis of the data generated also were completed and final conclusions made.

a) Effect of treatments on growth parameters

Plant height, number of tillers as well as number of productive tillers did not differ significantly with treatments at any stages of growth.

Table.1. Biometric characters as influenced by the treatments

Treatments	Plant height in cm			No of tillers		No. of productive tillers	
	At tillering	At PI	At harvest	At tillering	At PI	At PI	At harvest
T1	46.67	92.33	94.33	5.89	12.67	8.00	11.99
T2	45.33	99.10	98.00	7.67	14.43	10.67	13.33
T3	47.11	98.00	94.8	5.57	11.77	8.80	10.89
T4	47.22	92.47	99.73	9.47	9.77	8.43	13.11
T5	41.44	95.67	99.07	7.13	11.43	8.80	13.22
T6	47.11	95.1	93.87	5.10	12.80	8.10	13.11
T7	46.22	97.77	102.67	5.53	14.20	10.00	11.89
CD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

b) Effect of treatments on root parameters

Root length, width and weight did not vary significantly with the treatments

Table.2. Root studies as influenced by the treatments

Treatments	Length in cm	Width in cm	Weight in g
T1	18.93	5.83	71.33
T2	21.27	5.77	55.00
T3	16.53	5.43	43.13
T4	19.53	5.37	61.33
T5	19.60	6.23	76.67
T6	18.53	5.60	56.33
T7	20.53	6.90	93.33
CD	**NS**	**NS**	**NS**

c) Effect of treatments on yield parameters

Grain yield as well as straw yield did not vary significantly with the treatments. However the highest test weight, grain yield and straw yield was recorded for the treatment T4 which indicates the importance of zinc nutrition in Kuttanad soils. In addition the lowest yield was recorded with high doses of Zinc (T 6 and T7) which points to the fact that balanced zinc is essential for higher yield in direct sown rice of Kuttanad wetlands.

Table.3. Yield characters as influenced by the treatments

Treatments	1000 grain weight in g	Grain yield in t ha^{-1}	Straw yield in t ha^{-1}
T1	26.16	6.57	7.23
T2	25.04	5.90	6.49
T3	26.85	6.92	7.61
T4	27.87	7.25	7.98
T5	26.58	6.58	7.24
T6	26.96	5.07	5.58
T7	25.88	5.45	5.99
CD	NS	NS	NS

d) Effect of treatments on available soil nutrients

Perusal of the data in table 4 and 5 showed that soil nutrient status is highly dynamic in this system and it is the nutrient interactions linked with pH, aeration and presence of other elements decides the absorption of essential nutrients by plants which in turn decide the nutrients available for metabolism and thereby yield. Availability of a nutrient alone in the soil cannot indicate its absorption and its influence on yield.

Table.4. Initial nutrient status of the soil

		Available nutrients					
pH	Organic carbon	Phosphorus	Potassium	Calcium	Magnesium	Iron	Zinc
	%	kg ha^{-1}		ppm			
4.65	8.5	50.65	247.27	1300	140	223	17.52

Table.5.Available nutrient status in the soil after the experiment

Treatment	pH	Organic carbon	Available nutrients					
			Phosphorus	Potassium	Calcium	Magnesium	Iron	Zinc
		%	kg ha^{-1}		ppm			
T1	4.29	13.61	69.01	102.15	410.67	163.00	132.99	10.48

T2	4.12	12.01	73.06	125.93	379.00	283.67	154.85	8.30
T3	4.64	12.99	83.83	109.35	486.67	223.00	146.68	7.50
T4	3.73	13.58	66.42	111.31	379.33	163.23	128.31	5.09
T5	3.87	14.73	68.73	114.61	507.00	119.50	141.63	4.15
T6	4.41	14.07	72.48	107.87	558.33	87.00	138.61	4.57
T7	3.87	11.24	58.63	102.77	338.33	156.27	138.94	7.47
CD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**5.566**

e) Effect of treatments on plant nutrient parameters

In all the treatments at different stages of sampling, essential nutrients like potassium, calcium, magnesium and zinc were in the general sufficiency range except for deficient level of phosphorus and toxic level of iron which indicates that iron toxicity in the soil favoured excess absorption of iron and limited the uptake of phosphorus.All the treatments did not vary significantly in the plant content of nutrients except zinc content at panicle initiation. More zinc has been absorbed by plant at lower dose of soil applied zinc with and without AMF.

Table.6.Nutrient content in the plant as influenced by the treatments

Treatments	Phosphorus ,%			Potassium, %		
	Tillering	PI	Harvest	Tillering	PI	Harvest
T1	0.016	0.051	0.046	2.43	2.83	4.81
T2	0.041	0.093	0.032	2.32	2.13	2.94
T3	0.010	0.087	0.013	2.67	2.31	2.54
T4	0.017	0.099	0.001	2.60	2.61	3.30
T5	0.067	0.146	0.022	3.12	2.57	3.43
T6	0.092	0.165	0.040	2.51	3.59	2.60
T7	0.084	0.140	0.036	2.55	2.84	3.69
CD	0.049	0.083	**NS**	**NS**	1.138	1.698

Table.7.Nutrient content in the plant as influenced by the treatments

Treatments	Calcium,%			Magnesium,%		
	Tillering	PI	Harvest	Tillering	PI	Harvest
T1	0.355	0.681	0.681	0.249	0.178	0.231
T2	0.207	0.503	0.622	0.320	0.320	0.142
T3	0.355	0.829	0.651	0.320	0.107	0.124
T4	0.385	0.592	0.681	0.195	0.302	0.195

T5	0.503	0.533	0.651	0.142	0.444	0.213
T6	0.562	0.829	0.533	0.249	0.231	0.284
T7	0.355	0.829	0.533	0.426	0.160	0.320
CD	NS	NS	NS	NS	NS	NS

Table.8. Nutrient content in the plant as influenced by the treatments

Treatments	Iron, ppm			Zinc , ppm		
	Tillering	PI	Harvest	Tillering	PI	Harvest
T1	2003.33	1658.33	1621.67	23.87	24.27	75.07
T2	1025.00	1451.67	2068.33	20.20	21.53	92.53
T3	918.33	1541.67	1526.67	23.93	19.20	46.20
T4	1941.67	1508.33	1376.67	22.33	56.47	70.80
T5	4020.00	1545.00	1251.67	23.80	59.00	78.87
T6	3851.67	1536.67	1483.33	23.00	55.67	85.87
T7	2831.67	1500.00	1373.33	19.73	49.07	95.27
CD	1963.892	NS	642.946	NS	18.875	NS

f) Effect of treatments on mycorrhizal assays

No root colonization observed at tillering, panicle initiation and at harvest. It can be correlated with the anaerobic conditions created by heavy rainfall during the season. **The AMF culture containing *Glomus fasciculatum*,*Glomus etunicatum*,*Glomus mosseae*, *Sclerocystis microcarpus sp* and *Acaulospora sp*. cannot come up under anaerobic conditions In the paddy wetlands of Kuttanad.** Hence the AMF culture in the following years of experimentation has been changed to ***Glomus Intraradices*** which has been proved to come up under anaerobic conditions in nursery conditions.

DIRECT RICE – YEAR II

a) Effect of treatments on growth parameters

All biometric characters except number of productive tillers did not vary significantly with treatments. The number of productive tillers was highest in T6 soil application of RDN, zinc@10 kg ha^{-1} and AMF. It was on par with T2, T3, T7, T8 and T9.

Table.9. Biometric characters as influenced by the treatments under direct rice

Treatments	Plant height in cm			No of tillers		No. of productive tillers	
	At tillering	At PI	At harvest	At tillering	At PI	At PI	At harvest
T1	44.23	93.88	98.67	5.22	5.11	5.11	3.67
T2	43.00	90.00	101.89	4.56	5.22	4.89	6.33
T3	50.57	96.55	100.66	4.33	6.77	6.12	6.55
T4	50.23	97.55	95.66	4.55	6.89	6.32	4.11
T5	40.10	89.22	98.99	4.33	4.77	4.55	4.77
T6	38.47	95.33	99.11	4.11	8.00	7.77	7.66
T7	40.43	95.22	99.44	5.78	5.77	5.65	6.11
T8	60.33	101.22	102.33	6.11	6.44	6.22	6.67
T9	50.33	101.88	101.11	5.33	9.55	9.43	7.42
CD	**5.678**	**NS**	**NS**	**NS**	**NS**	**NS**	**1.629**

b) Effect of treatments on root parameters

Perusal of the data indicated that none of the root parameters varied significantly with treatments

Table.10.Root studies as influenced by the treatments under direct sown rice

Treatments	Length in cm	Width in cm	Weight in g
T1	21.50	33.39	59.77
T2	21.61	31.77	98.11
T3	20.77	30.77	113.14
T4	18.61	28.22	62.44
T5	22.00	29.33	60.31
T6	19.00	26.89	53.66
T7	21.54	30.66	56.10
T8	22.77	31.89	62.88
T9	18.88	27.89	66.14
CD	NS	NS	NS

c) Effect of treatments on yield parameters

Grain and straw yield recorded higher values with T 8 followed by T3. T3 with foliar application of Zinc is T8.However number of grains per panicle and 1000 grain weight did not differ significantly.

Table.11. Yield characters as influenced by the treatments under direct sown rice

Treatments	No. of grains per panicle	1000 grain weight in g	Grain yield in t ha^{-1}	Straw yield in t ha^{-1}
T1	100.18	19.65	4.24	4.66
T2	124.33	18.90	5.47	6.20
T3	135.00	22.84	5.64	6.20
T4	136.22	22.19	5.08	5.59
T5	132.33	21.39	4.58	5.03
T6	128.67	14.85	5.30	5.83
T7	122.67	21.73	4.62	5.08
T8	134.33	22.10	6.20	6.82
T9	144.00	21.12	5.23	5.75
CD	NS	NS	1.040	1.144

d) Effect of treatments on available soil nutrients

Perusal of the soil data of available nutrients before and after the experiment as well as at different critical growth stages of the crop emphasized that Kuttanad soils are highly dynamic with foxicities of iron, manganese and sulphur.

Table.12. Initial available nutrient status of the soil in direct sown rice field

	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Organic Carbon %	Manganese ppm	Copper ppm	Zinc ppm	Iron ppm
T1	9.85	502.46	4.85	4.30	2.35	2.49	622.5
T2	9.00	342.80	5.36	4.06	2.28	3.00	750
T3	14.25	340.34	5.36	2.36	1.77	2.64	660
T4	9.61	460.96	9.62	4.54	2.95	4.48	1120
T5	20.33	401.72	7.35	1.82	2.10	2.43	607.5
T6	17.52	453.46	4.90	1.95	1.37	1.99	497.5
T7	8.46	494.68	9.07	3.20	1.77	2.74	685
T8	7.65	270.11	5.00	2.96	1.69	3.41	852.5
T9	9.91	348.92	6.13	5.31	2.72	3.39	847.5

Table.13. Nutrient status of the soil in direct sown rice field at active tillering and panicle initiation

	Available soil nutrients at active tillering				Available soil nutrients at panicle initiation			
	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm
T1	25.49	1.75	1.25	596.0	13.77	3.60	1.60	262.93
T2	13.18	1.89	0.72	1375.6	23.75	3.47	1.32	198.90
T3	19.17	2.66	0.62	344.8	18.54	3.22	1.26	227.33
T4	14.46	2.79	0.79	929.7	12.66	3.17	1.24	192.93
T5	22.22	2.65	0.82	1202.4	16.40	4.96	1.47	246.37
T6	14.04	1.96	0.96	1273.3	11.83	3.52	1.49	218.70
T7	25.71	1.84	0.92	1158.6	15.39	3.86	1.30	194.33
T8	18.43	2.82	1.33	664.3	16.73	4.30	1.40	205.13
T9	17.91	0.98	0.75	419.7	11.16	3.65	1.73	268.97
CD	**NS**	**0.711**	**0.407**	**606.748**	**NS**	**NS**	**0.278**	**NS**

Table.14. Nutrient status of the soil after harvest in the direct sown rice

	Available soil nutrients							
	pH	EC	Organic carbon	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calcium ppm	Magnesium ppm	Sulphur ppm
T1	5.29	558.3	0.45	11.27	238.05	851.52	579.73	245.05
T2	5.89	437.5	0.98	14.62	156.03	947.89	653.09	316.61
T3	5.86	373.0	0.72	8.59	159.24	528.10	420.80	190.59
T4	5.69	344.0	0.45	7.49	164.72	575.11	631.30	230.43
T5	5.48	261.6	0.69	11.38	250.42	814.50	742.91	254.51
T6	5.53	371.0	0.87	13.82	228.93	802.39	654.32	117.22
T7	6.00	333.0	0.88	11.80	204.34	1010.31	890.35	259.88
T8	6.04	215.0	0.83	10.53	176.99	567.17	580.74	240.56
T9	5.65	389.3	0.78	17.37	326.81	1195.09	504.70	259.65
CD	**0.452**	**NS**	**NS**	**NS**	**102.929**	**NS**	**NS**	**NS**

Table.15. Micronutrient status of the soil after harvest in the direct sown rice

	Available soil nutrients				
	Boron. ppm	Copper, ppm	Zinc. ppm	Iron. ppm	Manganese. ppm
T1	1.13	1.77	6.70	1407.20	339.40
T2	1.42	12.80	9.43	855.27	309.90
T3	1.77	3.17	12.47	1875.40	303.03
T4	1.93	6.07	9.43	365.50	317.33
T5	1.40	10.07	9.33	772.67	282.43
T6	0.97	4.07	16.77	1420.67	297.37
T7	1.98	24.03	10.53	6551.67	315.50
T8	2.14	10.53	18.90	584.50	346.50
T9	0.53	0.33	9.03	747.50	385.80
CD	**NS**	**7.889**	**NS**	**1746.63**	**43.274**

e) Effect of treatments on plant nutrient parameters

Phosphorus recorded higher values with T 8 followed by T2 and T3.Potassium was highest in T3 followed by T8.Maximum values of zinc was recorded with respect to T5 and T1.Nutrient contents in plant did not show any difference with treatments at panicle initiation stage. Higher values of phosphorus observed with T8 and T9 at harvest. The potassium content in grain was the highest with T8 whereas magnesium with T9 followed by T3.Though not significant statistically zinc content in the grain was highest in T8 followed by T5,T9 and T3 respectively and least recorded in control.

Table.16. Plant nutrient content in direct sown rice at active tillering

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.24	0.55	0.43	0.52	4.33	23.63	89.67	115.13
T2	0.26	0.56	0.59	0.68	3.47	13.87	128.33	132.87
T3	0.26	0.67	0.55	0.59	3.30	18.67	136.00	107.57
T4	0.24	0.61	0.79	0.45	4.70	16.60	114.47	78.80
T5	0.25	0.56	0.47	0.54	4.03	24.07	138.33	113.60
T6	0.14	0.44	0.65	0.28	3.17	20.90	108.33	78.13
T7	0.14	0.42	0.50	0.45	3.03	18.97	135.33	112.33
T8	0.29	0.66	0.63	0.50	5.10	20.13	191.67	89.50
T9	0.17	0.45	0.54	0.43	4.43	20.37	86.33	55.60
CD	**0.065**	**0.173**	**NS**	**NS**	**NS**	**5.885**	**54.511**	**NS**

Table.17. Plant nutrient content in direct sown rice at panicle initiation

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.10	3.41	0.70	0.80	2.90	19.67	45.33	427.37
T2	0.10	2.26	0.95	0.70	3.13	21.33	84.53	451.40
T3	0.09	2.81	0.83	0.69	2.53	20.97	160.13	430.20
T4	0.12	3.01	0.60	0.77	3.67	23.23	102.00	452.20
T5	0.10	2.11	0.78	0.63	3.90	30.70	60.60	333.90
T6	0.09	2.31	0.76	0.64	1.87	20.63	16.37	362.03
T7	0.12	2.70	0.47	1.09	2.43	27.47	97.53	429.87
T8	0.13	2.92	1.09	0.58	2.40	22.43	146.10	384.23
T9	0.09	2.30	0.75	0.83	3.47	18.80	31.30	356.80
CD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**88.719**	**NS**

Table.18. Plant nutrient content in direct sown rice at harvest

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.17	0.89	0.52	1.05	39.75	13.75	61.50	158.90
T2	0.13	1.12	0.59	0.99	35.00	16.08	47.25	143.63
T3	0.14	1.10	0.40	0.99	32.33	48.00	32.92	150.20
T4	0.12	1.18	0.82	0.99	33.08	40.92	58.33	129.27
T5	0.15	1.46	0.45	1.21	39.67	24.92	52.00	151.20
T6	0.18	1.34	0.52	1.27	40.75	17.42	65.67	140.47
T7	0.17	0.87	0.42	0.88	39.92	28.00	64.58	113.17
T8	0.20	1.15	0.35	1.10	39.33	18.33	52.50	126.47
T9	0.19	1.23	0.42	1.10	43.25	15.83	54.08	142.20
CD	**0.041**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table.19. Nutrient content of grains in direct sown rice

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.22	0.69	0.59	0.69	1.47	3.10	375.93	30.57
T2	0.24	0.65	0.17	0.66	2.10	3.43	304.73	29.63
T3	0.24	0.60	0.26	0.81	1.40	3.70	294.17	37.20
T4	0.23	0.66	0.47	0.68	1.57	3.07	252.43	30.73
T5	0.22	0.64	0.14	0.56	1.10	3.77	244.23	26.10
T6	0.26	0.60	0.26	0.75	1.47	3.30	305.50	32.63
T7	0.25	0.62	0.14	0.47	1.57	3.50	238.17	26.87
T8	0.26	0.72	0.22	0.72	1.43	4.27	441.60	39.27
T9	0.21	0.64	0.43	0.86	3.57	3.73	987.67	35.40
CD	**NS**	**0.057**	**NS**	**0.184**	**NS**	**NS**	**284.485**	**5.863**

DIRECT RICE – YEAR III

a) Effect of treatments on growth parameters

Plant height varied significantly at active tillering and panicle initiation and highest values were recorded for T8 followed by T 3.Number of productive tillers at harvest was higher with T3 and T7 followed by T9.All other parameters did not vary significantly with treatments.

Table.20. Biometric characters as influenced by the treatments under direct rice

Treatments	Plant height in cm			No of tillers		No. of productive tillers	
	At tillering	At PI	At harvest	At tillering	At PI	At PI	At harvest
T1	30.33	59.77	90.83	3.00	5.89	3.55	4.55
T2	34.53	82.88	91.78	3.11	5.78	2.89	4.77
T3	36.67	87.33	89.83	3.12	6.10	5.22	6.33
T4	35.23	67.33	91.55	2.66	6.43	4.33	4.88
T5	29.67	66.44	87.55	2.66	5.79	2.89	4.11
T6	28.43	66.33	84.44	3.00	5.33	3.22	5.55
T7	29.90	79.11	90.66	3.00	7.79	3.55	6.33
T8	40.00	94.44	91.39	3.00	7.01	6.11	5.33
T9	29.53	71.11	88.78	2.78	7.01	5.33	6.22
CD	**3.821**	**8.665**	**NS**	**NS**	**NS**	**NS**	**1.452**

b) Effect of treatments on root parameters

Root length and width showed highest values with T8.Root weight did not differ significantly with treatments.

Table.21.Root studies as influenced by the treatments under direct sown rice

Treatments	Length in cm	Width in cm	Weight in g
T1	17.22	11.11	64.61
T2	14.77	8.50	42.70
T3	17.77	9.00	61.92
T4	17.22	8.66	59.83
T5	15.44	8.99	55.73
T6	18.11	9.82	77.98
T7	15.00	8.00	76.32
T8	21.22	11.33	74.80
T9	17.05	9.39	82.64
CD	3.263	1.605	NS

c) Effect of treatments on yield parameters

No difference observed in yield and yield attributing characters recorded with treatments. However pooled yield data over seasons in direct sown rice recorded maximum value with T8 which involved AMF application with foliar applied zinc.

Table.22. Yield characters as influenced by the treatments

Treatments	No. of grains per panicle	1000 grain weight in g	Grain yield in t ha^{-1}	Straw yield in t ha^{-1}	Pooled grain yield in t ha^{-1}
T1	70.00	21.55	4.64	5.10	4.44
T2	82.78	21.16	4.90	5.39	5.19
T3	90.00	24.37	4.14	4.55	4.89
T4	80.33	23.26	5.16	5.67	5.12
T5	69.33	20.87	3.20	3.52	3.89
T6	81.55	23.20	4.28	4.71	4.03
T7	90.89	25.45	3.77	4.15	4.20
T8	109.98	23.10	4.83	5.31	5.51
T9	104.22	22.84	4.27	4.70	4.75
CD	NS	NS	NS	NS	NS

d) Effect of treatments on available soil nutrients

Soil nutrient data varied differently among treatments indicating Kuttanad soils are highly dynamic with toxicities of iron, manganese and sulphur.

Table.23. Initial available nutrient status of the soil in direct sown rice field

	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Organic Carbon%	Manganese ppm	Copper ppm	Zinc ppm	Iron ppm
T1	5.04	302.06	6.42	59.73	4.92	10.67	320.57
T2	6.72	341.82	4.62	32.70	3.86	7.92	282.05
T3	6.05	287.06	3.12	34.14	3.60	8.67	279.32
T4	9.97	392.56	4.62	34.76	3.47	13.04	331.98
T5	5.94	343.17	4.62	27.57	3.68	15.39	240.03
T6	4.03	334.32	4.50	29.74	4.08	7.61	288.47
T7	9.52	354.48	4.26	19.76	2.72	7.47	275.18
T8	6.94	375.65	2.82	35.68	2.63	7.42	294.37
T9	3.81	346.64	5.34	26.63	3.95	8.77	305.76

Table.24. Nutrient status of the soil in direct sown rice field at active tillering and panicle initiation

	Available soil nutrients at active tillering				Available soil nutrients at panicle initiation			
	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm
T1	7.73	16.36	3.21	105.71	11.13	5.68	2.34	166.17
T2	7.99	5.15	2.33	110.91	8.18	5.21	1.99	164.89
T3	13.18	5.97	3.66	194.87	13.29	5.87	1.93	154.14
T4	11.54	5.98	2.60	148.63	6.76	6.38	1.96	126.06
T5	7.28	7.06	2.77	103.29	13.99	13.82	2.28	104.05
T6	9.30	6.44	2.68	133.81	15.49	6.59	2.61	140.73
T7	13.18	6.65	2.55	107.91	12.92	7.10	2.20	184.99
T8	6.83	5.14	1.91	183.48	16.54	6.82	2.06	96.48
T9	13.22	5.99	3.38	119.66	12.96	5.81	2.62	165.81
CD	**NS**	**NS**	**NS**	**NS**	**4.107**	**NS**	**0.445**	**NS**

Table.25. Nutrient status of the soil after harvest in the direct sown rice

	Available soil nutrients							
	pH	EC	Organic carbon	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calcium ppm	Magnesium ppm	Sulphur ppm
T1	4.56	826.67	6.10	13.48	326.44	896.00	728.33	245.49
T2	4.64	836.33	5.92	12.73	265.25	864.00	690.00	264.97
T3	4.57	746.67	4.72	14.41	201.19	633.60	513.67	228.97
T4	4.64	919.33	4.24	14.78	278.32	864.00	440.83	223.93
T5	4.77	697.67	4.18	13.18	304.56	806.40	647.83	234.85
T6	4.81	790.33	6.34	13.59	297.32	928.00	636.33	256.24
T7	4.64	795.67	5.42	14.00	297.25	1152.00	502.17	265.49
T8	4.49	1054.00	5.26	14.30	264.09	742.40	540.50	199.89
T9	4.71	883.00	4.34	11.61	321.29	928.00	701.50	210.27
CD	**0.156**	**NS**	**1.253**	**NS**	**NS**	**266.551**	**NS**	**NS**

Table.26. Micronutrient status of the soil after harvest in the direct sown rice

	Available soil nutrients				
	Boron, ppm	Copper, ppm	Zinc, ppm	Iron, ppm	Manganese, ppm
T1	1.49	2.03	6.52	339.40	28.33
T2	1.08	1.62	6.21	309.90	22.96
T3	0.73	1.23	5.75	303.03	18.85
T4	0.63	1.65	11.14	317.33	20.58
T5	0.76	1.06	8.12	282.43	18.12
T6	0.87	1.48	8.81	297.37	17.63
T7	0.40	1.40	8.27	315.50	20.29
T8	0.59	1.56	6.78	346.50	23.37
T9	0.70	2.91	6.65	385.80	27.89
CD	**0.447**	**0.710**	**NS**	**43.274**	**NS**

e) Effect of treatments on plant nutrient parameters

Plant phosphorus and iron were highest in T8 at active tillering stage. Potassium in index leaf was lowest with control and highest with T5 and was on par with T6, T7, T8 and T9.At harvest phosphorus content in the plant was highest with T8 and lowest

with control. Zinc content recorded higher values with T6, T7, T8 and T9 respectively. Calcium content in the grain varied significantly with treatments. Highest values were noticed in T7 and T8.Though statistically non significant grain zinc was maximum with T8, T7 and T5 and minimum in control.

Table.27. Plant nutrient content in direct sown rice at active tillering

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.21	2.24	0.81	1.01	0.04	37.87	70.11	17.41
T2	0.19	1.65	0.85	1.11	0.13	15.10	67.85	19.12
T3	0.21	2.13	1.04	0.82	0.19	40.43	77.76	48.11
T4	0.20	1.77	0.93	0.74	0.06	21.70	78.70	16.97
T5	0.21	1.75	0.81	0.91	0.11	53.77	77.54	22.30
T6	0.20	1.76	0.75	1.00	0.07	19.47	100.47	24.05
T7	0.17	1.73	0.73	0.83	0.18	18.53	105.52	25.43
T8	0.28	1.95	0.96	0.75	0.53	64.01	174.03	19.52
T9	0.20	2.08	0.90	0.77	0.11	32.37	128.33	22.24
CD	**0.046**	**NS**	**NS**	**NS**	**NS**	**NS**	**61.454**	**NS**

Table.28. Plant nutrient content in direct sown rice at panicle initiation

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.15	1.49	0.65	0.95	0.04	44.53	150.49	110.86
T2	0.14	1.72	0.83	0.68	0.06	60.83	68.46	12.39
T3	0.18	1.60	1.17	0.83	0.06	41.56	48.22	33.78
T4	0.17	1.68	1.17	0.74	0.04	46.33	61.35	24.50
T5	0.17	2.11	1.02	0.76	0.06	31.47	119.68	35.44
T6	0.16	1.97	0.96	0.74	0.09	37.94	166.08	44.29
T7	0.13	2.03	0.79	0.76	0.06	28.31	34.11	41.62
T8	0.18	1.95	1.08	0.76	0.10	44.07	50.89	32.52
T9	0.20	2.01	0.93	0.63	0.55	35.69	91.14	26.25
CD	**NS**	**0.266**	**NS**	**NS**	**0.275**	**NS**	**NS**	**NS**

Table.29. Plant nutrient content in direct sown rice at harvest

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Zinc ppm	Iron ppm	Manganese ppm
T1	0.08	1.71	0.49	0.46	18.13	38.24	88.05
T2	0.10	1.59	0.30	0.47	16.79	33.90	61.00
T3	0.09	1.52	0.42	0.61	26.43	27.48	62.18
T4	0.11	1.86	0.32	0.53	21.83	46.13	119.17
T5	0.11	1.72	0.49	0.50	19.91	39.80	98.16
T6	0.11	1.62	0.46	0.51	36.87	43.42	117.62
T7	0.10	1.67	0.32	0.74	33.37	37.78	141.60
T8	0.12	1.69	0.43	0.67	32.43	26.88	126.44
T9	0.11	1.69	0.54	0.43	29.74	30.74	129.73
CD	**0.017**	**NS**	**NS**	**NS**	**11.35**	**12.692**	**44.186**

Table.30. Nutrient content of grains in direct sown rice

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Zinc ppm	Iron ppm	Manganese ppm
T1	0.18	0.67	0.40	0.26	12.41	36.08	13.50
T2	0.23	0.62	0.24	0.46	12.75	43.36	15.58
T3	0.18	0.61	0.24	0.43	13.04	53.03	16.78
T4	0.27	0.60	0.05	0.47	13.17	47.11	18.12
T5	0.19	0.59	0.14	0.45	13.88	44.01	18.19
T6	0.25	0.61	0.18	0.48	13.41	58.87	15.69
T7	0.18	0.58	0.27	0.40	14.13	63.28	17.74
T8	0.20	0.57	0.25	0.40	14.22	57.95	16.87
T9	0.27	0.59	0.21	0.36	13.47	50.69	17.12
CD	**NS**	**NS**	**0.164**	**NS**	**NS**	**NS**	**NS**

TRANSPLANTED RICE – YEAR II

a) Effect of treatments on growth parameters

Number of tillers at active tillering stage was on par with T 7, T8 and T9 and recorded minimum values with T1.Number of productive tillers varied significantly with treatments at harvest. The highest value was recorded with T 6 and on par with T7, T8, T9 and T3.The lowest value was noticed in control. None of the other growth characters differed significantly with treatments.

Table.31. Biometric characters as influenced by the treatments under transplanted rice

Treatments	Plant height in cm			No of tillers		No. of productive tillers	
	At tillering	At PI	At harvest	At tillering	At PI	At PI	At harvest
T1	51.23	97.66	100.89	4.20	7.88	7.77	8.55
T2	46.20	101.11	98.11	5.23	10.11	9.21	9.55
T3	62.10	108.77	113.88	6.00	13.77	13.23	10.89
T4	80.00	96.11	104.66	6.00	10.55	9.68	9.55
T5	53.77	103.22	103.55	6.00	10.89	10.67	9.11
T6	49.57	98.55	106.65	7.67	10.22	9.55	13.11
T7	45.20	101.55	105.44	8.67	12.44	11.11	12.33
T8	59.53	100.55	116.11	8.10	10.44	10.00	10.88
T9	48.97	112.44	109.00	8.57	9.88	9.12	11.88
CD	**NS**	**NS**	**NS**	**1.925**	**NS**	**NS**	**1.629**

b) Effect of treatments on root parameters

Root length and width showed superiority in T3 followed by T8.However root weight showed no difference with treatments.

Table.32.Root studies as influenced by the treatments under transplanted rice

Treatments	Length in cm	Width in cm	Weight in g
T1	18.11	27.22	26.76
T2	13.99	22.33	23.31
T3	23.62	38.11	41.05
T4	20.77	32.00	18.07
T5	15.11	23.22	31.52
T6	16.88	27.33	35.25
T7	15.88	26.22	37.61
T8	20.89	33.33	28.50
T9	15.55	26.33	22.11
CD	**5.346**	**7.109**	**NS**

c) Effect of treatments on yield parameters

Number of grains per panicle, 1000 grain weight, grain and straw yield did not

differ significantly with treatments.

Table.33. Yield characters as influenced by the treatments under transplanted rice

Treatments	No. of grains per panicle	1000 grain weight in g	Grain yield in t ha^{-1}	Straw yield in t ha^{-1}
T1	101.89	19.38	4.80	5.28
T2	138.97	18.30	4.97	5.47
T3	132.11	23.50	5.55	6.11
T4	148.22	18.21	4.70	5.17
T5	124.33	20.96	5.52	6.07
T6	139.22	21.55	6.22	6.84
T7	139.00	22.83	5.69	6.26
T8	165.11	23.41	5.79	6.37
T9	148.89	20.66	6.14	6.75
CD	NS	NS	NS	NS

d) Effect of treatments on available soil nutrients

None of the available soil nutrients varied significantly at active tillering, panicle initiation and after harvest. Most of the treatment plots showed a deficient level of available phosphorus in the initial stage as well as at harvest though the level was sufficient at active tillering and panicle initiation. The soil available micronutrient varied differently which is inherent in Kuttanad soils.

Table.34. Initial available nutrient status of the soil in transplanted rice field

	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Organic Carbon %	Manganese ppm	Copper ppm	Zinc ppm	Iron ppm
T1	8.57	578.99	10.01	2.45	2.71	2.33	582.5
T2	2.70	407.33	9.08	2.64	2.33	2.81	702.5
T3	8.88	487.35	9.27	2.79	2.36	3.58	895
T4	12.60	561.95	11.85	2.83	2.59	2.91	727.5
T5	5.55	560.68	18.47	2.01	2.44	2.53	632.5
T6	7.06	461.88	9.13	5.14	2.27	2.62	655
T7	4.93	386.40	6.24	2.10	1.43	1.90	475
T8	18.19	462.95	4.64	2.66	1.79	3.29	822.5
T9	2.60	471.61	4.18	1.96	2.22	3.12	780

Table.35. Nutrient status of the soil in transplanted rice field at active tillering and panicle initiation

	Available soil nutrients at active tillering				Available soil nutrients at panicle initiation			
	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm
T1	11.17	2.27	1.29	674.50	15.52	3.64	1.21	115.87
T2	11.08	1.92	1.35	596.75	15.24	3.46	1.07	96.68
T3	21.88	1.93	0.77	1458.50	16.87	3.37	0.84	142.75
T4	16.16	2.10	1.14	811.00	15.38	6.23	0.96	119.46
T5	20.42	2.08	1.41	493.42	14.27	4.16	1.24	156.20
T6	11.19	2.02	1.34	692.58	12.59	4.13	1.18	166.73
T7	18.30	2.34	1.49	671.17	13.19	4.47	1.04	184.85
T8	29.86	1.78	0.90	482.75	17.73	3.26	1.00	157.30
T9	15.86	2.03	1.20	646.33	23.37	3.48	1.40	160.63
CD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table.36. Nutrient status of the soil after harvest in the transplanted rice

	Available soil nutrients							
	pH	EC	Organic carbon	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calcium ppm	Magnesium ppm	Sulphur ppm
T1	6.10	553.33	0.95	8.47	265.70	629.46	562.85	305.29
T2	5.92	547.67	0.84	7.06	293.35	822.01	520.40	142.17
T3	5.69	591.00	0.90	10.15	217.58	766.25	542.79	418.07
T4	5.60	558.00	0.69	9.09	252.19	930.99	658.34	312.93
T5	5.98	477.67	0.93	7.60	369.01	624.64	905.83	292.76
T6	6.18	666.33	0.94	7.00	315.83	798.03	687.26	355.11
T7	5.82	493.00	0.51	9.38	244.38	678.38	597.86	245.82
T8	5.59	634.33	0.91	8.29	229.08	638.83	543.29	79.45
T9	5.83	741.67	0.82	12.52	314.95	1021.65	806.82	233.70
CD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table.37. Micronutrient status of the soil after harvest in the transplanted rice

	Available soil nutrients				
	Boron, ppm	Copper, ppm	Zinc, ppm	Iron, ppm	Manganese, ppm
T1	0.93	1.63	7.20	307.53	128.95
T2	0.73	9.50	5.90	630.67	55.72
T3	0.71	0.90	5.43	591.50	71.18
T4	2.86	13.23	9.17	970.07	63.65
T5	1.46	6.43	7.20	437.83	62.73
T6	2.13	3.63	8.17	541.70	163.58
T7	1.95	14.67	15.67	1376.00	102.70
T8	1.06	4.73	6.00	668.57	54.00
T9	1.15	1.97	12.17	441.67	135.20
CD	**NS**	**8.652**	**5.587**	**414.733**	**40.778**

e) Effect of treatments on plant nutrient parameters

Perusal of the data showed that none of the plant nutrient content varied with treatments at active tillering and panicle initiation except zinc and iron at active tillering. Highest zinc values were observed for T8 and iron for T3.At harvest lowest values of potassium in T1 and highest value with T9.The grain phosphorus and iron were maximum with T8.However other nutrients were statistically non significant in paddy grains.

Table.38. Plant nutrient content in transplanted rice at active tillering

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	016	0.42	0.50	0.47	3.70	16.73	70.97	58.37
T2	0.12	0.43	0.65	0.47	5.73	21.53	76.00	39.50
T3	0.16	0.38	0.78	0.54	2.63	11.60	228.33	39.23
T4	0.18	0.52	0.53	0.51	3.37	15.17	203.33	174.90
T5	0.12	0.49	0.62	0.57	3.87	18.50	106.33	52.87
T6	0.13	0.53	0.66	0.62	3.80	19.43	105.33	60.30
T7	0.16	0.52	0.59	0.53	4.80	19.13	160.67	50.47
T8	0.23	0.60	0.82	0.56	3.27	23.80	135.67	35.43
T9	0.16	0.44	0.53	0.47	3.60	16.47	164.67	56.47
CD	**NS**	**NS**	**NS**	**NS**	**NS**	**5.130**	**64.554**	**NS**

Table.39. Plant nutrient content in transplanted rice at panicle initiation

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.18	2.66	1.11	0.67	3.17	20.00	144.77	442.17
T2	0.15	2.53	0.92	0.71	4.87	23.80	72.20	461.80
T3	0.15	1.80	1.00	0.78	2.27	15.63	115.07	297.07
T4	0.20	2.99	0.87	0.93	4.23	25.17	88.23	307.03
T5	0.18	2.49	0.76	0.84	3.17	26.17	66.27	436.53
T6	0.19	2.68	0.95	1.06	3.80	24.20	211.03	451.53
T7	0.28	2.48	1.29	0.69	2.73	20.00	41.57	286.00
T8	0.15	2.01	0.82	0.84	2.93	15.93	56.83	256.70
T9	0.21	2.68	1.01	0.78	2.83	20.57	53.77	525.60
CD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table.40. Plant nutrient content in transplanted rice at panicle initiation

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Zinc ppm	Iron ppm	Manganese ppm
T1	0.15	0.85	0.54	1.05	29.25	71.17	236.37
T2	0.16	1.20	0.42	0.97	21.83	38.67	284.23
T3	0.17	1.08	0.75	0.94	27.92	58.08	238.23
T4	0.18	1.31	0.52	1.07	30.50	58.17	223.83
T5	0.18	1.16	0.35	0.94	36.75	62.67	212.87
T6	0.17	1.24	0.60	0.88	42.83	73.00	179.47
T7	0.15	1.19	0.35	1.10	48.08	49.33	216.80
T8	0.19	0.89	0.66	0.94	30.75	51.67	256.37
T9	0.15	1.45	0.68	0.94	30.67	75.58	224.60
CD	**NS**	**0.259**	**NS**	**NS**	**NS**	**NS**	**NS**

Table.41. Nutrient content of grains in transplanted rice

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.22	0.68	0.62	0.82	1.07	3.23	297.87	27.03
T2	0.18	0.69	0.52	0.84	1.80	3.60	241.93	31.07
T3	0.27	0.65	0.47	0.76	1.30	3.57	437.13	28.77
T4	0.26	0.72	0.87	0.72	2.67	4.07	601.67	28.63

T5	0.24	0.69	0.64	0.55	1.37	2.97	343.47	24.77
T6	0.23	0.69	0.54	0.82	1.37	3.00	320.23	19.60
T7	0.21	0.69	0.78	0.88	2.07	3.10	188.37	19.63
T8	0.38	0.66	0.52	0.84	3.73	3.63	670.70	29.53
T9	0.24	0.67	0.33	0.89	1.83	3.70	45.27	25.70
CD	**0.07**	**NS**	**NS**	**NS**	**NS**	**NS**	**301.472**	**NS**

TRANSPLANTED RICE - YEAR III

a) Effect of treatments on growth parameters

Plant height recorded maximum values with T3 at active tillering while remained non significant at panicle initiation and harvest. Highest number of tillers observed with T4 at tillering and panicle initiation and lowest values with T 9.Number of productive tillers at harvest was maximum in T3 and on par with T6,T7,T8 and T9.

Table.42. Biometric characters as influenced by the treatments under direct rice

Treatments	Plant height in cm			No of tillers		No. of productive tillers	
	At tillering	At PI	At harvest	At tillering	At PI	At PI	At harvest
T1	34.93	82.11	68.54	8.10	12.66	11.44	8.11
T2	36.83	89.55	99.44	11.10	16.33	13.00	10.11
T3	38.53	99.89	96.78	14.87	14.33	13.22	13.11
T4	37.57	93.22	94.33	16.20	18.55	16.89	9.89
T5	34.00	85.00	100.65	7.57	14.00	11.99	9.44
T6	37.47	92.78	105.88	8.67	11.88	11.11	12.33
T7	31.00	89.22	101.22	11.47	15.66	14.11	11.91
T8	30.00	100.00	99.89	12.87	13.77	11.78	11.44
T9	27.67	92.22	102.76	6.43	9.55	9.00	12.12
CD 0.01	**5.101**	**NS**	**NS**	**4.263**	**4.838**	**NS**	**2.113**

b) Effect of treatments on root parameters

Root length, width and weight did not differ significantly with treatments.

Table.43.Root studies as influenced by the treatments under transplanted rice

Treatments	Length in cm	Width in cm	Weight in g
T1	17.11	10.05	25.35

T2	15.33	9.39	32.80
T3	17.11	9.50	24.70
T4	18.50	9.44	33.89
T5	16.11	9.38	19.75
T6	18.50	10.61	32.85
T7	15.88	9.50	28.45
T8	18.11	9.67	25.90
T9	18.94	9.83	26.52
CD	**NS**	**NS**	**NS**

c) Effect of treatments on yield parameters

Grain as well straw yield recorded maximum values with T8 and were on par with T9, T6 and T3. No significant difference was recorded for yield attributing characters like number of grains per panicle and 1000 grain weight. Pooled grain yield showed highest value with T8 followed by T9, T6 and T3.All the superior treatments included AMF which may prove its influence in maximizing yield.

Table.44. Yield characters as influenced by the treatments under transplanted rice

Treatments	No. of grains per panicle	1000 grain weight in g	Grain yield in t ha^{-1}	Straw yield in t ha^{-1}	Pooled grain yield in t ha^{-1}
T1	81.88	19.33	4.11	4.52	4.45
T2	75.55	21.13	5.42	5.96	5.20
T3	88.77	23.29	6.19	6.81	5.87
T4	94.66	22.38	6.13	6.74	5.42
T5	103.78	21.27	5.94	6.53	5.73
T6	95.00	25.00	6.62	7.28	6.42
T7	105.78	22.30	5.96	6.56	5.83
T8	91.66	23.49	8.14	8.95	6.96
T9	101.33	22.42	7.21	7.93	6.67
CD 0.05	**NS**	**NS**	**1.371**	1.508	**0.91**

d) Effect of treatments on available soil nutrients

Perusal of the data in table.46 indicated that before the experiment the soil showed deficient level of available phosphorus in most of the plots. Even after application of phosphorus fertilizers the available phosphorus remained low at active tillering and

panicle initiation. However the soil nutrient contents in available form varied differently with treatments emphasizing the complexities of dynamic soil system of Kuttanad wetlands. The soil available zinc at harvest was maximum with T6 and on par with T4 and T5.

Table.45. Initial available nutrient status of the soil in transplanted rice field

	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Organic Carbon %	Manganese ppm	Copper ppm	Zinc ppm	Iron ppm
T1	5.60	383.15	4.32	44.24	4.21	8.17	256.38
T2	12.54	297.25	3.54	32.34	3.30	9.36	289.38
T3	7.06	354.48	2.40	27.27	2.72	7.56	307.53
T4	4.70	281.79	2.82	30.31	3.18	8.24	292.52
T5	10.64	341.60	3.42	31.78	4.38	10.22	324.20
T6	5.04	387.52	3.72	54.94	4.61	9.22	263.69
T7	2.58	286.72	3.42	30.32	3.78	7.87	283.24
T8	3.92	386.40	2.10	33.34	3.92	7.59	305.24
T9	6.16	344.96	4.44	52.43	4.30	9.45	282.84

Table.46. Nutrient status of the soil in transplanted rice field at active tillering and panicle initiation

	Available soil nutrients at active tillering				Available soil nutrients at panicle initiation			
	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm	Phosphorus kg ha^{-1}	Zinc ppm	Copper ppm	Iron ppm
T1	10.45	6.09	3.10	158.13	12.54	7.41	2.74	115.87
T2	7.73	6.34	3.31	143.61	12.23	7.04	2.51	96.68
T3	9.52	6.27	2.06	136.76	13.51	5.85	2.19	142.75
T4	8.66	6.30	2.31	136.72	12.78	7.90	2.91	119.46
T5	8.59	10.49	2.63	132.08	10.08	7.34	2.65	156.20
T6	8.14	7.58	2.85	136.54	9.33	11.73	2.88	166.73
T7	4.44	6.03	2.53	144.68	14.37	8.76	2.97	184.85
T8	11.87	6.30	1.75	117.61	12.64	5.94	2.11	157.30
T9	14.34	7.81	3.37	150.19	11.82	6.48	2.68	160.63
CD	**4.821**	**NS**	**0.862**	**NS**	**NS**	**3.339**	**NS**	**NS**

Table.47. Nutrient status of the soil after harvest in the transplanted rice

	Available soil nutrients							
	pH	EC	Organic carbon	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calcium ppm	Magnesium ppm	Sulphur ppm
T1	4.71	779.67	3.76	11.69	303.60	908.80	567.33	259.69
T2	4.65	882.00	4.28	12.66	247.33	729.60	578.83	286.65
T3	4.57	774.67	3.22	13.03	233.37	729.60	540.50	209.43
T4	4.47	670.00	4.42	12.40	260.29	704.00	575.00	308.15
T5	4.72	842.00	3.50	13.52	339.32	992.00	667.00	257.28
T6	4.90	803.33	4.32	9.93	392.63	1088.00	598.00	227.17
T7	4.75	1019.67	4.14	10.86	277.05	748.80	728.33	215.92
T8	4.47	925.00	3.56	18.59	219.60	844.80	345.00	211.34
T9	4.81	885.67	4.30	12.81	291.31	1107.20	571.17	309.35
CD	**0.181**	**NS**	**NS**	**NS**	**56.568**	**240.026**	**NS**	**NS**

Table.48. Micronutrient status of the soil after harvest in the transplanted rice

	Available soil nutrients				
	Boron, ppm	Copper, ppm	Zinc, ppm	Iron, ppm	Manganese, ppm
T1	1.04	2.55	6.57	349.27	27.17
T2	0.84	2.46	7.01	387.43	21.74
T3	1.09	2.30	6.86	408.33	25.99
T4	1.25	2.28	12.21	395.03	27.91
T5	1.22	2.97	13.10	281.03	31.83
T6	1.07	3.43	13.45	290.14	38.78
T7	1.07	3.20	9.99	257.74	27.95
T8	0.41	2.64	7.77	273.96	30.25
T9	0.85	3.41	7.14	302.44	33.06
CD	**0.430**	**0.499**	**4.082**	**35.141**	**NS**

e) Effect of treatments on plant nutrient parameters

Potassium in the index leaf was highest with T9 at active tillering while Calcium recorded maximum values with T7 and T4.Plant nutrient contents did not differ significantly at panicle initiation Phosphorus in the plant at harvesting stage was highest with T1 and on par with T3, T8 and T9 while potassium was maximum with T3 and

minimum with T1.The zinc content was maximum with T5 and on par with T4 and T6. The trend was similar to available zinc in soil at harvest. Grain potassium was highest with T9 and on par with T8 whereas a higher value of grain zinc was noticed with T8 and on par with T9.

Table.49. Plant nutrient content in transplanted rice at active tillering

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.22	2.14	0.52	0.94	0.06	54.51	109.44	25.60
T2	0.24	2.28	0.62	0.87	0.09	28.07	111.75	41.90
T3	0.35	2.26	0.79	0.65	0.08	56.20	91.30	29.67
T4	0.27	2.39	1.04	0.62	0.04	48.33	96.14	34.56
T5	0.25	2.47	0.69	0.85	0.04	63.03	77.79	37.23
T6	0.23	2.92	0.98	0.65	0.06	36.28	251.10	28.25
T7	0.32	2.71	1.04	0.70	0.03	71.65	84.80	40.49
T8	0.30	2.46	0.79	0.77	0.03	34.47	275.95	25.34
T9	0.25	3.47	0.85	1.07	0.05	45.93	104.48	38.66
CD	**NS**	**0.485**	**0.268**	**NS**	**NS**	**NS**	**NS**	**NS**

Table.50. Plant nutrient content in transplanted rice at panicle initiation

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Copper ppm	Zinc ppm	Iron ppm	Manganese ppm
T1	0.13	1.58	0.94	0.81	0.06	22.75	77.91	48.92
T2	0.14	1.71	0.94	0.82	0.05	41.98	53.29	34.16
T3	0.17	1.73	1.15	0.80	0.05	47.31	58.82	6.92
T4	0.20	1.95	1.35	0.90	0.14	55.45	158.87	8.16
T5	0.13	1.47	0.75	1.09	0.13	21.84	176.01	21.22
T6	0.10	1.78	0.70	0.90	0.07	26.79	163.34	22.00
T7	0.14	1.81	1.15	0.73	0.02	50.70	115.34	26.96
T8	0.22	1.86	0.98	0.73	0.03	49.37	65.82	24.61
T9	0.17	2.18	0.83	1.17	0.05	58.61	221.53	17.31
CD	**NS**	**NS**	**NS**	**NS**	**0.071**	**NS**	**NS**	**NS**

Table.51. Plant nutrient content in transplanted rice at harvest

	Phosphorus %	Potassium %	Calcium %	Magnesium %	Zinc ppm	Iron ppm	Manganese ppm
T1	0.13	1.54	0.56	0.40	20.32	31.87	148.17
T2	0.09	1.66	0.30	0.58	26.00	29.19	145.50
T3	0.12	1.93	0.40	0.72	27.18	29.63	178.17
T4	0.10	1.76	0.32	0.74	41.03	34.62	146.87
T5	0.10	1.83	0.48	0.58	44.78	30.98	143.80
T6	0.08	1.91	0.43	0.48	40.55	33.78	149.93
T7	0.10	1.84	0.45	0.66	29.63	43.64	157.07
T8	0.12	1.61	0.40	0.56	22.89	40.49	121.10
T9	0.12	1.80	0.32	0.66	23.95	38.07	132.97
CD	**0.016**	**0.207**	**NS**	**NS**	**9.910**	**8.693**	**NS**

Table.52. Nutrient content of grains in transplanted rice

	Phosphorus %	Potassium %	Magnesium %	Zinc ppm	Iron ppm	Manganese ppm
T1	0.22	0.59	0.38	13.07	36.65	17.75
T2	0.22	0.59	0.51	13.02	32.75	15.71
T3	0.25	0.58	0.38	13.63	28.30	16.66
T4	0.18	0.57	0.44	14.44	23.44	15.05
T5	0.23	0.56	0.43	13.49	25.64	17.05
T6	0.18	0.56	0.47	13.78	31.33	16.55
T7	0.15	0.57	0.43	12.12	19.45	14.02
T8	0.24	0.61	0.33	21.83	24.12	17.73
T9	0.18	0.66	0.23	19.13	59.49	15.78
CD	**NS**	**0.032**	**NS**	**2.917**	**NS**	**NS**

Contributions made towards increasing the state of knowledge in the subject

a) Effect of treatments on growth parameters

In direct as well as transplanted rice, numder of productive tillers at harvest varied significantly with treatments. The maximum number was noticed in treatments with AMF and AMF + Zinc application which indicates that both of these inputs can have a crucial role in increasing yield.

b) Effect of treatments on root parameters

Root weight did not differ significantly either in direct or transplanted rice with any of the treatments. However root length and width varied in both systems of paddy cultivation. The improvement in root growth with AMF application was very much pronounced in mat nursery raised for transplanting (Plate.)

c) Effect of treatments on yield parameters

Maximum yield was recorded in treatments T3 and T8 in direct sown rice while T3, T6, T8 and T9 recorded higher yield in transplanted system.

d) Effect of treatments on soil nutrient parameters

In general under both systems of rice, soil nutrient status varied differently at different stages of sampling which stressed the dynamic soil character of Kuttanad wetlands which makes it difficult to manipulate and manage the soils to enhance plant nutrient absorption and thereby bring increased productivity. Thus it can be concluded that AMF application alone cannot manage zinc availability to plants as it is regulated by increase in uptake of Fe, Ca, Mg, Cu, Mn and P after flooding. Zinc uptake by rice depends not only in its concentration in the soil solution but particularly on concentration of iron and manganese in soil.In addition wide exchangeable Mg: Ca ratio i.e., > 1 may indicate zinc deficiency (Dobermann, A and Fairhurst,T,2000). It is noticed that the soil application of zinc fertilizer at recommended rates suggested to overcome zinc deficiency could not bring required increase in zinc absorption by plants and thereby increase in yield. This can be attributed to the soil nutrient complexities observed in Kuttanad conditions.

e) Effect of treatments on plant nutrient parameters

In transplanted rice zinc content was high in treatments with either soil or foliar applied zinc with and without AMF. The grain content of zinc was high in treatment with foliar application of zinc with AMF in both direct sown and transplanted rice. Similar result was reported by Solaiman , MZ and Hirata, H(1996).There may be a critical soil zinc concentration below which Zn uptake is enhanced by AMF and above which Zn translocation to plants is reduced. (Chen et.al.2003; Christie et.al,2004 ;Hildebrandt et al,2006).These responses are further complicated by uptake of other nutrients especially P via mycorrhizal pathway which may lead to a decrease in plant zinc concentration due to dilution effects (Burleigh et al,2003).However response of AMF on Zn acquisition is comparatively low when Zinc is applied at higher rate to soil.

f) Effect of treatments on mycorrhizal assays

Perusal of the results of the first year experiment has shown that the commercial AMF consortia **containing *Glomus fasciculatum*, *Glomus etunicatum*, *Glomus mosseae*, *Sclerocystis microcarpus* and *Acaulospora sp.*** cannot come up under anaerobic conditions in the paddy wetlands of Kuttanad. Higher soil moisture had a deleterious effect on AMF colonization in rice especially under flooded condition.(Sivaprasad et.al.,1990). It has been observed that response to AMF inoculation is related to root colonization (Khan, 1972) .Moreover, up to 2 fold higher

zinc uptake occurs in efficient genotypes under zinc deficiency upon inoculation with mycorrhiza in aerobic conditions (Hajiboland et al.,2009). ***Glomus intraradices*** is identified as appropriate AMF species that can come up in wetland conditions of Kuttanad rice fields under both direct sown and transplanted condition indicated by colonization and response in certain seasons. The presence of AMF is confirmed up to harvest stage in the roots by staining technique.(Plate.). Similar result was obtained in pot culture study under flooded condition where in ***Glomus intraradices*** was considered efficient and suitable for inoculation in to rice nurseries(Secilia and Bagyaraj,1992). The present study suggests that the technique of nursery level inoculation and transplanting with AMF *Glomus intraradices* is of more benefit to rice under transplanted conditions than direct sown rice as water has to be managed in the field in the latter at the time of broadcasting.

However *Glomus intraradices* can be recommended only after undertaking a large scale trial in research stations as well as farmers plots.

Summary

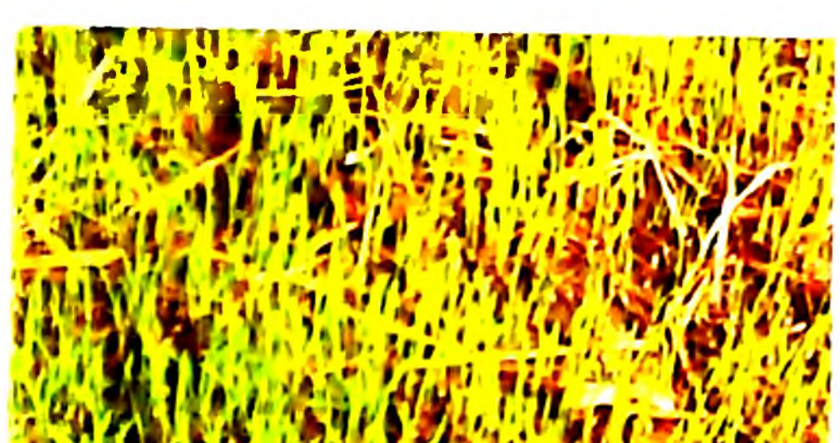
An experiment has been conducted in wetlands of RARS Kumarakom to explore the capacity of AMF to tap the nutrients like Zn and P in iron toxic soils thereby improving the growth ,productivity and profitabilityof lowland rice in an ecofriendly and sustainable manner under direct seeded rice.The experiment was laid out with seven treatments replicated thrice. The first year experiment has shown that the commercial AMF consortia containing *Glomus fasciculatum*, *Glomus etunicatum*, *Glomus mosseae*, *Sclerocystis microcarpus* and *Acaulospora sp*. cannot come up under anaerobic conditions in the paddy wetlands of Kuttanad. The experiment has been modified with two additional treatments repeated under both direct sown and transplanted rice using ***Glomus intraradices*** .

Glomus intraradices is identified as appropriate AMF species that can come up in wetland conditions of Kuttanad rice fields under both direct sown and transplanted condition indicated by colonization and response. The presence of AMF is confirmed up to harvest stage in the roots by staining technique. Pooled yield data over seasons in direct sown rice recorded maximum value with T8 which involved AMF application with foliar applied zinc. Pooled grain yield showed highest value with T8 followed by T9, T6 and T3.All the superior treatments included AMF which may prove its influence in maximizing yield. In transplanted rice zinc content was high in treatments with either soil or foliar applied zinc with and without AMF. The grain content of zinc was high in treatment with foliar application of zinc with AMF in both direct sown and transplanted rice.

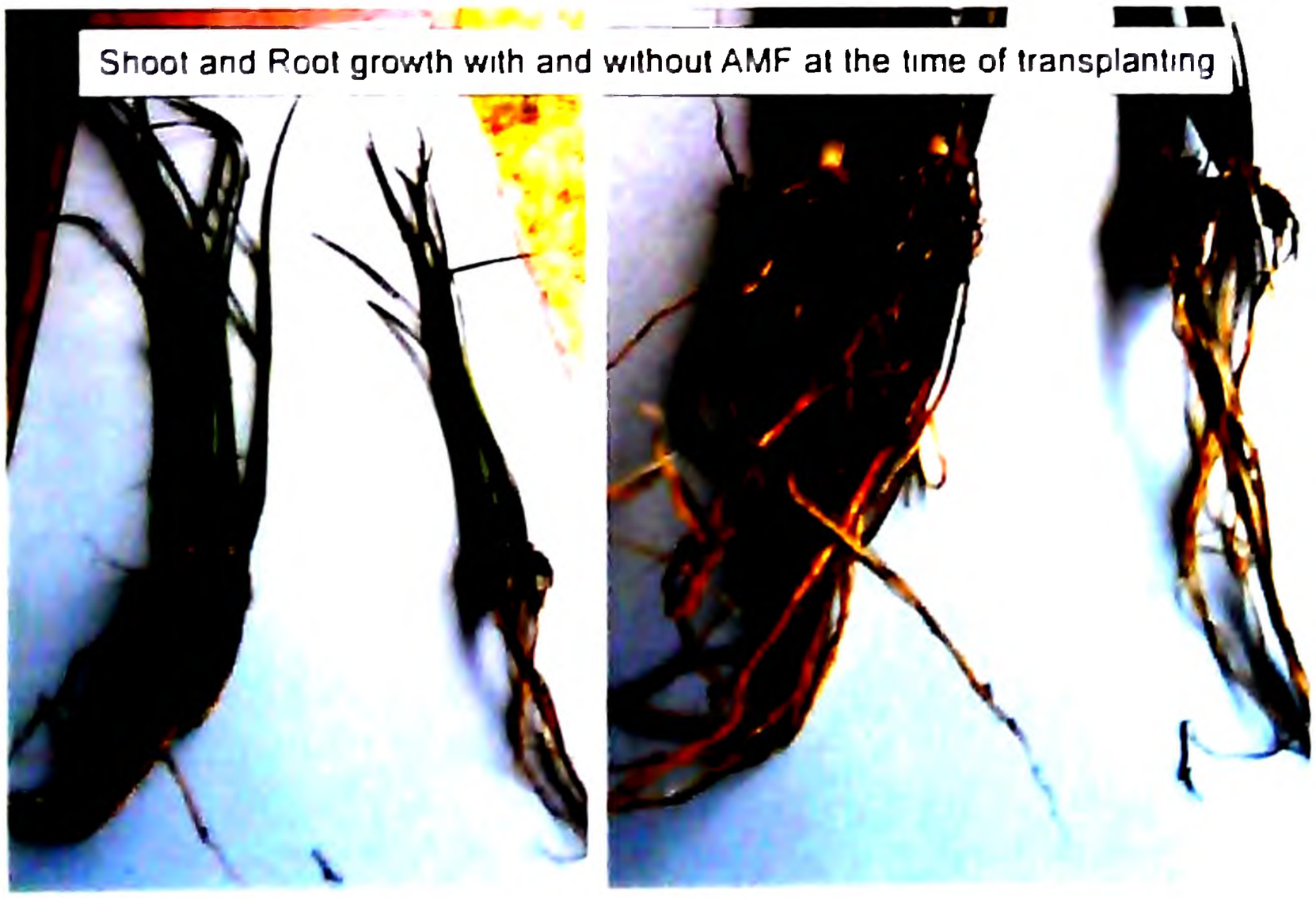
Scope of the future work

- Multi location trials and farm trials have to be designed to explore its efficacy in large scale plots for confirmatory results.
- The efficiency of AMF in different rice genotypes can be explored.
- Isolation of indigenous strains of *Glomus intraradices* from Kuttanad wetlands can be looked into,

Different stages of mat nursery



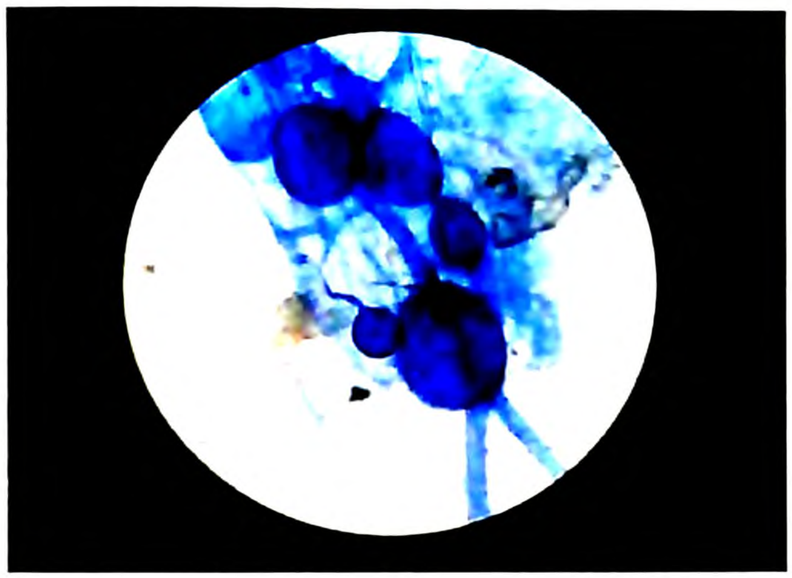
Root and shoot growth with and without AMF at earlier stages in mat nursery

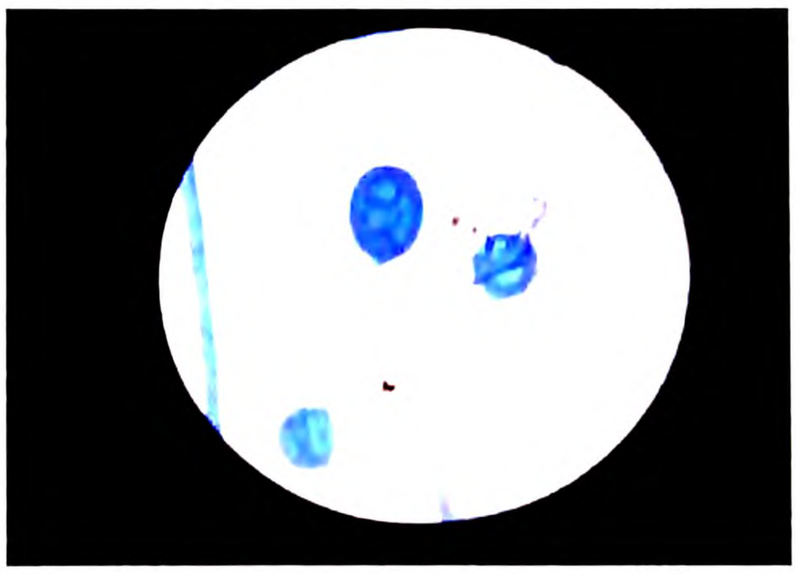


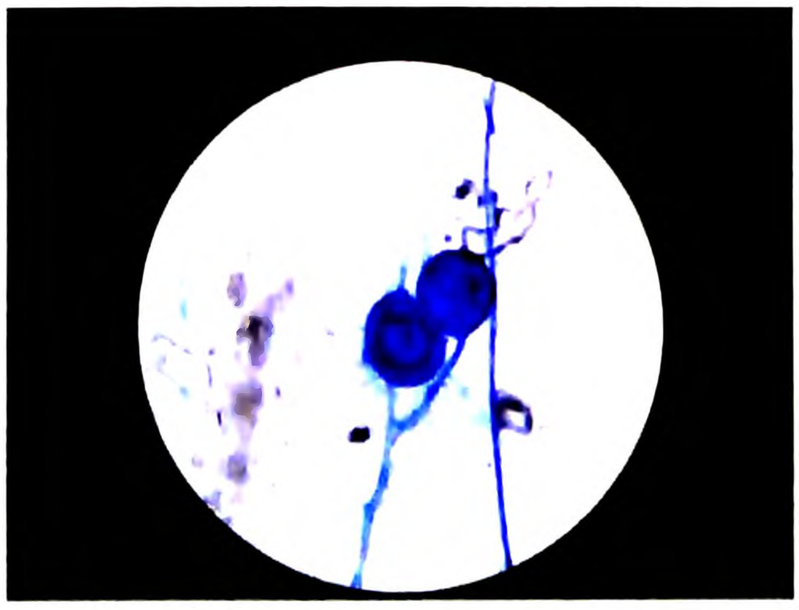
Shoot and Root growth with and without AMF at the time of transplanting

Glomus intraradices in rice roots at different crop growth stages

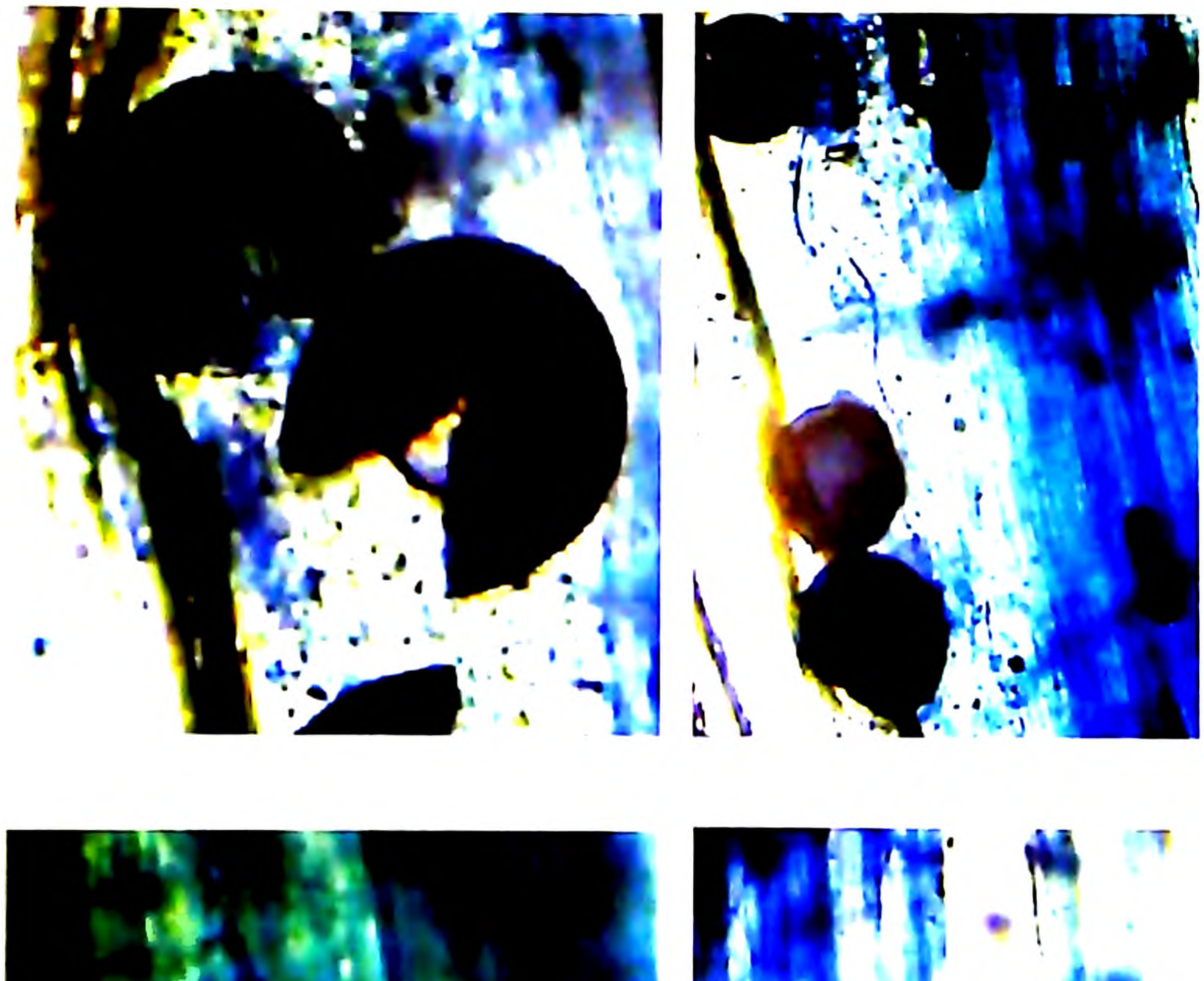
FIRST YEAR OF EXPERIMENTATION

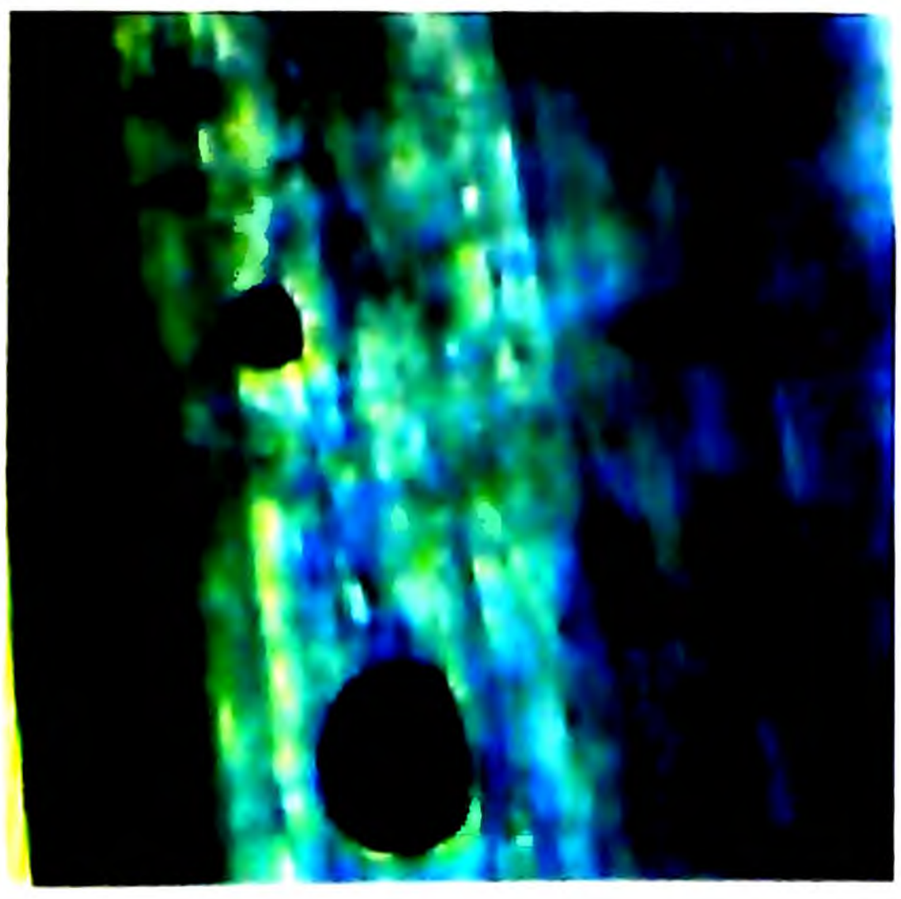


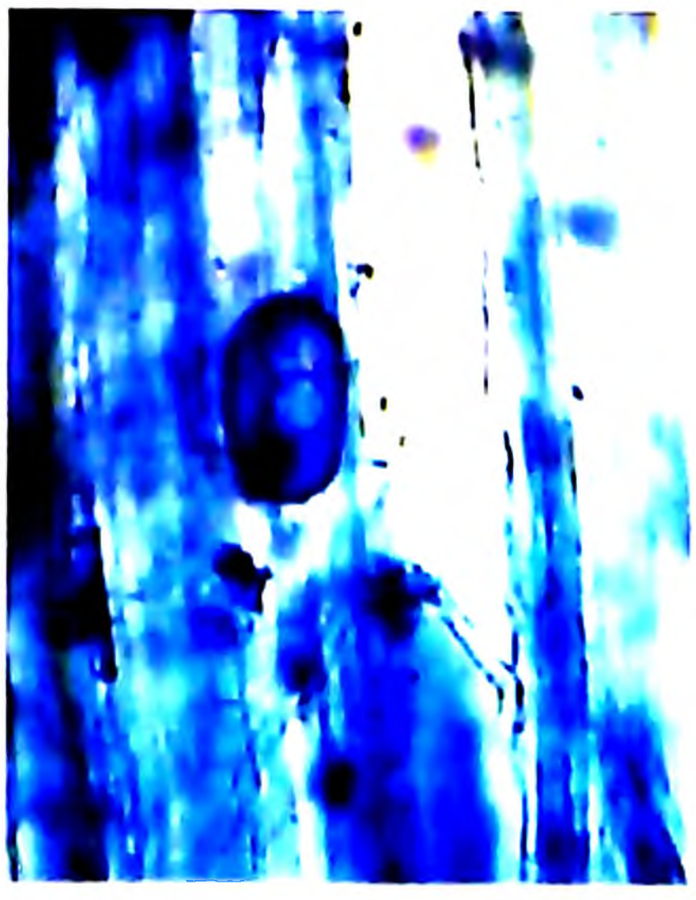




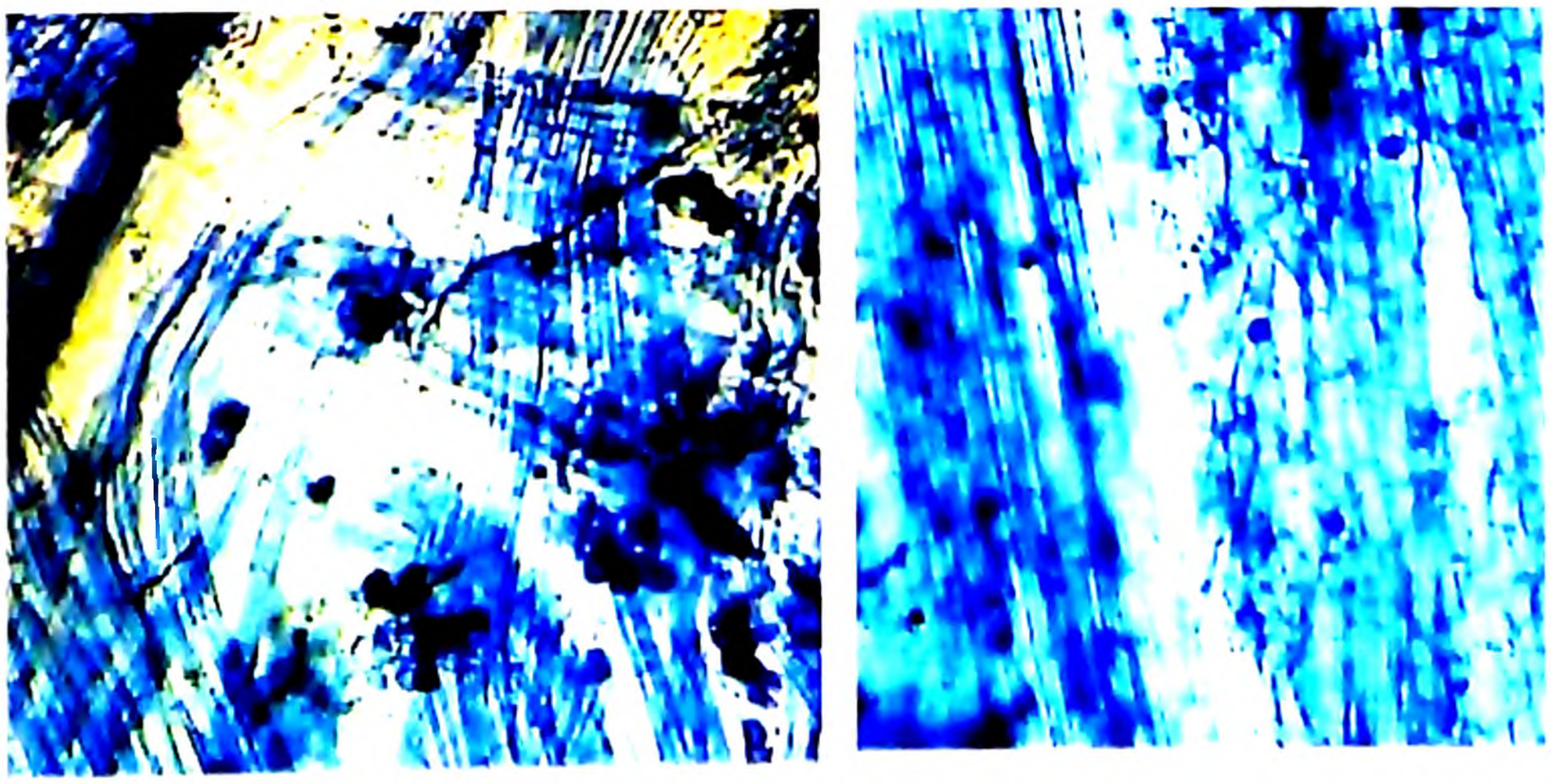
SECOND YEAR OF EXPERIMENTATION
IN DIRECT SOWN RICE







SECOND YEAR OF EXPERIMENTATION IN
TRANSPLANTED RICE



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Vandana Venugopal

KERALA STATE COUNCIL FOR SCIENCE, TECHNOLOGY AND ENVIRONMENT

Science Research Scheme

PROJECT COMPLETION REPORT

1. Title of the Project:

   Productivity enhancement in rice through promoting zinc nutrition using mycorrhizal symbiosis in Kuttanad soils **(No.003/SRSAGR/2013/CSTE)**

2. Principal Investigator(s) and Co-Investigator(s)

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3. **Implementing Institution(s) and other collaborating Institution(s):**

   Regional Agricultural Research Station
   Kumarakom, Kerala Agricultural University

4. **Date of commencement**: 26.3.2014
5. **Planned date of completion**: 25.3.2017
6. **Actual date of completion**: 25.3.2017

7. **Objectives as stated in the project proposal:**

- To evaluate the role of mycorrhizal symbiosis in Zinc nutrition of rice
- To evaluate the uptake of plant nutrients in the presence of AMF
- To develop an economical and environment friendly nutrient package for wet land rice
- To increase the productivity,profitability and sustainability of rice production systems in Kuttanad by resource management

8. **Deviation made from original objectives if any, while implementing the project and reasons thereof:**

The first Group Monitoring Workshop of KSCSTE suggested repeating the experiment under transplanted condition in addition to direct sown rice and the project coordination group – RICE of Kerala Agricultural University suggested two more treatments as detailed below.

T8 – T3+ Foliar application of Zn at the POP rate

T9 – T3 + Half the recommended dose of P and K

9. **Abstract of the project proposal** (Not more than 500 words)

The project is proposed to explore the capacity of AMF to tap the nutrients like Zn and P in iron toxic soils thereby improving the growth ,productivity and profitabilityof lowland rice in an ecofriendly and sustainable manner.

The experiment has been laid out in completely randomized block design with seven treatments replicated thrice under direct sown conditions.

The details of treatments are furnished below

T1 - Control

T2- Recommended dose of nutrients - Lime @ 600 kg/ha; FYM @5t/ha; NPK @ 90:45:45 kg/ha

T3 – T2 + Sowing seeds coated with AMF @ 1kg for 1 acre seeds (32 kg) + Soil application @ 1 kg AMF in 1t of FYM for 1 acre.

T4 – T2 + Zn as $ZnSO_4$ @ 10 kg/ha once during the cropping season

T5 – T2 + Zn as $ZnSO_4$ @ 20 kg/ha once during the cropping season

T6 – T4 + Sowing seeds coated with AMF @ 1kg for 1 acre seeds (32 kg) + Soil application @ 1 kg AMF in 1t of FYM for 1 acre.

T7 – T5 + Sowing seeds coated with AMF @ 1kg for 1 acre seeds (32 kg) + Soil application @ 1 kg AMF in 1t of FYM for 1 acre.

Biometric observations, yield and yield attributing characters, soil and plant nutrient statuses at different stages of growth have to be recorded. The data to be statistically analyzed using the ANOVA technique to draw results.

10. **Key words** (Not exceeding ten):

Transplanted rice, Direct sown rice, AMF, Kuttanad soils, Zinc nutrition, *Glomus intraradices*

11. **Achievements:**

i. List of Research publications

Vandana Venugopal and Haseena. M. 2016. Role of Arbuscular mycorrhizal fungus in zinc nutrition and productivity enhancement of rice in Kari soils. ***Green Farming.*** Vol 7 (5) : 1062-1065 NAAS rating 4.79

V.Vandana, M.Haseena and M.Midhila.2017. Effect of arbuscular mycorrhizal fungus on biometric characters of rice in Kuttanad wetlands. National Seminar on Biodiversity Conservation and Farming Systems in Wetland Ecology at KTDC Suvasam Lake resort, Thanneermukkom , RARS Kumarakom 22-23 February,2017

A leaflet in Malayalam for farmers including the results of the experiment "Karshikavilakalil Mycorrhiza" authored by Vandana Venugopal, Haseena,M., D.Ambikadevi and Vijayakumar,K."

ii. Manpower trained on the project

a. Senior Research Fellow – 1 No.

b. No. of Ph. D produced -Nil

c. Technical Personnel trained -

iii.Innovations/Technology developed

Unlike most strains of AMF available commercially, *Glomus intraradices* is found to survive in rice roots under both direct sown and transplanted system of cultivation in Kuttanad wetlands up to harvest. The performance of the strain in mat nursery was highly significant.

iv. Patents taken, if any -NA

v. **Application potential**

It has been proven that the commercial AMF consortia **containing *Glomus fasciculatum, Glomus etunicatum, Glomus mosseae, Sclerocystis microcarpus* and *Acaulospora sp.*** cannot come up under anaerobic conditions in the paddy wetlands of Kuttanad. Hence the unwanted expenditure on this commercial formulation by farmers in rice contributing to increased cost of cultivation can be limited. The performance of ***Glomus intraradices*** can be recommended only after undertaking a large scale trial in station as well as farmers plot.

12. Summary of the work done (not more than 500 words) highlighting the outcome

Attached separately.

13. **Financial Details:**

No.	Financial Position/Budget Head	Funds Sanctioned	Expenditure	% of Total cost
I	Salaries/Manpower costs	514161	489507	95.2 %
II	Equipment	50000	50000	100.0 %
III	Consumables	450000	426355	94.7 %
IV	Contingencies	60000	60000	100.0 %
V	Travel	45000	30968	68.8 %
VI	Labour charges	150000	149388	99.6 %
VII	Overhead Expenses	100000	100000	100.0 %
	Total	**1369161**	**1306218**	**95.4 %**

14. **Procurement/Usage of Equipment:**

a)

Sl. No.	Name of Equipment	Make/Model	Cost (FE/Rs.)	Date of Installation	Utilization Rate (%)	Remarks regarding maintenance/breakdown
1	pH meter	EUTECH pH meter Model Tutor	50000	16.12.2014	96.0	Excellent working condition

b) Plans for utilizing the equipment facilities in future:
For testing soil and water in the rice fields and water bodies

Name and Signature with Date

a. ----------
(Principal Investigator)

b. ----------
(Co-Investigator)

c. ----------
(Co-Investigator)