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Research Article

Effect of soil and crop management practices on sodicity stress alleviation and rice productivity under water scarce condition

P. Janaki*
Anbil Dharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620027 (Tamil Nadu), India
A. Alagesan
Anbil Dharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620027 (Tamil Nadu), India
J. Ejilane
Anbil Dharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620027 (Tamil Nadu), India
S. Nithila
Anbil Dharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620027 (Tamil Nadu), India
P. Balasubramaniam
Anbil Dharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620027 (Tamil Nadu), India
P. Santhy
Anbil Dharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620027 (Tamil Nadu), India

*Corresponding author. Email: janaki.p@tnau.ac.in

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Abstract
The prominent issue faced by the farmers of Cauvery Delta regionin Tamil Nadu particularly Tiruchirapalli District is the lack of timely release of water for rice nursery preparation and transplanting. Hence wet seeding of rice is recommended for timely cultivation. On the other hand, sodic nature of the soil warrants rice cultivation only. Therefore, the present investigation was carried out to study the different soil and crop management practices on alleviating sodicity stress and improving rice (variety ADT 3) productivity under water-scarce conditions. The experiment was laid in a split plot design with six mainplots,including rice wet seeding, daincha (*Sesbania aculeata*) application as green manure, anti-oxidant microbial consortia (AOMC) spray and four sub-plots with graded levels of NPK based on soil test values with three replication. Results showed that the daincha incorporation @ 6.25 t/ha followed by rice wet seeding + AOMC spray @1.5 % with 125 % soil test based NPK had significantly increased thechlorophyll content, SPAD values, proline content and grain and straw yields which remained on par with daincha incorporation @ 6.25 t/ha followed by rice wet seeding + AOMC spray @1.5 % with 100 % soil test based NPK.Significantly lower ESP at 5% level and higher phosphatase activity in soil was also recorded by daincha incorporation @ 6.25 t/ha followed by rice wet seeding + AOMC spray @1.5 % with 125 % and 100 % soil test based NPK. Gross return, net return and B:C ratio were also higher in the plot, which received daincha incorporation @6.25 t/ha followed by rice wet seeding + AOMC spray @1.5 % with 100 % soil test based NPK. The present study reveals that the inclusion of ectophytic microbial population spray in rice plants and the management practices helps the crop to tolerate the sodicity stress under water-scarce condition by maintaining required physiological functions like proline synthesis and enzyme activities etc which need to be further explored at the genotypic level.

Keywords: Anti-oxidant microbes, Daincha green manuring, Sodicity, Wet Seeded rice

INTRODUCTION

Rice is the staple food crop for 50% population in the world (Lou *et al.*, 2012) and 90 % of rice is grown in Asia and 20% is from India. Though the rice is a high yielding crop with an average production potential of 10 t ha^{-1}, its yield production is 10 to 15% lower than its potential due to environmental stresses (biotic or abiotic), management strategies, and nutrients deficiencies (Sajid *et al.,* 2017). Abiotic stresses are the major causes which affect the physiology of crop by altering its metabolism, growth, and development either directly or indirectly. Apart from drought, sodicity and salinity are the major abiotic stresses in arid and semiarid regions that substantially limit the crop production and reduce the average yield of major crops by more than 50% (Bray *et al*., 2000). Worldwide more than 1000 million hectares of land is affected by salinity or sodicity and over 50% of world's population lives in 13 countries affected severely by soil salinity (Chen *et al*., 2021).

Rice production in salt-affected soils is harshly reduced by poor physical constraints caused by the alkaline hydrolysis products such as sodium carbonate and bicarbonates together with sufficient exchangeable sodium. Due to salt stress, these soils are also intrinsically low in organic matter and available N and have poor microbial activity (Kumar and Sharma, 2020). The crop is greatly sensitive to salinity and sodicity at the early seedling stage, affecting the crop establishment and increasing the mortality rate. Hence, high sodium ion in rhizosphere inhibits K+ uptake and high Na uptake cause express cellular injury to plants (Rahman *et al.,* 2017). Incorporation of green manures, application of extra nitrogen and cultivating salt tolerant varieties is the common practices recommended for crop cultivation after ameliorating the sodic soil (Latha and Janaki, 2016).

In Tamil Nadu, rice is cultivated in an area of 1.83 m.ha with a production of 5.84 mt with major area in Cauvery Delta zone. Its cultivation period completely depends on river water release (Amrutha and Santhy, 2018). To reduce the time requirement for field preparation and cultivate rice matching the water release period, farmers of this region are adopting Wet Seeded Rice (WSR) technique. Though thisshift though helps to reduce water requirement and favors the timely cultivation of rice, still farmers are facing issues of water scarcity and saline-sodicity induced stresses in rice production. Hence the development of collective soil and crop management practices for improving the rice productivity in sodic soil under scarce conditions is the need of the hour. With this background, the present study was conducted to identify the suitable soil and crop management practices for improving the direct wetseeded rice yield in sodic soil under water-scarce conditions involving green manuring and foliar spray of anti-oxidant microbial consortia.

MATERIALS AND METHODS

The experiment was carried out during *rabi* 2018-19 at Anbil Dharmalingam Agricultural College & Research Institute Farm, Tamil Nadu Agricultural Farm (TNAU), Tiruchirapalli. The farm is situated in the Cauvery Delta Zone of Tamil Nadu at 10°45'N latitude and 78°36'E longitude with an altitude of 85 m above MSL. The experimental soil was sandy clay loam in texture have the pH 8.90, EC 0.39 dS/m, ESP – 32 c.mol (p+)/kg, organic carbon 0.58 %. The available N, P, and K status was found to be low, medium and low, respectively. The normal climatic condition of the location (mean of 30 years) was as follows: Mean annual rainfall of 815 mm distributed over 41 rainy days. The annual mean maximum and minimum temperatures were 36 and 32^{o}C, respectively. The relative humidity ranges from 65 to 90 per cent in the FN and 43 to 50 per cent in the AN. The mean bright sunshine hours per day are 8.2 hours with mean solar radiation of 475 cal cm^{-2} min^{-1}. During the experimental period, total rainfall of 131mm was received in 15 rainy days. The mean maximum and minimum temperatures were 22.3 and 32.7^{o}C, respectively. The mean relative humidity was 85 per cent in the FN and 58.2 percent in the AN. The mean sunshine hours were 5.8.

Experiment details

The experiment was laid in split plot design with six main plots and four sub-plots (of 5 m x4 m) with three replication using long duration salt tolerant rice variety TRY 3 as test crop. The main plot treatments are :M_1 : Rice transplanting ; M_2 : Rice wet seeding ; M_3 : Daincha(*Sesbania aculeata*) incorporation followed by rice wet seeding ; M_4 : Rice wet seeding + Daincha inter cropping ; M_5 : Daincha incorporation fb rice wet seeding + anti oxidant microbial consortia (AOMC); M_6 : Rice wet seeding + Daincha inter cropping + anti oxidant microbial consortia (AOMC). The sub plots consisted of S_1 : Control ; S_2 : 75 % soil test based NPK ; S_3 : 100% soil test based NPK ; S_4 : 125% soil test based NPK. The 100 per cent soil test based $N:P_2O_5:K_2O$ was worked out to be 196: 75: 75 NPK kg/ha which was calculated through Decision Support System for Integrated Fertilizer Recommendation (DSSIFER) software of TNAU, Coimbatore using the initial soil test values of available N, P and K. According to the treatments, 75 and 125 per cent of the soil test based NPK fertilizer levels was applied. Entire quantity of P and 25 per cent of N and K fertilizers were applied at the time of sowing and remaining 75 per cent of N and K fertilizers were top dressed in three equal splits at active tillering, panicle initiation and heading stage of rice. The AOMC consisting of *Bacillus subtilis, B.polymyxa* and *Pseudomonas species* isolated from native sodic soil was prepared in liquid formulation and sprayed during boot leaf and panicle initiation stages of the crop. These isolates would be deposited at (MTCC) IMTECH, Chandigarh for getting accession number.

Analysis of physiological parameters in plant and soil properties

Proline content was estimated at the flowering stage. Free proline was extracted according to the method of Bates *et al.* (1973). Total chlorophyll content was estimated following the method Yoshida *et al.* (1971) suggested and expressed as mg g^{-1} fresh weight. SPAD readings were recorded using Chlorophyll Meter (SPAD 502). The availability of nutrients in the soil at the time of harvest was assessed as described by Jackson (1973). The Exchangeable sodium percentage (ESP) was calculated as described by Janaki et al. (2020) for sodic soils. The activity of enzymes viz., urease, phosphatase and dehydrogenase in soil were assessed as reported by Tabatabai and Bremner (1969 &1972) and Casida *et al.* (1964).

The harvested plants from the net plot area were thrashed manually and each plot yield was separately sun-dried, cleaned, winnowed and weighed. Grain yield was computed at 14 per cent moisture content and expressed in kg/ha.

Statistical analysis

The data collected from the field experiment was statistically analyzed following the procedure given by Gomez and Gomez (2010) for split plot design. Whenever significant difference existed, critical difference was constructed at five per cent probability level. Such of those treatments where the differences are not significant were denoted as NS.

RESULTS AND DISCUSSION

Rice wet seeding is the recommended practice in the Cauvery Delta region to reduce the water requirement and for timely cultivation. Delay in water release affects the nursery preparation and further transplanting. On the other hand, the sodic nature of the soil warrants only rice cultivation but with less productivity. Many plant-growth-promoting rhizobacteria are known for providing protection to the plants from stressed environment. However, the survival of microorganism in stressed habitat is possible due to their ability of utilizing the resources available under that suitable niche (Damodaran *et al.*, 2014). Hence the effect of foliar spray of anti-oxidant microbial consortia on helping the rice growth at stressed environment might be useful and is evaluated along with other soil and crop management practices. The rice growth and yield related parameters recorded during the crop growing period and the results of soil analysis obtained are given in tables 1-6.

Physiological parameters

Chlorophyll concentration is an indicator of tissue tolerance to saline-sodicity in soil. Hence the total chlorophyll content and chlorophyll meter reading recorded at panicle initiation and flowering stages (Table 1 and 2). Both main and sub plot treatments and their interaction recorded significant difference (p=0.05).The daincha incorporation followed by rice wet seeding + AOMC + 125 % of soil test based NPK recorded maximum total chlorophyll content (3.34) among the interaction treatments at panicle initiation stage and was on par with rice wet seeding + daincha inter cropping + AOMC+ 125 % of soil test based NPK (3.11). Similar results were obtained during the flowering stage also.Incorporation of daincha and extra dose of NPK might have improved the rooting structure, increasing the availability and balanced uptake of N by the crop and hence might increase the leaf chlorophyll content. A similar result was reported by Islam *et al.* (2019) that the balanced nutrients supply in combination with *Sesbania aculeata* as green manure increased the leaf chlorophyll content in rice. The SPAD value is the indirect estimation of chlorophyll content. SPAD value increased from panicle initiation to flowering stage and declined towards maturity. The daincha incorporation followed by rice wet seeding + AOMC recorded the maximum value of 48.3 at the flowering stage. Among the sub plot treatments, 125 % soil test based NPK (46) was found to be effective, followed by 100 % soil test based NPK (44). This showed that the application of increased NPK in sodic soil enhances their uptake and rice growth. The combined application of daincha and AOMC increased the soil available nutrients and crop utilization and hence recorded higher SPAD values. The effect of green manuring with *Sesbania rostrata* on increasing the SPAD values in rice at different growth stages was also reported by Janaki *et al.* (2000) and Janaki and Thiaygarajan (2005).

Foliar spray of AOMC recorded higher chlorophyll and SPAD values which could be ascribed to production of osmolytes to maintain cell turgidity and metabolism to survive against osmotic stress in sodic condition. Further, the daincha incorporation might have also produced organic acids and polysaccharides and maintained a favorable microbial population, increasing the nutrient's availability by reducing the Na uptake. Effect of exopolysaccharides produced by bacteria *Azotobacter chroococcum* in the root zone on alleviating the salt stress by reducing Na uptake by the crop has been also reported by Arora *et al.* (2010). Shultana *et al.* (2020) also identified significant improvement in total chlorophyll content when rice was inoculated with *Bacillus tequilensis.*

Proline is one of the osmolyte to assess the salt tolerance capacity of the crops. Hence the variation in proline content due to imposed management practices was studied. The data on proline content of rice revealed that there was a gradual accumulation of proline from panicle initiation to flowering stage (Table 3).

Table 1. Effect of different management practices and fertilizer levels on total chlorophyll (mg g^{-1}) content in rice at panicle initiation and flowering stages

Main plots/ sub plots	M_1	M_2	M_3	M_4	M_5	M_6	Mean
Panicle Initiation stage							
Control	2.28	2.22	2.34	2.32	2.57	2.49	2.37
75 % ST-NPK	2.48	2.37	2.57	2.56	2.78	2.60	2.56
100 % ST-NPK	2.57	2.49	2.70	2.68	3.11	3.07	2.77
125 % ST-NPK	2.85	2.63	3.07	2.94	3.34	3.11	2.99
Mean	2.54	2.42	2.67	2.63	2.95	2.82	
	M	S	M x S	S x M			
CD(P=0.05)	0.053	0.021	0.069	0.051			
Flowering stage							
Control	2.44	2.33	2.53	2.41	2.58	2.44	2.45
75 % ST-NPK	2.51	2.45	2.71	2.72	2.77	2.46	2.60
100 % ST-NPK	2.65	2.52	2.91	2.82	3.08	3.09	2.84
125 % ST-NPK	2.95	2.72	3.12	3.06	3.15	3.10	3.01
Mean	2.63	2.50	2.82	2.75	2.89	2.77	
	M	S	M x S	S x M			
CD(P=0.05)	0.152	0.062	0.200	0.152			

M_1: Transplanted rice; M_2: Wet seeded rice; M_3: Wet seeded rice+ Daincha incorporation; M_4- Wet seeded rice+ Daincha intercropping; M_5: Wet seeded rice+ Daincha incorporation+ AOMC; M_6- Wet seeded rice+Daincha intercropping+AOMC; ST-NPK: Soil test based NPK

Table 2. Effect of different management practices and fertilizer levels on SPAD value in rice at panicle initiation and flowering stages

Main plots/ sub plots	M_1	M_2	M_3	M_4	M_5	M_6	Mean
Panicle Initiation stage							
Control	34.4	24.0	32.0	29.5	37.4	40.0	32.9
75 % ST-NPK	40.0	30.0	38.0	35.4	37.4	43.0	37.3
100 % ST-NPK	44.0	35.0	42.0	39.3	39.3	45.0	40.8
125 % ST-NPK	45.0	40.0	39.3	37.4	41.3	51.0	42.3
Mean	40.9	32.3	37.8	35.4	38.8	44.8	
	M	S	M x S	S x M			
CD(P=0.05)	3.06	1.39	4.50	4.10			
Flowering stage							
Control	39.3	30.0	35.0	34.4	44.3	43.0	37.7
75 % ST-NPK	44.0	38.0	40.0	39.3	34.4	45.0	40.1
100 % ST-NPK	47.0	40.0	44.0	43.3	39.3	50.0	43.9
125 % ST-NPK	48.0	42.0	42.3	44.3	44.3	55.0	46.0
Mean	44.6	37.5	40.3	40.3	40.6	48.3	
	M	S	M x S	S x M			
CD(P=0.05)	3.36	1.51	4.64	3.70			

M_1: Transplanted rice; M_2: Wet seeded rice; M_3: Wet seeded rice+Daincha incorporation; M_4- Wet seeded rice+ Daincha intercropping; M_5: Wet seeded rice+ Daincha incorporation + AOMC; M_6- Wet seeded rice+ Daincha intercropping+ AOMC; ST-NPK: soil test based NPK

Among the different management practices, rice wet seeding + daincha inter cropping + AOMC recorded a significantly higher amount of proline activity at the panicle initiation stage, which was on par with daincha incorporation followed by rice wet seeding + AOMC spray. Among the graded NPK levels, significantly (p=0.05) higher proline content was recorded by 125% soil test based NPK plot and was on par with 100 % soil test based NPK. The interaction effect was found to be significantly different among the treatment combinations. The results showed that the daincha intercropping with AOMC spray and an extra 25% N helps the direct seed rice to develop defense mechanisms for ionic and osmotic stresses caused by the sodicity. The role of proline in cell osmotic adjustment, membrane stabilization and detoxification of injurious ions in plants exposed to salt stress is widely reported (Rahman *et al.*, 2017). Hence, the osmotic adjustment is one of the major physiological phenomena vital for sustaining the growth of plants under osmotic stress. The influence of microorganisms like *Pseudomonas fluorescent* on the accumulation of proline under osmotic stress has also been reported (Ansary *et al.*, 2012) and under stress conditions, proline protects plants from damage because it can scavenge ROS (Natarajan *et al.*, 2012).

Grain and straw yield

Significantly higher rice grain and straw yield were recorded by daincha incorporation followed by rice wet seeding + AOMC spray,which was on par with rice wet seeding +daincha inter cropping + AOMC spray (Table 4). Among the main plots, the lower yield was recorded under rice transplanting and was on par with rice wet seeding. Under different fertilizer levels, yield was higher with 125 % soil test-based NPK which was on par with 100 % soil-based NPK. The interaction effect was found to be significant. The rice wet seeding + daincha inter cropping + AOMC with 125% soil test based NPK recorded significantly higher grain yield (4368 kg/ha) and remained on par with daincha incorporation followed by rice wet seeding + AOMC with 125 (4368 kg/ha) and 100% (4210 kg/ha) soil test based NPK plots. The daincha incorporation followed by rice wet seeding + AOMC spray with 125 % soil test based NPK application recorded significantly higher straw yield and was on par with rice wet seeding + daincha intercropping + AOMC with 125% soil test based NPK application. The combined effect of green manuring using *Sesbania* species and N fertilization on increasing the rice grain yield in Tamil Nadu was reported by many researchers (Chithra and Janaki, 1999; Janaki and Thiyagaran, 2005; Islam *et al.,* 2019). Swarup (1987) also recorded average increase in rice grain and straw yield of 1.44 and 1.16 t/ha, respectively as a result of green manuring (*S. aculeata*) in sodic soil. Increased grain yield with the combined application of green manure +AMOC+125% NPK and 100% NPK in the present study could be ascribed to the improvement in root length, higher leaf K^+, increased leaf soluble protein content, total soluble sugars, anti-oxidant enzymes activity, relative water content and stomatal conductance while declined of leaf Na^+, electrolyte leakage, proline

Table 3. Effect of different management practices and graded level of NPK on proline content (μg g^{-1}) in rice leaf at panicle initiation and flowering stages

Main plots/ sub plots	M_1	M_2	M_3	M_4	M_5	M_6	Mean
Panicle initiation stage							
Control	250	232	264	264	298	300	268
75 % ST-NPK	269	258	285	268	290	316	281
100 % ST-NPK	335	333	343	323	345	315	332
125 % ST-NPK	342	330	360	348	374	395	358
Mean	299	288	313	301	327	332	
	M	**S**	**M x S**	**S x M**			
CD(P=0.05)	25	12	35	28			
Flowering stage							
Control	270	254	289	270	364	318	294
75 % ST-NPK	280	269	298	286	305	324	294
100 % ST-NPK	348	340	354	334	316	390	347
125 % ST-NPK	355	350	362	364	382	395	368
Mean	313	303	326	314	342	357	
	M	**S**	**M x S**	**S x M**			
CD(P=0.05)	26	12	36	29			

M_1: Transplanted rice; M_2: Wet seeded rice; M_3: Wet seeded rice+ Daincha incorporation; M_4- Wet seeded rice+ Daincha intercropping; M_5: Wet seeded rice+Daincha incorporation+AOMC; M_6- Wet seeded rice+ Daincha intercropping+ AOMC; ST-NPK: soil test based NPK

Table 4. Effect of different management practices and graded level of NPK on grain and straw yield

Main plots/ sub plots	M_1	M_2	M_3	M_4	M_5	M_6	Mean
Grain yield (kg/ha)							
Control	3099	2899	3211	3055	3828	3475	3261
75 % ST-NPK	3336	3075	3523	3342	3909	3761	3491
100 % ST-NPK	3535	3356	3870	3638	4258	3859	3753
125 % ST-NPK	3844	3552	4073	3962	4210	4368	4002
Mean	3454	3221	3669	3499	4051	3454	
	M	S	M x S	S x M			
CD(P=0.05)	147	101	252	246			
Straw yield (kg/ha)							
Control	3953	3856	4055	3919	4813	4456	4175
75 % ST-NPK	4138	3865	4235	4097	4933	4712	4330
100 % ST-NPK	4491	4297	4779	4538	5317	4856	4713
125 % ST-NPK	4935	4448	4983	4851	5675	5587	5080
Mean	4379	4117	4513	4351	5189	4903	
	M	S	M x S	S x M			
CD(P=0.05)	112	57	165	140			

M_1: Transplanted rice; M_2: Wet seeded rice; M_3: Wet seeded rice+ Daincha incorporation; M_4- Wet seeded rice+ Daincha intercropping; M_5: Wet seeded rice+Daincha incorporation+ AOMC; M_6- Wet seeded rice+Daincha intercropping+AOMC; ST-NPK: soil test based NPK

content (Osman *et al.,* 2021). The present study observed a significant and positive correlation of grain yield with proline concentration at panicle initiation (r^2 = 0.759**) and flowering stages (r^2 = 0.642**) for the wet seeding plots (Fig 1). A positive association between abiotic stress tolerance and accumulation of proline was reported by Ashraf *et al.* (2018). Similar to grain yield, the straw yield was significantly higher with rice wet seeding + daincha inter cropping + AOMC with 125% soil test based NPK plots and remained on par with daincha incorporation followed by rice wet seeding + AOMC with 125 (4368 kg/ha) and 100% (4210 kg/ha) soil test based NPK plots.

In addition, the higher grain and straw yield under AOMC sprayed plots could be attributed to the higher proline content and thehigher activities of superoxide dismutase, polyphenol oxidase and catalase which increased the ability of the plants to tolerate salt stress and formulate Na^+ exclusion mechanism as reported by Damodaran *et al.* (2014). The AOMC spray might have also enhanced the defense mechanism in the rice plants due to the elevated level of enzyme activity (Ashraf and Foolad, 2007; Rais *et al.*, 2017). Shultana *et al.* (2020) recorded increased rice grain yield in saline soil due to significant improvements in total chlorophyll content, relative water content (%), total dry matter, reduction of electrolyte leakage (%), and Na/K ratio, when rice was inoculated with *Bacillus tequilensis.*

Soil properties

Imposing of different management practices in the present study with green manure, AOMC and fertilizer levels did not make any drastic variation in EC and pH of the post harvest soil except the main plot treatments influence on soil pH (Fig. 2). Daincha incorporation and intercropping significantly decreased the soil pH and could be ascribed to the acidifying effect of green manure decomposition. Significant reduction in soil pH due to dhiancha *in situ* green manuring in cotton grown sodic soil at Akola, Maharastra was also reported by Pawar *et al.* (2016). Similarly, the daincha incorporation followed by rice wet seeding + AOMC recorded significantly lower amount of ESP which was on par with rice wet seeding +daincha intercropping + AOMC. This could be ascribed to the reclamation effect provided by the decomposing green manure through the release of

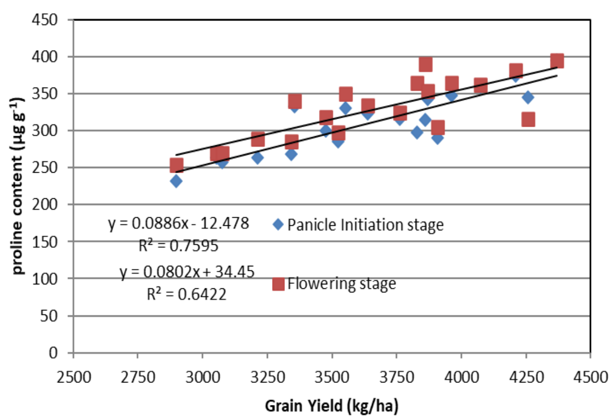


Fig. 1. *Correlation plot of proline content with grain yield in the wet seeding plots*

Table 5. Effect of different management practices and graded level of NPK on soil enzyme activities at panicle initiation stage (60 DAS)

Main plots/ sub plots	M_1	M_2	M_3	M_4	M_5	M_6	Mean
Urease activity (µg NH^4-N released g^{-1} soil h^{-1})							
Control	5.32	5.73	5.82	5.94	7.41	6.12	6.06
75 % ST-NPK	5.75	5.81	5.92	6.01	7.82	6.65	6.33
100 % ST-NPK	5.90	5.98	6.21	6.32	8.14	7.20	6.63
125 % ST-NPK	6.24	6.12	6.46	7.42	8.82	8.24	7.12
Mean	5.80	5.91	6.10	6.42	7.90	7.05	
	M	S	M x S	S x M			
CD(P=0.05)	1.07	0.93	NS	NS			
Phosphatase activity (µg PNPP g^{-1} of soil / h)							
Control	22.23	22.27	22.68	25.78	27.55	29.21	24.95
75 % ST-NPK	27.30	28.33	29.32	29.81	31.82	30.31	29.48
100 % ST-NPK	29.32	28.92	31.90	31.96	32.55	32.98	31.27
125 % ST-NPK	31.45	33.45	32.41	32.78	33.56	33.52	32.86
Mean	27.58	28.24	29.08	30.08	31.37	31.51	
	M	S	M x S	S x M			
CD(P=0.05)	1.37	0.98	1.52	1.60			
Dehydrogenase activity (µg TPF released g^{-1} of soil /24h)							
Control	4.13	4.13	4.12	4.84	7.84	6.11	5.20
75 % ST-NPK	4.86	4.92	4.96	5.62	8.02	6.24	5.77
100 % ST-NPK	5.15	5.61	5.61	6.91	7.11	6.72	6.19
125 % ST-NPK	5.32	5.94	5.92	7.04	7.24	7.29	6.46
Mean	4.87	5.15	5.15	6.10	7.55	6.59	
	M	S	M x S	S x M			
CD(P=0.05)	0.87	0.75	NS	NS			

M_1: Transplanted rice; M_2: Wet seeded rice; M_3: Wet seeded rice+ Daincha incorporation; M_4- Wet seeded rice+ Daincha intercropping; M_5: Wet seeded rice+ Daincha incorporation+AOMC; M_6- Wet seeded rice+ Daincha intercropping+ AOMC; ST-NPK: soil test based NPK

CO_2, organic acids and enhanced microbial activity (Swarup, 1987). Significant increase of available NPK in soil at harvest was recorded by the daincha incorporation followed by rice wet seeding + AOMC spray (Fig.3), which might be the result of greater mineralization and mobilization of major nutrients by the decomposing products of green manure beside supplying additional N to the soil and for uptake (Swarup, 1987; Kumar *et al.*, 2020). Similarly, the daincha incorporation followed by rice wet seeding + AOMC recorded significantly lower amount of ESP which was on par with rice wet seeding + daincha intercropping + AOMC (Fig. 4).

The enzyme activities viz., Urease, Dehyrdogenase and Phospatases were determined in the soil at panicle initiation stage (Table 5). The activity of alkaline phosphatase was significantly higher in the soil when comparing urease and dehydrogenase activity. This is in accordance with the results of Singh *et al.* (2013) who reported that maximum activities of alkaline phosphatase in the soils with high pH which is necessary to convert the organic P to available P which is the main fraction of P in sodic soils incorporated with green manure. Among the different management practices, daincha incorporation followed by rice wet seeding + AOMC recorded significantly higher level of enzyme activities which was on par with rice wet seeding + daincha inter cropping + AOMC. Among the sub plots, significantly higher activities of all the three enzymes were recorded by 125% soil test based NPK plot and were on par with 100 % soil test based NPK plot. A significant increase of dehydrogenase activity in sodic soil due to daincha in-situ green manuring was also observed by Pawar *et al.* (2016) cultivated with cotton. Mallikarjun and Maity (2018) found increased urease and dehydrogenase activity in rice soil due to green manuring in the lateritic soil of west Bengal.

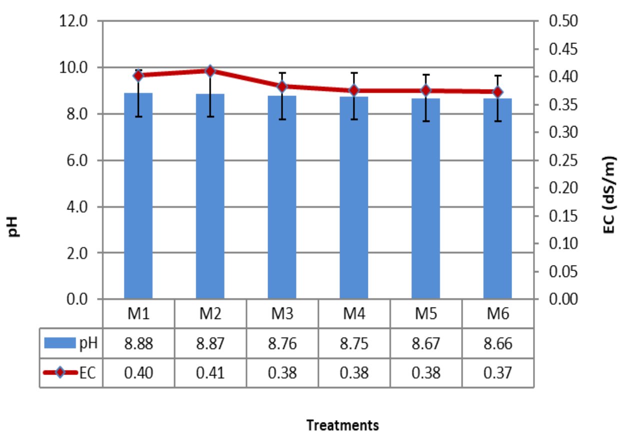
B:C ratio

Higher gross return, net return and B:C ratio were obtained (Table 6) in the treatment combination of

Table 6. Effect of different management practices and NPK fertilizer levels on the economics of rice

Treatments	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net return (Rs./ha)	Benefit cost ratio
M_1S_1	27951	40609	12658	1.4
M_1S_2	31665	47989	16324	1.5
M_1S_3	32921	53195	20274	1.6
M_1S_4	34141	55235	21094	1.6
M_2S_1	28501	54305	25804	1.9
M_2S_2	32215	63249	31034	1.9
M_2S_3	33471	70799	37328	2.1
M_2S_4	34691	73037	38346	2.1
M_3S_1	29501	63425	33924	2.1
M_3S_2	33215	75125	41910	2.2
M_3S_3	34471	83065	48594	2.4
M_3S_4	35691	85611	49920	2.4
M_4S_1	29501	63033	33532	2.1
M_4S_2	33215	73811	40596	2.2
M_4S_3	34471	82893	48422	2.4
M_4S_4	35691	84103	48412	2.3
M_5S_1	32701	73513	40812	2.2
M_5S_2	36415	88297	51882	2.4
M_5S_3	37671	96463	58792	2.5
M_5S_4	38891	97929	59038	2.5
M_6S_1	32701	73073	40372	2.2
M_6S_2	36415	88109	51694	2.4
M_6S_3	37971	93947	55976	2.5
M_6S_4	38891	95287	56396	2.4

M_1: Transplanted rice; M_2: Wet seeded rice; M_3: Wet seeded rice+ Daincha incorporation; M_4- Wet seeded rice+Daincha intercropping; M_5: Wet seeded rice+ Daincha incorporation+AOMC; M_6- Wet seeded rice+ Daincha intercropping+ AOMC; S_1 : Control ; S_2 : 75 % soil test based NPK ; S_3 : 100% soil test based NPK ; S_4 : 125% soil test based NPK



M_1: Transplanted rice; M_2: Wet seeded rice; M_3: Wet seeded rice+Daincha incorporation; M_4- Wet seeded rice+Daincha intercropping; M_5: Wet seeded rice+Daincha incorporation+AOMC; M_6- Wet seeded rice+Daincha intercropping+AOMC

Fig. 2. *Effect of different soil and crop management practices on soil pH and electrical conductivity at harvest*

daincha incorporation followed by rice wet seeding + AOMC with 125% soil test based NPK which remained on par with daincha incorporation followed by rice wet seeding + AOMC with 100 % soil test based NPK and rice wet seeding + daincha inter cropping + AOMC with125 % soil test based NPK application. Since B:C ratio is on par for 100 and 125% NPK applied plots, the daincha incorporation followed by rice wet seeding + AOMC spray with 100% NPK fertilizer application could be considered as the best and optimum management option for growing wet seeded rice in sodic soil under water scarce condition. Always the additional N application is recommended to cultivate crops in salt-affected soil which will be met by the green manure addition in the present study. The higher net return and B:C ratio due to AOMC spray could be ascribed to the improved defense mechanism in rice for salt stress. Singh *et al.* (2016) found that the additional net-gain became negative when N application is increased

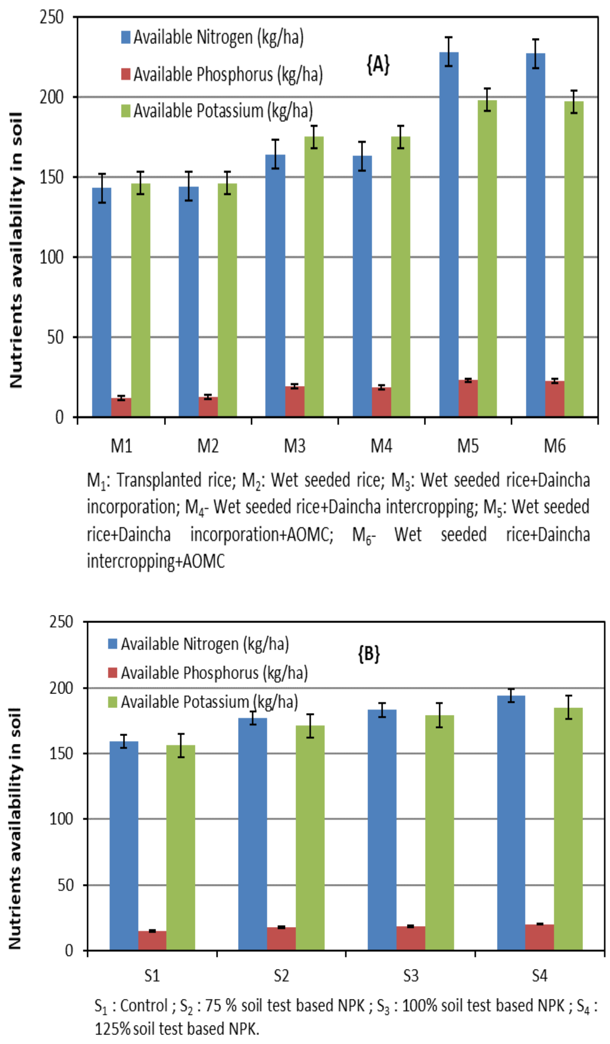


Fig. 3. *Effect of different soil and crop management practices {A} and graded levels of NPK fertilizer {B} on availability of major nutrients in soil at harvest*

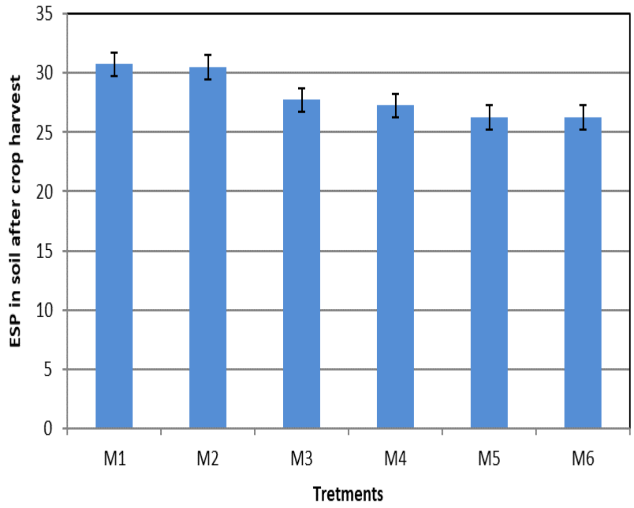


Fig. 4. *Effect of different soil and crop management practices and graded levels of NPK fertilizer on exchangeable sodium percent (ESP) in soil at harvest*

above optimum and reported decreasing returns from additional N in sodic soil grown with rice at Lucknow, India. Mohamed Faten and Abou-Zeid (2011) also found a reduction of about 25% of recommended dose of NPK for rice cultivation due to the application of diazotrophs and plant growth-promoting rhizobacteria isolated from saline-sodic soil.

Conclusion

The present study concluded that the daincha incorporation @ 6.25 t/ha followed by rice wet seeding and anti oxidant microbial consortia foliar spray @1.5 % at boot leaf and panicle initiation stages of rice with 100 or 125 % soil test based NPK was effective in improving the rice productivity in sodic soil under water-scarce conditions. Besides significant reduction in ESP and increase of phosphatase enzyme activity in sodic soil due to dhaincha incorporation was observed. The influence of the combined application of green manure and AMOC spray @1.5 % spray on enhancing the ectophytic microbial population in rice plants and changes in the activity of enzymes like glutathione and metabolic and physiological variation in rice plants needs to be explored. Detailed research on this line will help to transform these technologies to other crops grown under water-scarce conditions in sodic soil to enhance the production and productivity under semi-arid situations.

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Conflict of interest

The authors declare that they have no conflict of interest.

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