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Research Article

Mitigating of waterlogging associated problems by the management practices in the rice ecosystem of the Deltaic zone of Tamil Nadu

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Abstract
Cauvery Delta is the major rice-growing tract of Tamil Nadu. Continuous waterlogging is inevitable in the delta region due to unexpected heavy rain, leading to stunted crop growth and poor soil conditions. The present study aimed to alleviate the waterlogging-associated problems of stunted growth, crop nutrition deficiency, heavy algal growth and poor soil aeration issues in the heavy clayey soils of deltaic region of Tamil Nadu. Field experiments were laid out with the treatments viz., $CuSO_{4,}$, (5kg/ha) (T_1), Gypsum (500 kg/ha) (T_2), Conoweeding+Alternate Wetting and Drying Irrigation(AWDI) (T_3), microbial consortia (K and Zn solubilising Bacteria 500 ml/ha) (T_4) control (T_5) and combination of all (T_6) except $CuSO_4$ along with control . The results indicated that the T_6 recorded higher plant height (110.2 cm), productive tillers/m^2 of 332, filled grains of 118.3 and less chaffy grains of 20.3 nos, high nutrient status of 265 kg/ha of available N,35.4 kg/ha of available P,342 kg/ha of available K, 21.1meq/100 g of Ca,8.2 meq/100 g of Mg and root length and volume. The algal population in terms of dry biomass was reduced to 3.1 (g/m2) from the control group of 11.2 (g/m^2) at 15 days after imposing treatment. The per cent increase of 26.0 % grain yield was also recorded in the combination treatment over control. From the present research, combined application of gypsum @500 kg/ha +Cono weeding twice +AWDI and microbial consortia of Zn and K solubilising bacteria @500ml/ha could be recommended for better soil environment and rice production in the delta region.

Keywords: Alleviation, Alternate wetting and drying, Gypsum, Rice, Waterlogging

INTRODUCTION

Waterlogging is an important visual phenomenon where free water covers the surface of soil in cropland (Striker, 2012). Twelve per cent of the world's upland soils could be waterlogged frequently, with 20% crop yield reduction (Setter and Waters, 2003). In the future, soil waterlogging is expected to increase in frequency due to changes in global climate, especially in lowland regions under more unpredictable rainfall (He, 2014). At the same time, soil containing more clay with high compaction due to repeated use of machinery could have poor drainage, leading to increased waterlogging (Ploschuk *et al*., 2018). Therefore, waterlogging is an increasingly adverse stress that results in the obvious yield reduction of various crops. Rice (*Oryza sativa* L.) can grow well in excess water stress and handles submergence stress by internal aeration and growth controls. Soil submergence due to more rainfall and heavy clay in the Cauvery Delta zone creates a unique environment for the growth and nutrition of rice through seasonal flooding and drainage. However excess water logging for a prolonged period leads to nutrient imbalance and reduces rice growth. This problem exists wherever rice is grown in the world. During waterlogging, the air in soil pores is replaced by water, resulting in suppression of root respiration, stomatal closure, reduction of CO_2 entry, reduction of transpiration rate and photosynthetic rate, and eventually, crop yield reduction or failure (Tian *et al*., 2019).
Steffens *et al*. (2005) reported that water logging might inhibit plant growth primarily by nutrient deficiency . Manik *et al*. (2019) stated that a decrease in water-soluble Zn and Ca concentration is one of the disad-

vantages of flooding soils for rice. Zn deficiency in flooded rice soils may result from the combined effect of high pH, high HCO_3 level of irrigation water,low available Zn content and impeded internal drainage.Rainfall in most areas rises with the progress of global warming (IPCC, 2021). Excessive rainfall can easily lead to waterlogging, which affects up to 20% crop losses (Ren *et al*., 2016). Waterlogging first impacts the root activity of crops, and then affects the growth of aboveground plants (Huang *et al*., 2022). During waterlogging, the air in soil pores is replaced by water, resulting in suppression of root respiration, stomatal closure, reduction of CO_2 entry, reduction of transpiration rate and photosynthetic rate, and eventually, crop yield reduction or failure (Tian *et al*., 2019).

Studies have shown that waterlogging reduces crop yield and quality (Ren *et al*., 2013). Otie *et al*. (2019) suggested that waterlogging at a critical stage affected nutrient uptake. Manik *et al*. (2019) reported that waterlogging remains a significant constraint to crop production across the globe in areas with high rainfall and poor drainage. Nutrient deficiency is one of the major effects of waterlogging on plants, resulting in reduced photosynthesis and net carbon fixation ultimately leading to a reduction in growth and yield (Steffens, 2005) . pH values of waterlogged soil can be further reduced by the accumulation of volatile organic acids and the high concentration of CO_2 . Another potential toxic metabolite found in waterlogged soil is ethylene, which suppresses root expansion and growth. Deficiencies of K, Ca, Mg, P and Mn increase iron uptake and decrease the roots' oxidation capacity. Application of essential nutrients will assist in mitigating the negative effects of abiotic stresses like waterlogging, leading to increased productivity (Noreen *et al*., 2018).Arduini *et al*.(2019) opined that roots adequately resume growth during the recovery from water logging. The accumulation of dry matter in shoots and roots of rapeseed was significantly reduced when plants faced the waterlogging stress conditions at the seedling stage.

Also, decreasing molecular oxygen prompts a sequence of changes in the physico-chemical properties of the soil. Many also change soil chemicals and electrochemicals by decreasing redox potential and excess electron changes (Singh and Setter, 2017). Thus, solubility of iron and manganese rises to toxic levels, which are potentially damaging to plant roots (Sharma *et al*., 2018). Apart from the elemental toxicities to the sensitive root tips, increased concentration of secondary metabolites such as phenolics and volatile fatty acids may become injurious in the low-pH rhizosphere (Coutinho *et al*., 2018). The damaging effects of waterlogging can only be partially alleviated by adding fertilizers due to the reduced capability of roots to absorb nutrients (Kisaakye *et al*., 2017). Potassium fertilizer has also been reported to ameliorate the detrimental effects of waterlogging in several crops (Ye *et al*., 2019).

Based on the above literature, the water logging issue in the rice ecosystem needs attention to improve and sustain rice productivity in the Cauvery Delta Zone of Tamil Nadu. As per the Department of Agriculture officials, in the Delta region, rice growth and yield are getting reduced due to soil constraints by stagnating water, which produces varying symptoms, viz., stunted growth, yellowing and poor soil aeration and algal growth, eventually affecting the growth and yielding ability of rice (20-30 % of cultivated rice area). Nutrient deficiency is one of the major effects of waterlogging on plants, resulting in reduced photosynthesis and net carbon fixation, ultimately reducing growth and yield (Sarkar *et al*., 2019). Hence, the present work was initiated to study the issues like stunted growth , yellowing and poor soil aeration to improve the rice productivity in the Cauvery delta zone of Tamil Nadu.

MATERIALS AND METHODS

Study area

Field experiments were conducted from June 2020 to March 2022 at Tamil Nadu Rice Research Institute, TRRI, Aduthurai and Krishi Vigyan Kendra, Needamangalam of Thanjavur District, Tamil Nadu. The details of field experiments are depicted in Table 1. $CuSO_4$ is a already recommended practice to control algal growth induced by waterlogging in these areas. The gypsum will act as an amendment to improve physical conditions like aeration in the soil and supplement calcium. Microbial consortia will mobilise the Zn and K, which are deficit in the waterlogged areas. Hence, the treatments tried were: T_1 – $CuSO_4$ (5 kg/ha); T_2 – Gypsum @500 kg/ha ; T_3–Conoweeding+AWDI; T_4 –microbial consortia of Zn and K solubilising bacteria @500ml/ha; T_5 –control and T_6 in a combination of T_2+T_3+T_4 .Treatments were imposed as per the treatment details and crops were

Table 1. Details of experiments

Location/season/ Varieties	Tamil Nadu Rice Research Institute,Aduthurai		Krishi Vigyan Kendra Needamangalam	
	Kuruvai	Samba/thaladi	Kuruvai	Thaladi
2020-21	ADT 43	CR1009	CO51	Swarna sub 1
2022	ADT53	ADT 51	ADT53	
Duration	105	135	105	125
Weeding	30 th day	45 th day	30 th day	45 th day
Soil type	Old Cauvery delta, Montmorillonitic, isohyperthermic, UdorthonticChrom usterts with heavy clay texture, Kalathur soil series			

harvested. Soil samples were collected and analysed for EC, pH, organic carbon, available N, P K. Ca, Mg, Fe , Zn, Cu and Mn and the initial soil characteristics are furnished below. The soil characteristics were estimated by using standard analytical methods *viz.*, Organic carbon by Chromic acid wet digestion (Walkey and Black 1934), available N by alkaline permanganate method (Subbiah and Asija, 1956), available P by 0.5 $NaHCO_3$ (pH-8.5) (Olsen, 1954), available K by Neutral Normal Ammonium Acetate Method (Stanford and English, 1949), Exchangeable Calcium and Magnesium by Neutral Ammonium Acetate (pH – 7.0), available sulphur by 0.15% $CaCl_2$ (Jackson ,1973) and available Micronutrients viz., Fe , Zn, Cu and Mn (Piper, 1966).The initial soil of TRRI, Aduthurai contains clay content of 45.2 and 46.9 per cent with clayey texture at TRRI,Aduthurai and KVK need amangalam, respectively. The medium in organic carbon status, low in available nitrogen, high in available phosphorus and medium in available potassium. The soil's available sulphur and Zinc status is below the critical limit and high in available iron, manganese and copper contents. The mean weather parameters were: maximum temperature (32.8 ^{o}C),minimum temperature (21.6 ^{o}C), relative humidity (91 %t , total rain fall (2014 mm) with total rainy days of 77 days in the delta zone. Compared to ten ten-year mean (71.4 mm), in 2021 during winter, there was higher rainfall of 402.1 mm observed, and during summer, lower rainfall of 48.9 mm was recorded against ten-year mean of 72.3 mm. However, during South West Monsoon (SWM), higher rainfall (RF) was recorded during this reporting year 2021 of 460.51 mm compared to the year's mean of 320.41 mm. During North East Monsson (NEM), the current year recorded more RF of 1097.9 mm than ten years mean of 697.78 mm.

RESULTS AND DISCUSSION

Influence of treatments on rice yield and yield attributes

The results showed that compared to *kuruvai* season, samba seasan recorded higher grain yield. (Table 2). Combining gypsum @500 kg/ha, Cono weeding twice, and alternate wetting and drying (AWDI) with microbial consortia of Zn and K solubilising bacteria @500ml/ha (T_6)led to a higher grain yield (5455 kg/ha) compared to the individual treatment effects of gypsum (5111 kg/ha), cono weeding (4994 kg/ha), and microbial consortia (4835 kg/ha) (Table 3; Fig1). This combination treatment (T_6) recorded a 26.0% increase in grain yield over the control of normal practice alone (T_5) (Table3) . The same trend of results was observed across all seven trials that enhanced rice growth with Combined Application of Gypsum, Conoweeding, AWDI and Microbial Consortia. Table 4 shows that T_6 (Gypsum @500 kg/ha+ Conoweeding+AWDI + microbial consortia) resulted in the highest plant height (110.2 cm), with 332 productive tillers/m2, 118.3 filled grains, and 20.3 fewer chaffy grains. Additionally, T_6 showed longer roots (31.2 cm) and greater volume (92.5 cm3) than the control group, T_5, which scored 27.2 cm and 72.1 cm3, respectively. The improved yield in T_6 may be attributed to the physical disturbances caused by conoweeding, which increases oxygen supply, and alternate wetting and drying, which releases water molecules and provides aeration. Additionally, gypsum application,

Table 2. Effect of treatments on grain yield (kg ha $^{-1}$) of rice during 2020-21

Treatments	TRRI, Aduthurai		KVK,Needamangalam	
	Kuruvai 2020	Samba 2020-21	Kuruvai 2020	Samba 2020-21
T_1 – $CuSO_4$	4635	4530	4150	5486
T_2 – Gypsum	5012	4928	4980	5891
T_3 – Conoweeding+AWDI	4925	4802	4840	5841
T_4 – microbial consortia	4902	4798	4450	5625
T_5 – control	4568	4468	4125	5355
T_6 -T_2+T_3+T_4		5524		6125
CD(5%)	623	395	342	322

Table 3. Effect of treatments on grain yield (kg ha $^{-1}$) of rice during 2021-22

Treatments	TRRI, Aduthurai		KVK,Needamangalam	Overall grain yield	% increase over control
	Kuruvai 2021	Samba 2021-22	Kuruvai 2021		
T_1 – $CuSO_4$	4732	4530	4150	4602	2.01
T_2 – Gypsum	5056	4928	4980	5111	13.26
T_3–Conoweeding+AWDI	4910	4802	4840	4994	10.37
T_4 –microbial consortia	4823	4798	4450	4835	6.85
T_5 –control	4568	4468	4125	4525	--
T_6 -T_2+T_3+T_4	5235	5124	5268	5455	20.6
CD(5%)	326	395	342		

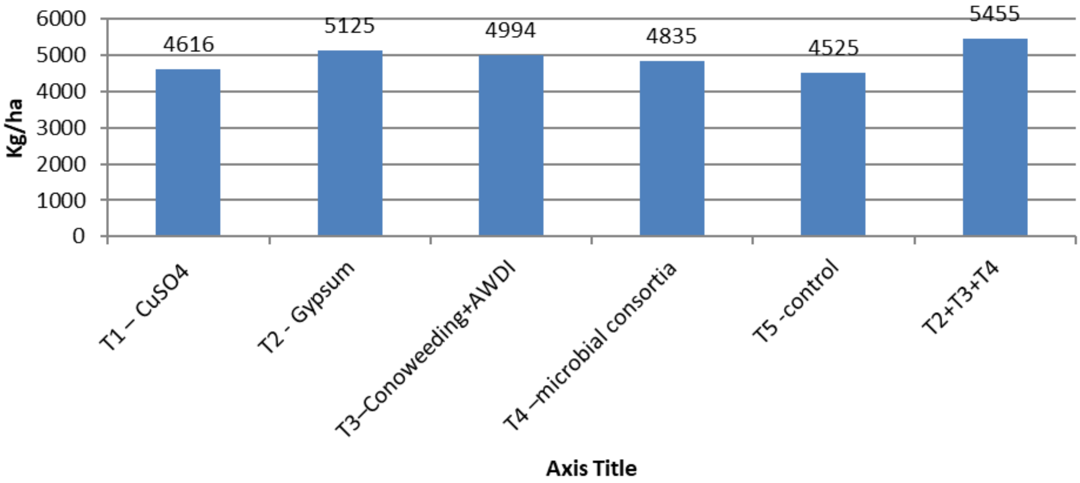

Fig 1. Influence of treatments on grain yield (kg/ha) of rice (pooled mean of seven trials)

which contains calcium, makes the soil friable, thus improving soil health. Microbial consortia may also have played a role in mobilizing K and Zn from the soil for better rice growth in the affected areas. These results are consistent With Tian *et al*.(2021) through meta-analysis of 2,419 comparisons from 115 studies to comprehensively evaluate the overall change in crop yield induced by waterlogging in the global region. The results suggested that waterlogging decreased crop yield by 32.9% on average, compared with no waterlogging, which was a result of reduced 1,000-grain weight (13.67%), biomass (28.89%), plant height (10.68%), net photosynthetic rate (P_n, 39.04%), and leaf area index (LAI, 22.89%).

Influence of treatments on soil fertility

Also, gypsum improves the ability of soil to drain and improves the soil aeration, not allowing the soil to be waterlogged. Improvements in infiltration rate and hydraulic conductivity with use of gypsum add to the ability of soils to have adequate drainage (Jaiswal and Srivastava, 2018).The available nutrient status results (Table 5) showed that the available nutrient status of 265 kg/ha of nitrogen ,35.4 kg/ha of phosphorus,342 kg/ha of potassium, 21.1meq/100 g of calcium,8.2 meq/100 g of magnesium was recorded in the T_6 treatment of the combined application of gypsum @500 kg/ha + Cono weeding twice +alternate wetting and drying (AWDI) and microbial consortia of Zn and K solubilising bacteria @500ml/ha. However, the Fe content was reduced to 9.5 ppm compared to the control of 15.2 ppm (value recorded for only T_6 treatment) . The increased availability might be due to good aeration by applying gypsum and alternate wetting and drying irrigation methods. The increased potassium and zinc availability was due to the application of microbial consortia containing K and Zn solubilising bacteria. Masunaga and Marques (2019) reported that improved soil management practices could have increased infiltration, reduced surface runoff, and improved plant water and nutrients availability. Management practices can alter soil structure directly or indirectly (Unger *et al*., 2018). Management-induced changes in soil structure are much more permanent and could maintain the structure of soil (Belmonte *et al*., 2018). In the present investigation, the gypsum and combination of cono weeding and drainage would have facilitated better soil aeration and improved nutrient availability .Gypsum provides calcium which is needed to flocculate clays in soil. It is the process in which many individual small clay particles are bound together to form larger particles. Such flocculation is needed to give favorable soil structure for root growth and air and water movement (Arthur Wallace,1994). The improvement of the soil's physical condition would be possible by the gypsum application in the present investigation itself.

Table 4. Effect of treatments on growth attributes of rice

Treatments	Plant height (cm)	No. of productive tillers / m^2	Root length (cm)	Root volume (cm^3)	Chaffy grains/ panicle	Filled grains/ panicle
T_1 – $CuSO_4$	97.3	228	27.2	72.1	32.2	92.8
T_2 – Gypsum	108.7	324	29.9	91.5	21.8	114.2
T_3-conoweeding+AWDI	102.0	310	28.4	87.2	22.5	112.3
T_4 –microbial consortia	101.3	305	28.0	82.3	26.4	99.8
T_5 –control	88.7	221	24.2	62.7	33.2	90.8
T_6-T_2+T_3+T_4	110.2	332	31.2	92.5	20.3	118.3
Sed	4.3	17	1.0	5.2	1.7	4.3
CD(p=0.05)	8.0	26	2.3	12.3	3.5	9.2

Table 5. Effect of treatments on soil properties of rice grown soil

Treatments	Av. N (kg ha $^{-1}$)	Av. P (kg ha $^{-1}$)	Av. K (kg ha $^{-1}$)	OC (%)	Ca (meq/ 100g)	Mg (meq/ 100g)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
T_1 – $CuSO_4$	262	33.2	315	0.60	16.3	7.6	15.2	4.5	3.2	1.71
T_2 – Gypsum	255	35.1	324	0.63	20.2	8.1	10.1	4.6	3.5	1.40
T_3– Conoweeding+AWDI	244	34.3	328	0.60	17.1	7.8	12.3	3.8	4.0	1.50
T_4 –microbial consortia	251	32.4	333	0.62	18.3	7.5	12.0	4.6	3.6	1.58
T_5 –control	242	33.1	319	0.60	16.2	7.3	16.5	4.2	3.0	1.29
T_6 -T_2+T_3+T_4	265	35.4	342	0.64	21.1	8.2	9.5	4.8	3.4	1.32
SEd	11	NS	11	NS	1.4	0.6	0.7	Ns	0.4	0.11
CD(p=0.05)	22		20		3.0	1.0	1.3	NS	1.0	0.23

Influence of treatments on nutrient uptake

Based on the recorded data from Table 6, T_6 showed a higher grain nutrient uptake of compared to T_3 and T_4; N (71.2 kg/ha), P (10.98 kg/ha), K (41.0 kg/ha),Ca (9.34 kg/ha), Mg (3.94 kg/ha) and S(8.25 kg/ha) uptake of grain in the combined T_6 treatment. The same trend of results was also observed for straw uptake (Table 7). The improved nutrient uptake might be due to the influence of combined application of treatments on grain yield, which would have indirectly affected the nutrient uptake of rice . The treatment without any remedial measures recorded lower uptake of nutrients. The results are in conformity with GutierezBoem *et al*. (1996) that water logging resulted in a decrease of N, P, K and Ca uptake by Brassica napus L, which also changes the available ion concentration of the soil solution Morad and Silvestre (1996) also observed a decrease of mineral element concentration in various plants due to absence of oxygen. On waterlogged sites, low redox potential causes both Mn toxicity and N deficiency in waterlogged soils. Root metabolism and root growth are also inhibited under these anaerobic conditions; since the lack of O_2 affects the plant's energy status (Drew, 1988), the nutrient uptake is also reduced. Improved soil management can increase availability of water and nutrients to plants (Masunaga and Marques, 2018). Ferronato *et al*. (2019) also reported that waterlogging affects the ability of soil to provide an optimum medium for plant growth and alters its physical, chemical, electrochemical and biological characteristics. Sarkar *et al*.(2019) also observed impaired roots' inefficient nutrient ion absorption capacity due to waterlogging.

Influence of treatments on soil microbial population

Based on the microbial population assessment, it was found that the T6 treatment, which received microbial consortia along with amendments and AWDI , had the highest microbial population of bacteria (126 x10^6cfu/gm) and actinobacteria (7x10^4cfu/gm) (Table 8). Previous research has indicated that limited oxygen availability in periodically waterlogged agricultural fields is a significant constraint for soil microbial communities (Nguyen *et al*., 2018).The algal growth was recorded as a great menace during this water logging period and the effect of treatments on algal growth is given in Ta-

Table 6. Effect of treatments on rice plant nutrients up take in grain

Treatments	N	P	K	S	Ca	Mg
	kg ha $^{-1}$					
T_1 – $CuSO_4$	63.8	9.21	37.2	8.10	5.92	3.72
T_2 – Gypsum	70.1	10.64	40.4	8.12	9.21	3.92
T_3–Conoweeding+AWDI	67.8	8.65	38.3	8.04	6.56	3.56
T_4 –microbial consortia	66.2	7.98	39.9	8.12	6.24	3.41
T_5 –control	61.2	8.96	37.8	8.04	5.75	3.51
T_6 -T_2+T_3+T_4	71.2	10.98	41.0	8.25	9.34	3.94
SEd	2.3	0.42	1.5	0.29	0.21	Ns
CD(p=0.05)	4.7	0.85	2.0	0.58	0.48	

Table 7. Effect of treatments on rice plant nutrients (kg ha $^{-1}$) uptake in straw

Treatments	N	P	K	S	Ca	Mg
	kg ha $^{-1}$					
T_1 – $CuSO_4$	26.3	8.52	59.1	16.5	9.00	3.79
T_2 – Gypsum	32.8	11.18	70.6	19.7	11.86	4.52
T_3–Conoweeding+AWDI	29.6	9.89	66.7	18.2	10.56	4.39
T_4 –microbial consortia	26.5	9.57	66.4	18.6	10.21	4.25
T_5 –control	25.0	8.03	55.7	15.6	8.45	3.57
T_6 -T_2+T_3+T_4	33.2	11.23	71.6	20.8	12.02	4.58
Sed	1.4	0.41	3.7	0.92	0.56	0.26
CD(p=0.05)	2.8	0.84	7.8	1.9	1.2	0.51

Table 8. Effect of treatments on total microbial population of rice

Treatments	Bacteria (10^6cfu/gm)	Fungi (10^4cfu/gm)	Actino bacteria (10^3cfu/gm)
T_1 – $CuSO_4$	95	4	42
T_2 – Gypsum	109	6	48
T_3–Conoweeding+AWDI	104	5	45
T_4 –microbial consortia	121	6	55
T_5 –control	80	5	37
T_6 -T_2+T_3+T_4	126	7	58
SEd	7	Ns	5
CD(p=0.05)	13		9

Table 9. Effect of treatments on algal dry biomass in rice fields

Treatments	Initial dry biomass	15 days after imposing	30 days after imposing
T_1 – $CuSO_4$	10.2	11.2	8.5
T_2 – Gypsum	9.5	4.2	2.6
T_3–Conoweeding+AWDI	10.6	5.8	3.2
T_4 –microbial consortia	11.6	6.1	4.8
T_5 –control	9.8	10.5	8.1
T_6 -T_2+T_3+T_4	10.2	3.1	1.8
SEd	0.61	0.73	
CD(p=0.05)	1.23	1.42	NS

ble 9. The menace of the algal population could be reduced to 3.1 (g/m^2) of dry biomass than control of 11.2 dry biomass (g/m^2) 15 days after imposing treatment . During the 30th day, the same trend of results was observed. The combined application of Gypsum @500 kg/ha+ Conoweeding+AWDI + microbial consortia was observed to reduce the algal growth to a greater extend. Waterlogging facilitated the high algae production, which is in line with Ramaraj et al. (2015), who stated that the production of algae by the natural water medium is potentially feasible. Grogan *et al*. (2023) reported that potentially toxic cyanobacteria are the predominant group across diverse freshwater systems and might have reduced plant nutrient efficiency.

Conclusion

From the seven field trials conducted at the old Cauvery Delta Zone of Tamil Nadu, India, to reclaim the water logging issues of lack of nutrients availability, poor aeration and heavy algal mass, the application of gypsum @500 kg ha -1 +conoweeding(twice) +AWDI (10.37%) and microbial consortia @ 500ml/ha (T_6) increased the yield upto 20.6 % than individual treatments, The growth and yield attributes also favourably enhanced by the application of the treatments. The recommendation emanated from the study to ameliorate the water logging issue in the delta region of clay soils of Tamil Nadu for getting higher grain yield and better soil fertility is the application of gypsum @500 kg ha^{-1}+conoweeding- twice+Alternate wetting and drying irrigation method+microbialconsortia (K and Zn solubilising bacteria) @500 ml ha^{-1} (T_6).

Conflict of interests

The authors declare that they have no conflict of interest.

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