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Post-harvest soil health of wetland rice ecosystem as influenced by spatial arrangements and integrated nutrient management

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Abstract
A field experiment was conducted at Annamalai University Experimental Farm, Department of Agronomy, Annamalai University, Annamalainagar to study the effect of spatial arrangements and integrated use of green leaf manure with inorganic nutrition on soil fertility and microbial population of post harvest soil of wetland rice. The results revealed that the spatial arrangements and integrated nutrient management were significantly influenced the post harvest soil health and microbial population. Among the treatment combinations, spot seeding of rice at 30 × 30 cm spacing for Thaladi and 25 × 25 cm spacing for Navarai season under the integrated application of 50 per cent N *via.*, *Albizia lebbeck* along with 50 per cent N *via.*, inorganic fertilizer significantly improved the post harvest soil available N (268.51 and 244.56 kg ha^{-1}), P_2O_5 (23.89 and 24.67 kg ha^{-1}) and K_2O (382.92 and 337.04 kg ha^{-1}) during the Thaladi and Navarai seasons, respectively. The same trend was also recorded in the soil microbial population of bacteria (58.78 and 46.33 x 10^{-6} g^{-1} of soil), fungi (39.78 and 34.00 x 10^{-4} g^{-1} of soil) and actinomycetes (8.00 x 10^{-6} g^{-1} of soil), respectively.

Keywords: Green leaf manuring, microbial population, *Oryza sativa,* post harvest soil fertility

Introduction
Rice is the major staple food for about 70 per cent of the India’s population, and thus it is act an important foundation for food security of our country. Introduction of resource expensive high yielding rice varieties are almost tripled food grain production within a span of three decades during the green revolution. However, rapid grain productivity achieved during 1970’s and 80’s could not be maintained during the first and second decade of 21st century, even though annual growth of fertilizer use on rice has been from three to 40 times faster than the growing of rice yields. Intensive agriculture with exhaustive high yielding varieties of rice, has led to heavy withdrawal of nutrients from the soil. Imbalanced and discriminate use of chemical fertilizers has resulted in deterioration of soil health. In this situation to achieve the projected target of 122 million tonnes by 2030, the productivity of rice has to be increased with the help of suitable integrated agronomic approaches (Allen, 2017) [1].

Integrated use of NPK fertilizers and organic manures are helpful for maintaining higher availability of soil nutrients. Use of organic manures in today’s agriculture is increasing, because of its utility improving the physical, chemical and biological properties of soil and also maintaining the good soil health. The negative impacts of chemical fertilizers, coupled with escalating prices, have led to growing interests in the integrated use of organic and inorganic source of nutrients. A suitable combination of organic and inorganic sources of nutrients is necessary for sustainable agriculture that can ensure food production (Sultana *et al*. 2016) [12]. There is a felt need to evaluate a suitable agronomic strategy which emphasis on eco-friendliness to accomplish the twin objectives of achieving the sustained production and maintenance of soil health in terms of soil fertility over a long period.

Proper spatial arrangement have more advantages such as maximize solar utilization efficiency, improves aeration within crop canopy, enhances soil respiration, sustained soil fertility and provides better conducive climate for multiplication of soil microbes. As organic matters are the favoured energy source for the microbes, ecosystems with high organic substances tend to have higher microbial biomass load as well as its activities (Babu *et al*., 2017) [3]. The world’s elite society is giving emphasis on utilization of organic materials, are the safer sources of plant nutrient which have no detrimental effect to crops, soil and environment (Mirza *et al.*, 2010) [8]. Bulky sources of organic nutrients are often proposed as alternative to commercial mineral fertilizers, but its availability is very low.

In this situation, transfer of biomass from agroforestry systems to puddled rice ecosystem is one of several techniques under investigation for replenishment of soil fertility. With this background, the present agronomic investigation was carried out to study the soil fertility status and microbial biomass after harvesting of rice as influenced by spatial arrangements and organic and inorganic nutrition.

Materials and methods

Field experiments were conducted at Experimental Farm, Department of Agronomy, Annamalai University, Annamalainagar (11°24′ North latitude, 79°44′ East longitude and at an altitude of +5.79 m MSL). The climate is moderately warm with hot summer months. The experiments were conducted during Thaladi (September to January, 2010) and Navarai (January to April, 2011). Thaladi season received 1122 mm of rain and distributed over 43 rainy days, while Navarai season received 127 mm distributed over six rainy days. The mean maximum and minimum temperatures of 31.5°C and 23.4°C, respectively with an average relative humidity of 89 per cent were recorded during Thaladi season. While, the mean maximum temperature of 33°C, mean minimum temperature of 25.8°C and average relative humidity of 85 per cent are observed during Navarai season. The soil is clay in texture, neutral to moderately saline (7.2 and 8.3), EC (0.56 and 5.37 dSm^{-1}), low in organic carbon (0.23 and 0.47 %) and low in available nitrogen (227 and 213 kg ha^{-1}), medium in available phosphorus (17 and 18.5 kg ha^{-1}) and high in available potassium (346 and 298 kg ha^{-1}) during the first and second experiments, respectively.

The experiment was laid out in split plot design with three replications by using four spatial arrangements in main plots (M_1: 40 × 40, M_2: 35 × 35, M_3: 30 × 30 and M_4: 25 × 25 cm) and four integrated nutrient management practices in sub plots (S_1: control, S_2 - 50 % N *via*., *Pongamia pinnata* and remaining 50 % N *via*., urea, S_3: 50 % N *via*., *Albizia lebbeck* and remaining 50 % N *via*., urea and S_4: 50 % N *via*., *Azadirachta indica* and remaining 50 % N *via*., urea). Rice cultivars CO 43 (medium duration for Thaladi season) and ADT 43 (short duration for Navarai season) were used as test variety. The green foliage was obtained from the trees grown on the field bunds of the Experimental Farm and incorporated in the experimental plots as per the treatment schedule before puddling (15 DBS). As per the Tamilnadu state government fertilizer recommendation (medium duration crop - 150 : 50 : 50 and short duration - 120 : 38 : 38 N, P_2O_5 and K_2O kg ha^{-1}, respectively), the required quantity of inorganic fertilizers worked out and applied in the form of urea, single super phosphate and muriate of potash. Inorganic nitrogen fertilizer was applied as three splits *viz*., 20 per cent at the appearance of 2nd tiller, 40 per cent at maximum tillering and 40 per cent at panicle initiation stage, while the entire doses of phosphorus and potassium were applied at 15 DAS.

The seed rate used for treatments M_1, M_2, M_3 and M_4 were 12, 9, 6 and 5 kg ha^{-1}, respectively for Thaladi season (CO 43) and 7.5, 5, 4 and 3 kg ha^{-1}, respectively for Navarai season (ADT 43). The sprouted seeds were carefully spot sown @ 3 seeds per hole in the field with a thin film of water as per the treatment schedule. Depending on weather conditions plots were kept under a saturated condition (alternate wetting and drying method - application of 2 cm depth of water after the formation of hairline crack). Irrigation was withheld 12 days before harvest. Need based plant protection measures were followed based on the economic threshold level of insect pests and diseases. Soil samples were collected before the start of the experiment and after the harvest of the crop at 15 cm depth. The chemical properties *viz.*, available N, P_2O_5 and K_2O were analyzed in the post harvest soil. The population of bacteria, fungi and actinomycetes were estimated by serial dilution and plate count technique by plating on appropriate media and was expressed as colony forming units (CFU) g^{-1} of soil. The critical differences were worked out at 5 per cent probability level for comparison as per the procedures suggested by Gomez and Gomez (1984) [6].

Results

Post harvest soil nutrient status

The difference in available soil nutrient status was noticed due to different plant spacing's at post harvest soil (Table 1-3). The highest post harvest soil available N, P_2O_5 and K_2O (247.76, 21.49 and 360.95 kg ha^{-1}, respectively) were recorded in 30 × 30 cm spacing (M_2) during Thaladi season. However, in Navarai season plant spacing at 25 × 25 cm (M_1) registered a higher post harvest soil available N, P_2O_5 and K_2O of 224.38, 21.19 and 316.86 kg ha^{-1}, respectively. The experimental results further revealed that INM treatments had noticeably increment in the availability of N, P_2O_5 and K_2O in the post harvest soil over control. Among them, the maximum post harvest soil available N (260.37 and 228.46 kg ha^{-1}), P_2O_5 (22.11 and 21.17 kg ha^{-1}) and K_2O (363.68 and 319.78 kg ha^{-1}) during Thaladi and Navarai season, respectively were recorded in incorporation of 50 per cent N *via., Albizia lebbeck* GLM along with 50 per cent N *via.*, inorganic fertilizer (S_3). Interaction effect between spatial arrangements and GLM treatments were significantly influenced the post harvest soil available nutrients. Among the treatment combinations, spot seeding of rice at 30 × 30 cm spacing for Thaladi season (M_2S_3) and 25 × 25 cm spacing for Navarai season (M_1S_3) and application of 50 per cent N *via., Albizia lebbeck* GLM along with 50 per cent N *via.*, inorganic fertilizer significantly improved the N (268.51 and 244.56 kg ha^{-1}), P_2O_5 (23.89 and 24.67 kg ha^{-1}) and K_2O (382.92 and 337.04 kg ha^{-1}) in the post harvest soil.

Soil microbial population

Among spatial arrangement treatments, highest microbial colony forming units (CFU) were recorded in adoption of 30 × 30 cm spacing (M_2) in the Thaladi season (42.91 x 10^{-6} g^{-1} of soil for bacteria, 31.70 x 10^{-4} g^{-1} of soil for fungi and 6.27 x 10^{-3} g^{-1} of soil for actinomycetes), while planting at 25 × 25 cm spacing (M_1) registered the maximum CFU of 32.67 x 10^{-6} g^{-1} of soil for bacteria, 24.78 x 10^{-4} g^{-1} of soil for fungi and 4.64 x 10^{-3} g^{-1} of soil for actinomycetes in the Navarai season. Among the integrated nutrient management treatments, the maximum CFU for bacteria (43.89 and 31.66 x 10^{-6} g^{-1} of soil), fungi (32.06 and 23.78 x 10^{-4} g^{-1} of soil) and actinomycetes (6.92 and 4.28 x 10^{-4} g^{-1} of soil) during Thaladi and Navarai season, respectively were recorded in the application of 50 per cent N *via., Albizia lebbeck* GLM along with 50 per cent N *via.*, inorganic fertilizer (S_3). Among the spatial arrangements and GLM treatment combinations, spot seeding of rice at 30 × 30 cm spacing for Thaladi season (M_2S_3) and 25 × 25 cm spacing for Navarai season (M_1S_3) and 50 per cent N *via., Albizia lebbeck* GLM along with 50 per cent N *via.*, inorganic fertilizer significantly recorded the highest CFU for bacteria (58.78 and 46.33 x 10^{-6} g^{-1} of soil), fungi (39.78 and 34.00 x 10^{-4} g^{-1} of soil) and actinomycetes (8.00 x 10^{-6} g^{-1} of soil).

Discussion

Adoption of optimum spatial arrangement offered favorable microclimate for the multiplication of microbes. It served as a sink (immobilization) and a source (mineralization) of nutrient elements *viz*., N, P_2O_5 and K_2O on top soil. Moreover the added nutrients through GLM would have been the source for the unutilized portion of available N, P_2O_5 and K_2O in the post harvest soil. Green leaf manure N is less prone to loss mechanisms than mineral N fertilizer and contributed to long term residual effects on soil fertility. It also increased the availability of phosphorus and potassium through the mechanism of reduction and chelation processes. In addition, the nutrients secreted by plant roots in the form of soluble root exudates *viz*., amino and organic acids, sugars, polysaccharides, peptides, proteins and other photosynthates enhanced the multiplication of microbial population like bacteria, fungi and actinomycetes and accelerated its activity thereby stabilize, mobilize and solubilize the native and applied nutrients in the soil. The enhanced availability of N, P_2O_5 and K_2O and microbes in the post harvest soil due to integrated application of GLM's and along with inorganic nutrients was reported by Fosu *et al*. (2007) [4], Gautam *et al*. (2008) [5], Indrani *et al*. (2008) [7], Selvi and Kalpana (2009) [10], Shah *et al*. (2010) [11], Anas *et al*. (2011) [2] and Prakash *et al*. (2019) [9].

Table 1: Effect of spatial arrangements and integrated N management on post harvest soil available nitrogen (kg ha^{-1})

Treatments	Thaladi (CO 43)					Navarai (ADT 43)				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**	**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	206.37	210.89	201.30	195.23	203.45	191.67	188.00	178.25	172.50	182.61
S_2	258.70	257.92	254.09	255.52	256.56	236.15	228.01	217.26	213.12	223.64
S_3	259.79	268.51	256.79	256.38	260.37	244.56	234.65	219.00	215.64	228.46
S_4	255.29	253.73	247.84	248.19	251.26	225.13	226.54	213.51	212.85	219.51
Mean	245.04	247.76	240.01	238.83		224.38	219.30	207.01	203.53	
	S. Ed		CD (0.05)			S. Ed		CD (0.05)		
M	0.61		1.22			1.32		2.64		
S	0.72		1.45			1.97		3.95		
MS	0.78		1.59			2.56		5.12		

Table 2: Effect of spatial arrangements and integrated N management on post harvest soil available phosphorus (kg ha^{-1})

Treatments	Thaladi (CO 43)					Navarai (ADT 43)				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**	**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	17.03	17.96	16.31	15.20	16.63	17.33	16.61	15.54	14.63	16.03
S_2	21.25	22.70	21.47	19.63	21.26	22.65	20.99	19.06	18.16	20.22
S_3	22.56	23.89	21.86	20.14	22.11	24.67	22.06	19.30	18.65	21.17
S_4	21.56	21.40	19.82	19.13	20.48	20.12	20.46	18.21	18.15	19.24
Mean	20.60	21.49	19.87	18.53		21.19	20.03	18.03	17.40	
	S. Ed		CD (0.05)			S. Ed		CD (0.05)		
M	0.36		0.72			0.29		0.58		
S	0.31		0.62			0.36		0.72		
MS	0.52		1.05			0.37		0.75		

Table 3: Effect of spatial arrangements and integrated N management on post harvest soil available potassium (kg ha^{-1})

Treatments	Thaladi (CO 43)					Navarai (ADT 43)				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**	**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	320.96	326.32	315.29	305.65	317.06	285.25	282.86	277.13	268.32	278.39
S_2	362.50	374.75	346.58	338.13	355.49	329.66	321.63	305.62	300.78	314.42
S_3	369.66	382.92	358.29	343.86	363.68	337.04	327.50	309.64	304.92	319.78
S_4	362.29	359.80	343.12	334.56	349.94	315.47	318.74	303.19	299.06	309.12
Mean	353.85	360.95	340.82	330.55		316.86	312.68	298.90	293.27	
	S. Ed		CD (0.05)			S. Ed		CD (0.05)		
M	3.01		6.03			2.06		4.12		
S	2.41		4.84			2.43		4.86		
MS	3.52		7.09			2.63		5.27		

Table 4: Effect of spatial arrangements and integrated N management on bacterial population (CFU x 10^{-6} g^{-1} of soil) in post harvest soil

Treatments	Thaladi (CO 43)					Navarai (ADT 43)				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**	**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	19.00	22.55	17.44	15.00	18.50	19.78	16.00	12.44	10.33	14.64
S_2	36.33	48.00	29.78	24.55	34.67	34.00	28.55	22.44	15.78	25.19
S_3	47.55	58.78	35.44	42.89	43.89	46.33	34.44	23.88	22.00	31.66
S_4	33.88	42.33	26.78	26.88	32.47	30.55	20.00	21.33	16.55	22.11
Mean	34.19	42.91	27.36	24.05		32.67	24.75	20.02	16.17	
	S. Ed		CD (0.05)			S. Ed		CD (0.05)		
M	2.70		5.42			1.58		3.18		
S	2.99		6.00			1.48		2.96		
MS	2.06		4.12			1.52		3.05		

Table 5: Effect of spatial arrangements and integrated N management on fungal population (CFU x 10^{-4} g^{-1} of soil) in post harvest soil

Treatments	Thaladi (CO 43)					Navarai (ADT 43)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
S_1	18.78	20.00	16.33	14.55	17.42	15.33	14.88	10.00	8.78	12.25
S_2	32.44	35.00	27.88	23.55	29.72	27.00	24.33	16.55	12.78	20.17
S_3	33.78	39.78	30.33	24.33	32.06	34.00	28.55	18.00	14.55	23.78
S_4	26.00	32.00	24.55	21.78	26.08	22.78	20.33	14.33	10.78	17.06
Mean	27.75	31.70	24.77	21.05		24.78	22.02	14.72	11.72	
	S. Ed			CD (0.05)		S. Ed			CD (0.05)	
M	1.57			3.15		1.21			2.42	
S	1.03			2.05		1.43			2.86	
MS	0.56			1.11		1.58			3.16	

Table 6: Effect of spatial arrangements and integrated N management on actinomycetes population (CFU x 10^{-3} g^{-1} of soil) in post harvest soil

Treatments	Thaladi (CO 43)					Navarai (ADT 43)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
S_1	3.87	4.87	3.00	3.00	3.69	3.55	2.33	1.00	1.00	1.97
S_2	6.88	7.33	5.00	4.87	6.02	4.33	4.78	2.33	2.00	3.36
S_3	7.55	8.00	6.33	5.78	6.92	6.33	5.00	3.78	2.00	4.28
S_4	5.00	4.87	4.00	3.55	4.36	4.33	3.55	3.55	1.33	3.19
Mean	5.83	6.27	4.58	4.30		4.64	3.92	2.67	1.58	
	S. Ed		CD (0.05)			S. Ed		CD (0.05)		
M	0.16		0.32			0.29		0.58		
S	0.33		0.67			0.32		0.63		
MS	0.20		0.40			1.42		NS		

Conclusion

The post harvest soil health properties such as available nitrogen, available phosphorous and exchangeable potassium contents and microbial population were increased by the adoption of 30 × 30 cm spacing for medium duration rice and 25 × 25 cm for short duration rice along with integrated application of 50 per cent of nitrogen through *Albizia lebbeck* GLM and remaining 50 per cent of nitrogen through inorganic fertilizer. Accordingly, it was proposed that green leaf manure incorporation in rice growing agroecosystems pave a way for sustaining the soil health and net improvement of land productivity.

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