The Pharma Innovation Journal 2023; 12(7): 1160-1165

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(7): 1160-1165

www.thepharmajournal.com
Received: 14-04-2023
Accepted: 17-05-2023

Phurailatpa Pooja Sharma
Assistant Professor in Agronomy, South Asian Institute of Rural and Agricultural Management, Langjing Achouba, Imphal West, Manipur, India

S Jawahar
Faculty of Agriculture, Annamalai University, Annamalainagar, Tamil Nadu, India

Corresponding Author:
Phurailatpa Pooja Sharma
Assistant Professor in Agronomy, South Asian Institute of Rural and Agricultural Management, Langjing Achouba, Imphal West, Manipur, India

Effect of different silicon sources on post-harvest soil available nutrients of rice under different establishment methods

Phurailatpa Pooja Sharma and S Jawahar

Abstract
Field experiments were conducted during Kuruvai and Navarai seasons at two different locations. Location – I was conducted in wetland (Field No. Q7 and A2) of Experimental Farm, Annamalai University, Annamalai Nagar, Komaratchi Block and Location – II were conducted in farmer fields at Kiliyanoor Village, Keerapalayam block, Cuddalore District, Tamil Nadu, India to study the effect of different silicon sources on post-harvest soil available nutrients (N, P, K and Si) of rice under different establishment methods. The field experiments were laid out in a split-plot design with two replications. The main plots comprised of M_1- Dry Seeded Rice (DSR), M_2- Wet Seeded Rice (WSR) and M_3- Transplanted Rice (TR) and subplots are S_1- RDF, S_2 - S_1 + 100 kg Si ha^{-1} through Calcium Silicate + Silicate solubilising bacteria, S_3 - S_1 + 200 kg Si ha^{-1} through Calcium Silicate + Silicate solubilising bacteria, S_4 - S_1 + 100 kg Si ha^{-1} through Diatomaceous Earth, S_5 - S_1 + 200 kg Si ha^{-1} through Diatomaceous Earth, S_6 – S_1 + 100 kg Si ha^{-1} through Lignite Fly ash + Silicate solubilising bacteria and S_7 – S_1 + 200 kg Si ha^{-1} through Lignite Fly ash + Silicate solubilising bacteria. Among the methods of establishments, transplanted rice recorded higher post-harvest soil available nutrients (NPK) status and dry-seeded rice registered the higher post-harvest soil available silicon status which was followed by wet-seeded rice, Regarding silicon sources and levels, DE @ 200 kg Si ha^{-1} along with RDF recorded higher values for post-harvest soil available NPK status. This was followed by DE @ 100 kg Si ha^{-1} along with RDF whereas calcium silicate @ 200 kg Si ha^{-1} + silicate solubilising bacteria along with RDF recorded the highest post-harvest soil available silicon status followed by lignite fly ash @ 200 kg Si ha^{-1} + silicate solubilising bacteria along with RDF. From this investigation, it can be concluded that DE @ 200 kg Si ha^{-1} + RDF to transplanted rice is a viable practice to enhance the post-harvest soil available NPK status of rice and dry seeded rice applied with calcium silicate + silicate solubilising bacteria along with RDF is a viable practice to enhance the post-harvest soil available silicon status of rice.

Keywords: Silicon sources, establishment methods, Rice and post-harvest soil available nutrients (N, P, K and Si) status

Introduction

Rice is an important cereal crop grown extensively in tropical and sub-tropical regions of the world. It is the major source of calorie intake and the staple food for more than three billion people in the world (Datta *et al.*, 2017) [8]. Globally, rice is cultivated in an area of 162.09 million hectares with the production of 494.22 million tonnes and productivity of 4.55 tonnes per hectare (Anonymous, 2019) [1]. About 90 per cent of the rice grown in the world is produced and consumed in the Asian region with China leading in production followed by India. India has the largest acreage under rice of 44.16 million hectares with a production of 116.48 million tonnes and productivity of 3.96 tonnes per hectare (Anonymous, 2020a) [2]. In Tamil Nadu, it is cultivated in an area of 1.88 million hectares with the production and productivity of 7.2 million tonnes and 4 tonnes per hectare, respectively (Anonymous, 2020b) [3].

Rice has been cultivated by different methods in different ecosystems all over the world. In India, rice cultivation is practised predominantly under a transplanted method that involves raising the seedlings in the nursery, uprooting them and transplanting them in the main field. The transplanting method is becoming increasingly scarce due to lack of resources such as labour, water and energy-intensive and thus becoming less profitable (Mahajan *et al.*, 2013 and Jnanesha and Kumar, 2017) [20, 14]. Transplanting is an expensive operation and it consumes a large quantity of standing water for puddling (Bouman and Tuong, 2001) [6].

Scarcity of irrigation water and labourers triggers the search for alternative rice crop establishment methods *viz*., wet and dry-seeded rice. For wet-seeded rice, the soil has to be puddled prior to the sowing of pre-germinated seed by manual broadcasting or line seeding on the saturated soil surface. Wet-seeded rice grows faster and matures earlier than transplanted rice which reduces the cost of cultivation and increases the benefit-cost ratio (Rajkumara *et al.,* 2003) [29]. In direct dry seeding, rice seeds are directly sown in dry unpuddled soil conditions. Direct dry seeding can be done either by hand broadcasting or by line sowing. Improved short duration and high yielding varieties, nutrient and weed management techniques encourage the farmers to shift from the traditional system of transplanting to direct dry seeded rice culture. It could reduce labour needs by more than 20 per cent in terms of working hours and requires 20 per cent less water as compared to transplanted rice (Sattar and Khan, 1994) [34]. Direct dry-seeded rice reduces production cost and increases the net return by 37 per cent, in addition, matures about 8-10 days earlier (Isvilanonda, 2002) [13].

Rice yields are declining due to deteriorating soil health, imbalance in fertilizer use, lack of suitable rice varieties, pest infestation, frequent floods and drought (Datta *et al.,* 2017) [8]. Among them, an inadequate supply of macro and micronutrients affects the growth and yield of rice. In a more specific study of nutrients, an element called silicon has been found equally important as macronutrients and is gaining the attention of scientists for enhancing the yield and quality of rice.

Silicon (Si) is the second most abundant element in the earth's crust after oxygen which improves the yields and qualities of a large group of crops (Epstein, 1999) [9]. Sufficient Si supply enhances the plants strength, rigidity, minimizes lodging of cereal crops, improves defence against biotic and abiotic stresses and enhances agricultural productivity (Guntzer *et al.,* 2012) [12]. Silicon application produces more biomass which helps to improve light interception and photosynthetic efficiency. The addition of silicon strengthens the root canal, supply of sufficient oxygen to roots and minimizes water loss by evapotranspiration (Malav *et al.,* 2018) [21]. Application of Si as soil amendments is needed for both optimized soil fertility and improved plant nutrition (Ma and Takahashi, 2002) [18] and it is very important for vegetative growth which aids the plant in healthy development under stresses in different grasses especially in rice (Khan *et al.,* 2018 and Singh *et al.,* 2020) [16, 36].

Rice cultivation without silicon addition and continuous straw removal depleted the available silicon in the soil. The lower values for Si in the soil is due to long-term intensive crop cultivation, severe and frequent soil erosion and also due to the desilication process, Si in the soil is continuously lost as the result of leaching process. The depletion of plant-available Si in soils where rice is grown could be a possible limiting factor that contributes to declining yields (Meena *et al.,* 2014) [24]. This suggests that Si may become a yield-limiting element for rice production therefore, the application of exogenous Si fertilizer may be necessary for an economic and sustainable rice production (Ning *et al.,* 2014) [28].

Hence, it is essential to study the effect of certain silicon fertilizers through calcium silicate, diatomaceous earth, lignite fly ash and silicate solubilising bacteria (SSB) as a source of silicon on rice crops. Keeping the above facts, the present investigation was conducted to study the effect of different silicon sources on post-harvest soil available nutrients (N, P, K and Si) status of rice under different establishment methods.

Materials and Methods

Field experiments were conducted during Kuruvai and Navarai seasons at two different locations. Location – I were conducted in wetland (Field No. Q7 and A2) of Experimental Farm, Annamalai University, Annamalai Nagar, Komaratchi Block and Location – II were conducted in farmer fields at Kiliyanoor Village, Keerapalayam block, Cuddalore District, Tamil Nadu, India to study the effect of different silicon sources on post-harvest soil available nutrients (N, P, K and Si) of rice under different establishment methods. The soil of the experimental field in location –I is clay loam in texture and the experimental field in location – II is sandy clay loam in texture. The experiment was laid out in a split plot design with two replications. The main plots comprised of M_1- Dry Seeded Rice (DSR), M_2- Wet Seeded Rice (WSR) and M_3-Transplanted Rice (TR) and subplots are S_1- RDF, S_2 - S_1 + 100 kg Si ha^{-1} through Calcium Silicate + Silicate solubilising bacteria, S_3 - S_1 + 200 kg Si ha^{-1} through Calcium Silicate + Silicate solubilising bacteria, S_4 - S_1 + 100 kg Si ha^{-1} through Diatomaceous Earth, S_5 - S_1 + 200 kg Si ha^{-1} through Diatomaceous Earth, S_6 – S_1 + 100 kg Si ha^{-1} through Lignite Fly ash + Silicate solubilising bacteria and S_7 – S_1 + 200 kg Si ha^{-1} through Lignite Fly ash + Silicate solubilising bacteria. Rice variety Co-51 was used for this study and was fertilized with 120:40:40 kg NPK ha^{-1}. The entire dose of P_2O_5 was applied as basal. N and K were applied in four equal splits at basal, tillering, panicle initiation and heading stages. Silicon sources and SSB were applied as basal as per the treatments. The data were statistically analysed as suggested by Gomez (1994) [11].

Results and Discussion

Post-harvest soil available nutrients (n, p, k and si) status

The post-harvest soil available nutrients (N, P, K and Si) were significantly influenced by rice establishment methods and Si sources and its levels. With reference to rice establishment methods, transplanted rice recorded higher on soil available N, P, K over wet and dry seeded rice. Higher soil available nutrients in the transplanted establishment method of rice might be due to the puddling effect in the soil which allows destruction of soil aggregates, dispersion of soil particles and greater amount of water penetrating into the field. These all factors might have led to better nutrient availability under transplanted rice (Gangwar *et al.,* 2008 and Thapliyal *et al.,* 2020) [10, 37]. Soil available Si was recorded higher on dry seeded rice over wet and transplanted rice due to lesser solubilization of amorphous silica into orthosilicic acid in the soil.

Among the Si sources, DE recorded the highest post-harvest soil available NPK due to the synergistic effect of Si with NPK. This was in accordance with the finding of Bharathiraja (2014) [5] who reported that the application of Si through DE significantly enhanced the NPK uptake in rice. This was followed by lignite fly ash +SSB due to an increase in the availability of N, P, K and Si by the action of SSB (Mishra *et al.,* 2007) [24]. Similar finding was earlier reported by Rani and Kalpana (2010) [29] who stated that the application of fly ash + SSB to soil increased the nutrient availability such as nitrogen, phosphorus, and other micronutrients. The highest post-harvest available Si was recorded under calcium silicate + SSB. Application of silicate-solubilizing bacteria (SSB) may take a longer time to improve the solubilization of insoluble Si (calcium silicate), that could delay the Si uptake and may lead to higher post-harvest available Si in calcium silicate + SSB (Kang *et al.*, 2017) [15]. The lesser post-harvest soil available NPK was observed under calcium silicate + SSB. However, the least soil-available Si was noticed under DE due to the maximum uptake of applied Si by the plant.

Among the graded levels of Si, 200 kg Si ha^{-1} through DE to rice registered superior over its lower levels and other sources and recorded the highest post-harvest soil available NPK. The improved N status in the soil by the use of N and Si fertilization can be explained by the high adsorption capacity of Si and increased microbial activity resulting in high accumulation of N in the treated soil (Bernal, 2008) [4]. Silicon and nitrogen has got synergistic relationship that improved the N status of the soil, besides a reduction in leaching loss of N (Das *et al.*, 2013) [7]. The available P content in the soil after the experiment was high. The mono-silicic acid anions released from Si sources may have replaced the phosphate anions released from Fe and Al phosphate, resulted in higher phosphorus status in the soil (Rao *et al*., 2018) [30]. The silicon in solution renders phosphorus available to plants reversing its fixation as Si itself competes for phosphorus fixation in the soil (Matichenkov and Bocharnikova, 2010) [22]. Sowbika (2018) [36] reported that utilization of native phosphorous with increasing levels of Si which resulted in the building up of higher soil P status and an increase in the quantity of mobile phosphorous in soil. The increase in available K content of soil could be due the positive interaction of Si with potassium which reduces K leaching and increases soil potassium status. Mohanthy *et al.* (1982) [25] observed that exchangeable potassium displaced from cation exchange sites into the soil solution due to competition for exchange sites from Fe and Mn might have increased the potassium concentration in the soil solution. This result agrees with the reports of Selvakumari *et al.* (2000) [34] and Matichenkov and Bocharnikova (2010) [22]. The maximum post-harvest soil available Si was recorded with 200 kg Si ha^{-1} through calcium silicate + SSB. The higher post-harvest Si observed under calcium silicate + SSB could be due to lesser solubility and a minimum supply of Si to rice at the early stages of crop growth and supply higher quantity of soil available Si at the lateral stages of rice which remain unutilised in the soil and also due to the action of SSB which might be the reason for higher Si availability in post-harvest soil. Similar result was earlier reported by Narayanaswamy (2007) [26]. The lesser uptake of Si by rice plants under Calcium silicate + SSB and very slow dissolution kinetics of soil Si caused more available Si in the soil (Lindsay, 1979). Application of Si would have prevailed in the soil as mono silicic acid ($H_4S_IO_4$) due to its residual activity and enhanced soil-available Si (Rao *et al.*, 2018) [30]. Lignite fly ash @200 kg Si ha^{-1} was next in order to post-harvest soil available N, P, K and Si. The least soil post-harvest soil available N, P, K and Si was observed under 0 kg Si ha^{-1} (RDF alone) due to lack of Si supply to rice crops.

Among the combined effect between different establishment methods and Si sources and its levels, transplanted rice applied with DE @ 200 kg Si ha^{-1} recorded the highest soil available N, P, K during kuruvai and navarai seasons in locations I and II due to optimum soil condition and the positive influence of Si in NPK. This is in accordance with Bharathiraja (2014) [5] who reported that the application with DE @ 100 kg Si ha^{-1}. The higher soil is available Si was found in calcium silicate @ 200 kg Si ha^{-1} + SSB in dry-seeded rice during kuruvai and navarai seasons in locations I and II. This could be due to lesser root growth, poor adaptation of crop, delayed release of Si and lesser Si uptake by the crop. This is an agreement with the findings of Ravinchandran *et al.* (2002) and Sandhya (2010) [32]. Transplanted rice applied with DE @ 100 kg Si ha^{-1} was next in order to post-harvest soil available NPK and dry seeded rice applied with lignite fly ash +SSB @ 200 kg Si ha^{-1} was next in order to soil available Si. The least post-harvest soil available N, P, K and Si was recorded under RDF alone due to lesser availability of applied nutrients by rice crop.

Table 1a: Effect of silicon fertilization under different rice establishment methods on post-harvest soil available N, P and K (kg ha^{-1}) status of rice (Kuruvai -location I)

Main Plot Sub Plot	Available nitrogen (kg ha^{-1})				Available phosphorus (kg ha^{-1})				Available potassium (kg ha^{-1})			
	M_1	**M_2**	**M_3**	**MEAN**	**M_1**	**M_2**	**M_3**	**MEAN**	**M_1**	**M_2**	**M_3**	**Mean**
S_1	184.61	190.91	194.76	190.09	15.67	17.67	18.63	17.32	195.89	202.78	205.68	201.45
S_2	192.94	198.26	202.55	197.92	16.42	18.42	19.38	18.07	205.68	211.20	214.83	210.57
S_3	203.85	209.96	214.47	209.43	17.27	19.27	20.23	18.92	226.19	229.41	232.99	229.53
S_4	209.33	215.44	220.08	214.95	18.64	20.44	21.40	20.16	237.34	243.23	247.27	242.61
S_5	224.05	217.39	221.91	221.12	18.89	20.89	21.85	20.54	245.74	249.32	253.36	249.47
S_6	202.63	208.74	213.22	208.20	16.91	18.91	19.87	18.56	223.87	227.09	230.67	227.21
S_7	206.04	212.11	216.67	211.61	17.90	19.90	20.86	19.55	228.73	231.95	235.44	232.04
MEAN	203.35	207.54	211.95		17.39	19.36	20.32		223.35	227.85	231.46	
	M	S	M x S		M	S	M x S		M	S	M x S	
S.Ed	2.10	0.14	2.55		0.47	0.19	0.65		1.78	1.16	1.94	
CD (*p*=0.05)	4.25	2.87	5.15		0.95	0.39	1.32		3.59	2.35	3.91	

Table 1b: Effect of silicon fertilization under different rice establishment methods on post-harvest soil available N, P and K (kg ha^{-1}) status of rice (Kuruvai - location II)

Main Plot Sub Plot	Available nitrogen (kg ha^{-1})				Available phosphorus (kg ha^{-1})				Available potassium (kg ha^{-1})			
	M_1	**M_2**	**M_3**	**MEAN**	**M_1**	**M_2**	**M_3**	**MEAN**	**M_1**	**M_2**	**M_3**	**Mean**
S_1	198.96	207.08	210.62	205.55	16.64	18.49	19.23	18.12	234.23	240.73	244.83	239.93
S_2	212.79	219.80	224.84	219.14	17.43	19.28	20.02	18.91	252.41	257.70	262.44	257.52
S_3	223.95	231.27	235.66	230.29	18.26	20.11	20.85	19.74	282.79	286.81	292.55	287.38
S_4	231.69	239.70	244.28	238.56	19.57	21.42	22.16	21.05	295.13	311.91	306.63	304.56

S_5	233.62	241.50	245.11	240.08	20.21	22.06	22.80	21.69	307.19	314.06	319.99	313.75
S_6	221.98	229.29	233.69	228.32	17.95	19.8	20.54	19.43	280.54	284.23	289.37	284.71
S_7	226.20	233.32	237.78	232.43	18.98	20.83	21.56	20.46	285.43	289.21	294.49	289.71
MEAN	221.31	228.85	233.14		18.43	20.28	21.02		276.82	283.52	287.19	
	M	S	M x S		M	S	M x S	S x M	M	S	M x S	
S.Ed	2.16	0.98	2.5		0.36	0.17	0.56	0.33	1.81	1.36	3.10	
CD (p=0.05)	4.36	1.98	5.05		0.72	0.35	1.14	0.67	3.65	2.75	6.27	

Table 2a: Effect of silicon fertilization under different rice establishment methods on post-harvest soil available N, P and K (kg ha^{-1}) status of rice (Navarai - location I)

Main Plot Sub Plot	Available nitrogen (kg ha^{-1})				Available phosphorus (kg ha^{-1})				Available potassium (kg ha^{-1})			
	M_1	M_2	M_3	MEAN	M_1	M_2	M_3	MEAN	M_1	M_2	M_3	Mean
S_1	196.39	203.39	207.39	202.39	15.75	17.95	18.62	17.44	200.48	208.07	211.17	206.57
S_2	206.70	213.34	217.97	212.67	16.52	18.72	19.45	18.23	214.63	218.60	222.68	218.64
S_3	218.29	224.64	231.59	224.84	17.41	19.61	20.28	19.10	235.5	240.40	244.96	240.30
S_4	227.13	232.76	237.86	232.58	18.62	20.82	21.49	20.31	246.89	254.70	259.00	253.53
S_5	228.13	235.00	240.34	234.49	19.09	21.29	21.96	20.78	259.46	266.43	271.25	265.71
S_6	217.91	223.05	229.64	223.53	17.03	19.23	19.9	18.72	233.36	238.29	242.80	238.15
S_7	220.31	227.06	232.28	226.55	18.06	20.26	20.93	19.75	239.65	243.10	247.61	243.45
MEAN	216.41	222.75	228.15		17.50	19.70	20.38		232.85	238.52	242.78	
	M	S	M x S		M	S	M x S		M	S	M x S	
S.Ed	2.09	0.72	2.91		0.33	0.19	0.60		2.03	1.07	2.76	
CD (p=0.05)	4.23	1.46	5.87		0.66	0.39	1.21		4.10	2.17	5.57	

Table 2b: Effect of silicon fertilization under different rice establishment methods on post-harvest soil available N, P and K (kg ha^{-1}) status of rice (Navarai - Location I)

Main Plot Sub Plot	Available nitrogen (kg ha^{-1})				Available phosphorus (kg ha^{-1})				Available potassium (kg ha^{-1})			
	M_1	M_2	M_3	MEAN	M_1	M_2	M_3	MEAN	M_1	M_2	M_3	Mean
S_1	202.66	208.86	212.82	208.11	16.94	18.93	19.31	18.39	245.12	251.77	255.32	250.74
S_2	217.94	222.52	228.40	222.95	17.77	19.77	20.14	19.23	264.73	269.7	274.55	269.66
S_3	229.00	234.53	240.16	234.56	18.68	20.68	21.05	20.14	296.60	302.43	308.15	302.39
S_4	237.62	243.34	249.42	243.46	20.07	22..07	22.44	21.26	311.30	317.23	322.85	317.13
S_5	241.59	248.38	253.47	247.81	20.75	20.75	23.12	21.54	324.78	331.81	337.38	331.32
S_6	227.89	232.38	239.18	233.15	18.33	20.33	20.70	19.79	294.45	300.28	306.00	300.24
S_7	232.32	237.34	243.16	237.61	19.44	21.44	21.81	20.90	299.25	305.08	310.80	305.04
MEAN	227.00	232.48	238.09		18.85	20.32	21.22		290.89	296.90	302.15	
	M	S	M x S		M	S	M x S		M	S	M x S	
S.Ed	2.22	0.92	2.81		0.44	0.18	0.79		1.41	1.02	3.02	
CD (p=0.05)	4.49	1.86	5.67		0.89	0.36	1.59		2.85	2.16	6.11	

Table 3a: Effect of silicon fertilization under different rice establishment methods on post-harvest soil available silicon (mg kg^{-1}) status of rice (Kuruvai - location I and II)

Main Plot Sub Plot	Location I				Location II			
	M_1	M_2	M_3	MEAN	M_1	M_2	M_3	Mean
S_1	74.54	69.86	61.81	68.74	43.68	39.46	31.96	38.37
S_2	92.49	87.75	79.70	86.65	60.51	56.32	48.82	55.22
S_3	98.50	93.82	87.46	93.26	66.49	62.3	54.80	61.20
S_4	79.54	74.86	66.81	73.74	49.32	45.10	37.60	44.01
S_5	83.83	79.12	71.07	78.01	53.03	48.84	41.37	47.75
S_6	87.83	83.15	75.10	82.03	52.51	50.67	45.01	49.40
S_7	94.12	89.44	81.39	88.32	63.37	59.18	51.68	58.08
MEAN	87.26	82.57	74.76		55.56	51.70	44.46	
	M	S	M x S		M	S	M x S	
S.Ed	2.25	0.85	3.14		2.15	1.43	3.84	
CD (p=0.05)	4.55	1.72	6.34		4.35	2.89	7.76	

Table 3b: Effect of silicon fertilization under different rice establishment methods on post-harvest soil available silicon (mg kg^{-1}) status of rice (Navarai - Location I and II)

Main Plot Sub Plot	Location -I				Location-II			
	M_1	M_2	M_3	MEAN	M_1	M_2	M_3	Mean
S_1	62.81	57.85	48.91	56.52	37.48	33.54	27.32	32.78
S_2	81.56	76.60	67.66	75.27	52.45	48.51	42.29	47.75
S_3	87.40	82.44	73.50	81.11	56.50	52.56	46.34	51.80
S_4	69.00	64.04	55.10	62.71	41.61	37.67	31.45	36.91
S_5	73.40	68.44	59.50	67.11	45.19	41.25	35.03	40.49

S_6	77.55	72.59	63.65	71.26	49.00	45.06	38.84	44.30
S_7	83.92	78.96	70.02	77.63	54.35	50.41	44.19	49.65
MEAN	76.52	71.56	62.62		48.08	44.14	37.92	
	M	S	M x S		M	S	M x S	
S.Ed	2.4	1.21	4.03		1.92	1.07	2.09	
CD (p=0.05)	4.8	2.45	8.15		3.87	2.16	4.23	

References

1. Anonymous. Annual report 2018-19. Area production and yield of principal crops, Agricultural Statistics at a Glance, (Publ.) Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi; c2019.
2. Anonymous. Annual report. 2019-20. Policy note, Demand no.5, Department of Agriculture. Government of Tamil Nadu, India; c2020a. p. 1-19.
3. Anonymous. Annual report 2019-20, World Agricultural Production, United States Department of Agriculture, Foreign Agricultural Service, Circular Series. 2020b;WAP 5-20:1-37.
4. Bernal J. Response of rice and sugarcane to magnesium silicate in different soils of Colombia, South America. Paper presented in 4th International Conference on silicon in agriculture, held at University of Kwa Zulu-Natal, South Africa. 2008;26-31:26.
5. Bharathiraja P. Response of aerobic rice to silicon fertilization. M.Sc. (Ag.) Thesis, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India; c2014.
6. Bouman BAM, Tuong TP. Field water management to save water and increase its productivity in irrigated rice. Agricultural Water Management. 2001;49(1):11-30.
7. Das BK, Choudhury BH, Das KN. Effect of integration of fly ash with fertilizers and FYM on nutrient availability, yield and nutrient uptake of rice in Inceptisols of Assam, India. Int. J. of Advancements in Research & Technology. 2013;2(11):190-208.
8. Datta A, Ullah H, Ferdous Z. Water Management in rice. In: Chauhan BS, Jabran K, Mahajan G. (Eds.). Springer International Publishing: Cham, Switzerland; c2017. p. 255-277.
9. Epstein E. Silicon. Annual reviews plant physiology and plant molecular biology. 1999;50(1):641-664.
10. Gangwar KS, Gill MS, Tomar OK, Pandey DK. Effect of crop establishment methods on growth, productivity and soil fertility of rice-based cropping system. Indian Journal of Agronomy. 2008;53(2):102-06.
11. Gomez KA, Gomez AA. Statistical procedures for Agricultural Research, 11th ed. John Wiley and Sons., New York. 1994. p. 68.
12. Guntzer F, Keller C, Meunier JD. Benefits of plant silicon for crops: A review. Agricultural Sustainable Development. 2012;32(1):201-213.
13. Isvilanonda S. Development trends and farmers' benefits in the adoption of wet-seeded rice in Thailand. Direct Seeding: Research Strategies and Opportunities. International Rice Research Institute; c2002. p. 115-124.
14. Jnanesha AC, Kumar A. Effect of Crop Establishment methods on growth yield and water productivity of rice. International Journal of Agricultural Sciences. 2017;8(1):40-45.
15. Kang SM, Waqas M, Shahzad R, You YH, Asaf S, Khan MA. Isolation and characterization of a novel silicate-solubilizing bacterial strain Burkholderia eburnea CS4-2 that promotes the growth of japonica rice (*Oryza sativa* L.) *cv*. Dongjin). Journal of Soil Science and Plant Nutrition. 2017;63(3):233–241.
16. Khan FH, Adil M, Jahan S, Iqbal M, Mozumder MM, Sultana A, *et al.* A consequence of foliar application of silicon on yield and quality of rice in T. Aman season of Bangladesh. Journal of eco-friendly Agriculture. 2018;11(9):88-92.
17. Lindsay WL. Chemical equilibria in soils. John Wiley and Sons Ltd; c1979.
18. Ma JF, Takahashi E. Soil fertilizer and plant silicon research in Japan. Elsevier Science, Amsterdam, Netherlands; c2002. p. 1-294.
19. Ma JF, Tamai K, Yamaji N, Mitani N, Konishi S, Katsuhara M, *et al.* An efflux transporter of silicon in rice. Nature. 2007;448(12):209-212.
20. Mahajan G, Chauhan BS, Gill MS. Dry-seeded rice culture in Punjab state of India: Lessons learned from farmers. Field Crop. Research. 2013;144:89-99.
21. Malav JK, Ramani VP, Patel JK, Pavaya RP, Patel BB, Patel IM, *et al.* Rice yield and available nutrients status of loamy sand soil as influenced by different levels of silicon and nitrogen. International Journal of Current Microbiology and Applied. 2018;7(2):619-632.
22. Matichenkov VV, Bocharnikova EA. Technology for natural water protection against pollution from cultivated areas. 15th Annual Australian Agronomy Conference; c2010. p. 15-18.
23. Meena VD, Dotaniya ML, Vasssanda Coumar, Rjendiran S, Ajay S Kundu, Subba Rao A. A case for silicon fertilization to improve crop yields in tropical soils. Proceedings of the National Academy of Sciences, India Section-B Biological Sciences. 2014;84(3):505-518.
24. Mishra M, Sahu RK, Padhy RN. Growth, yield and elemental status of rice (*Oryza sativa* L.) grown in fly ash amended soils. Ecotoxicology. 2007;16(2):271-278.
25. Mohanthy SK, Patnaik S, Ranga Reddy P, Sridhar R. Effect of submergence on the chemical changes in different rice soils. Acta Agronomica Acadamy Sciences Hungary. 1982;2:187-191.
26. Narayanaswamy C. Calibration and categorization of plant available soil silicon in different rice ecosystems for evaluating drought and disease resistance in rice genotypes. Ph.D. Thesis, UAS, Bangalore, India; c2007.
27. Ning DF, Song A, Fan FL, Li ZJ, Liang YC. Effects of slag-based silicon fertilizer on rice growth and brown spot resistance. Plos One. 2014;9(7):102681.
28. Rajkumara S, Hanamaratti NG, Prashanthi SK. Direct wet seeding in rice- A review. Agricultural Reviews. 2003;24(1):57-63.
29. Rani K, Kalpana S. Utilization in agricultural and related field; a better alternative for eco-friendly maintenance of coal fly ash. Journal of Chemical and Pharmaceutical Research. 2010;2(5):365-372.
30. Rao GB, Poornima Yadav PI, Syriac EK. Effect of various silicon sources on nutrient uptake by rice and

available nutrient status in soil. Journal of Pharmacognosy and Phytochemistry. 2018;7(2):1449-1452.
31. Ravichandran M, Rasavel M, Sriramachandrasekharan MV, Vaiyapuri V. Effect of sulphur fertilization on the nutrient uptake, nutrient availability and sulphur use efficiency of rice. Paper presented in national seminar on recent trends in sulphur and silicon nutrition of crops held at AC and RI, Madurai, 12-13th; c2002 June. p. 21-22.
32. Sandhya TS. Genotypic variation in finger millet for silicon accumulation and effect of foliar silicon on growth and nutrient uptake. M.Sc. (Ag.) Thesis, UAS. Bangalore, India; c2010.
33. Sattar MA, Khan MAK. An assessment of the wet-seeded rice cultivation method in Bangladesh. Paper presented in the international workshop on constraints, opportunities and innovations for wet-seeded rice. 31 May - 3 Jun, 1994 at Maruay Garden Hotel. Bangkok, Thailand; c1994.
34. Selvakumari G, Baskar M, Jayanthi D, Mathan KK. Effect of integration of fly ash with fertilizers and organic manures on nutrient availability, yield and nutrient uptake at rice in Alfisols. Journal of the Indian Society of. Soil Science. 2000;48(1):34-37.
35. Singh V, Singh V, Singh S, Khanna R. Effect of Zinc and Silicon on Growth and Yield of Aromatic Rice (*Oryza sativa* L.) in North-Western Plains of India. Journal of Rice Research and Developments. 2020;3(1):82-86.
36. Sowbika A. Response of low land rice to silicon sources. M.Sc. (Ag.) Thesis, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India; c2018.
37. Thapliyal SD, Singh DK, Pandey PC, Nanda G, Gupta S. Effect of Different Establishment Methods and Varieties of Rice (*Oryza sativa* L.) on Growth, Yield, NPK uptake and Soil Fertility after Harvest in Mollisols. International Journal of Current Microbiology Applied Science. 2020;9(6):2857-2866.
38. Vijayakumar S, Kumar D, Shivay YS, Anand A, Saravanane P, Poornima S, *et al*. Effect of potassium fertilization on growth indices, yield attributes and economics of dry direct-seeded basmati rice (*Oryza sativa* L.). An International Journal of Rice. 2019;56(2):214-220.