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Distribution of silicon in rice growing soils of Jammu plains in relation to some physico-chemical properties

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Abstract
Rice is known as silicon (Si) accumulating plant because of its high requirement which contains Si at levels up to 10% of dry matter weight. The present study was conducted to assess the available Si content of important rice growing soils of Jammu plains and its relationship with physico-chemical properties of soil. The chemical analysis of the soil samples show that most soils are generally moderately acidic to moderately alkaline in reaction, with limited salt content. The mean values of organic carbon (g kg^{-1}) and cation exchange capacity (cmol (p^{-1}) kg^{-1}) in rice growing soils of Jammu district were higher with values being, 7.04 and 8.90, followed by Kathua with values as 7.03 and 8.33 and lowest in Samba district, the values being 5.66 and 7.72, respectively. The available Si content in soils varied from 10.1 to 632.0 mg kg^{-1} with an overall mean of 233.0 mg kg^{-1}. Among the districts, the soils of Kathua (261.65) mg kg^{-1} showed highest available silicon content followed by Jammu (227.59 mg kg^{-1}). The highest mean values of available nutrients in Jammu district. The relationship between plant available Si content and soil properties revealed that PA-Si content in soil decreased with increasing sand content and increased with increasing pH, clay content, OC, CEC, available N, P and K content of the soils.

Keywords: Available silicon, rice, Jammu plains, cation exchange capacity, organic carbon

Introduction
Rice is the most important cereal crop and is a staple food for more than half of the world's population. Adequate nutrient management is essential to enhance its productivity to satisfy the rising global demand without adverse impact on environment. Rice is considered as Si accumulator plant and it is estimated that to produce grain yield of 5.0 t ha^{-1}, rice crop removes 230-470 kg Si ha^{-1} from soil, which was about 108% more than the nitrogen, thus Si may be a yield limiting element for rice production (Datnoff *et al.*, 1997) [7]. Monosilisilic acid (H_4SiO4) is the form of Si used by plants (Jones and Handreck, 1967) [17]. But natural release of monosilicic acid from silica is a slow process (Raven, 1983). The concentration of the monosilicic acid in the soil solution is also influenced by the soil pH, soil texture, redox potential, amount of clay mineral, organic matter, and oxides and hydroxides of Fe/Al, which are collectively related to the geologic age of the soil. The positive correlation with clay content and the negative correlation with sand content suggest that the available Si is essentially released from finer fractions of soils (Makabe *et al.*, 2009) [23]. In view of the multiple vital roles of Si for rice crops, it is necessary to determine the available Si status of various rice eco-systems and, as a result, design appropriate Si management choices for achieving or maintaining increased rice cultivar yield potentials.

Materials & Methods
The research was carried out in the plains areas of Jammu division. The soil samples were taken from rice growing plains of three districts *viz.*, Jammu, Kathua, and Samba. Surface soil samples (0-15 cm) from 140 rice-growing areas were collected randomly across the Jammu plains of these three districts. The soil samples were then air-dried in the shade, mixed well, grounded in a pestle and mortar, and passed through a 2 mm sieve for silicon and other soil parameters analysis. Mechanical analysis of soil was done by hydrometer method using Bouyoucos hydrometer (Bouyoucos, 1962) [2]. The pH of the soil was evaluated using a glass electrode pH meter in 1:2.5 soil water suspensions (Jackson, 1973) [13]. The electrical conductivity of the soils was evaluated using a soil-water suspension (1:2.5) using the Jackson technique (Jackson, 1967) [12].

Organic carbon content was determined using the Walkley and Black (1934) [44] method, CEC using the Piper (1966) [30] method, available N content of the soils by Subbiah and Asija (1956) [41], available P content of the soils by Olsen *et al.* (1954) [28], available K content of the soils by Jackson (1973) [13], available S content of the soils using the Chesnin and Yien method (1951) [3] and available Si content of soil by using extractant mixed well, 0.01 M $CaCl_2$ solution (Korndorfer *et al.*, 1999) [18]. The data was subjected to descriptive analysis.

Results and Discussion

Soil Texture

The textural classes of rice growing soils of Jammu plains, varied from sandy loam to sandy clay. Five textural classes of soils were identified by using soil textural triangle (United States Department of Agriculture System) *viz*., sandy loam, sandy clay loam, loam, clay loam and sandy clay soils (Table 1). The mechanical separates (the relative proportions of sand, silt and clay) percentage of Jammu, Kathua and Samba districts revealed that the sand percent ranged from 43.20 to 71.88, 54.02 to 71.20 and 59.10 to 72.40 and having mean value of 63.82, 65.22 and 66.80 percent, respectively in three districts (Fig. 1). Samba district has the highest average sand percentage, followed by Kathua and lowest in Jammu district. The silt content in the surface layer of the rice growing soils of Jammu, Kathua and Samba districs varied from 2.57 to 35.78, 5.00 to 27.20 and 8.00 to 20.40 percent with average values of 15.54, 14.37 and 12.91 percent, respectively (Fig. 2). Highest average silt content was found in Jammu district, followed by Kathua and lowest percent was observed in Samba district. The clay content in the surface layer of the rice growing soils of Jammu, Kathua and Samba districts varied from 6.33 to 39.20, 9.76 to 32.48 and 16.00 to 22.50 percent with an average value of 20.63, 20.41 and 20.36 percent, respectively (Fig. 3). This change in soil texture is affected by organic matter, climate, vegetation and topography, humidity, land use and other colloidal substances. The data revealed that the dominant soil texture was found to be sandy clay loam followed by sandy loam. These results are similar to the results reported by Jalali *et al*. (1989) [16] who also noticed similar textural classes in soils of Jammu region. Rai *et al.* (2018) [32] reported similar soil texture for four blocks of Samba district and they observed that soils varied from sandy clay loam to clay loam.

Table 1: Soil textural classes under rice growing soils of Jammu plains

Textural class	No. of samples
Sandy loam	57
Sandy clay loam	77
Loam	2
Clay loam	2
Sandy clay	2
Total	140

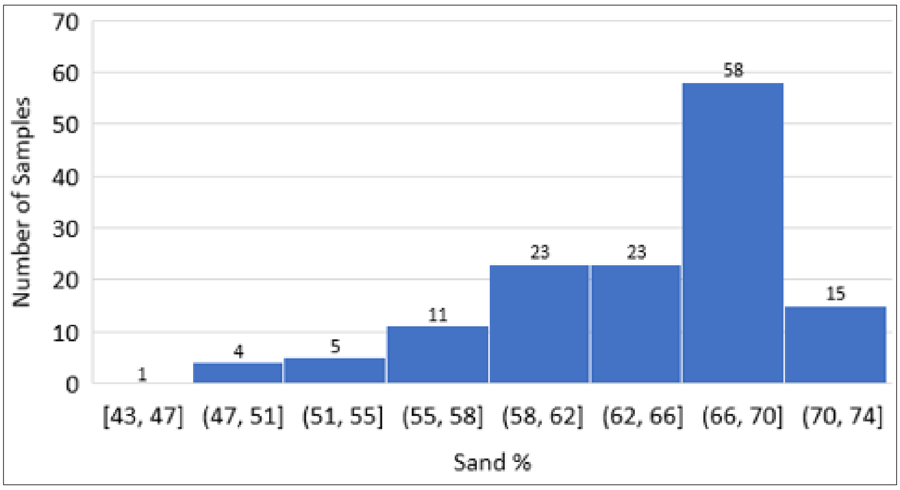

Fig 1: Sand percentage in rice growing soils of Jammu plains

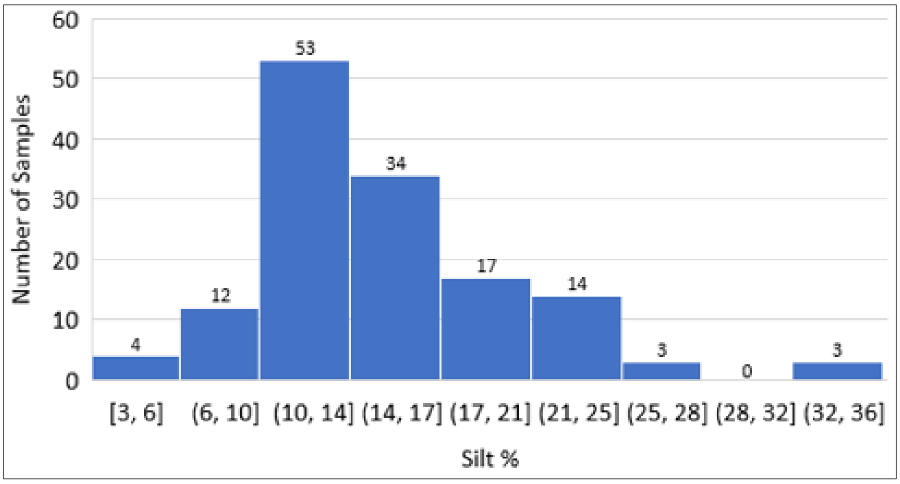

Fig 2: Silt percentage in rice growing soils of Jammu plains

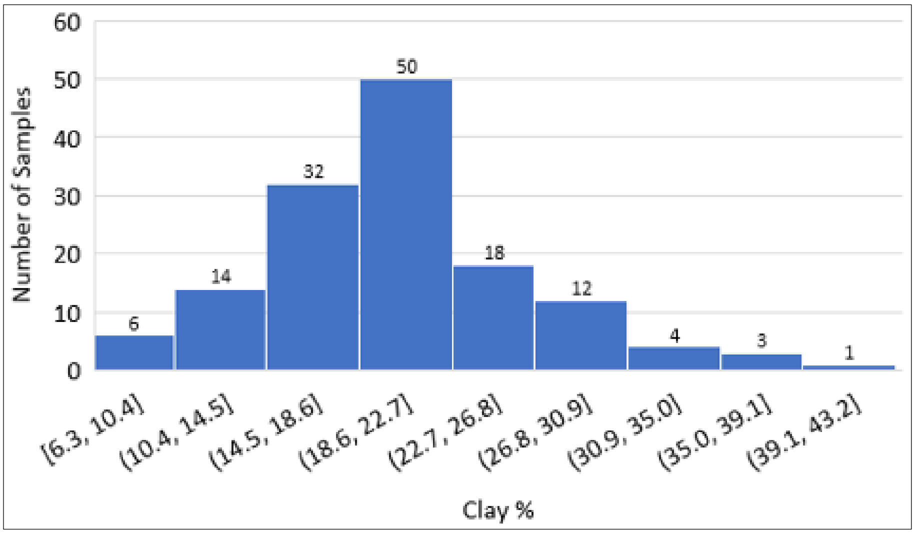

Fig 3: Clay percentage in rice growing soils of Jammu plains

Soil reaction (pH)

The pH value of the soil directly affects the life and growth of plants, because it affects the utilization of all plant nutrients, the microbial activity and the physical condition of the soil. The pH of the rice growing soils of Jammu plains varied from moderately acidic to moderately alkaline (5.9 to 8.3) in reaction. The pH value for the soils of Jammu, Kathua and Samba districts varied from 5.9 to 8.1, 6.0 to 8.3 and 6.1 to 7.9 with mean value of 6.7, 7.1 and 6.8, respectively (Table 2 and Fig. 4). The variation in soil pH was mainly on account of variation in topography and use of FYM at varying rates in three districts. Kour *et al.* (2007) [19] also reported that soil pH in various locations of Samba and Kathua districts ranged between neutral (7.2) to slightly alkaline (8.6).

Table 2: Physico-chemical properties and available Si status in rice growing soils of Jammu plains

Soil property	Districts								
	Jammu			Kathua			Samba		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
pH	5.9-8.1	6.7	0.62	6.0-8.3	7.1	0.70	6.1-7.9	6.8	0.57
EC	0.03-0.39	0.18	0.09	0.04-0.33	0.16	0.07	0.07-0.31	0.17	0.07
OC (g kg^{-1})	2.10-12.90	7.04	2.12	3.80-9.30	7.03	1.34	3.5-6.90	5.66	1.23
CEC	6.25-15.35	8.9	2.07	6.59-10.45	8.33	0.96	6.84-9.54	7.72	0.74
Av. N (kg ha^{-1})	119.4-440.0	272.44	72.53	125.7-445.2	293.21	82.02	142.4-350.0	238.5	57.02
Av. P(kg ha^{-1})	2.0-56.1	25.13	12.36	10.2-63.8	24.64	13.26	6.9-22.1	14.66	4.97
Av. K(kg ha^{-1})	100.0-390.0	165.45	63.22	76.372.2	201.9	86.91	109.0-202.0	144.9	24.53
Av. S(mg kg^{-1})	2.5-55.0	18.15	9.01	5.0-51.3	15.89	9.95	5.0-27.3	14.68	7.24
Av. Si(mg kg^{-1})	10.1-632.0	227.59	133.86	62.0-535.5	261.65	115.96	45.2-389.0	225.97	103.59

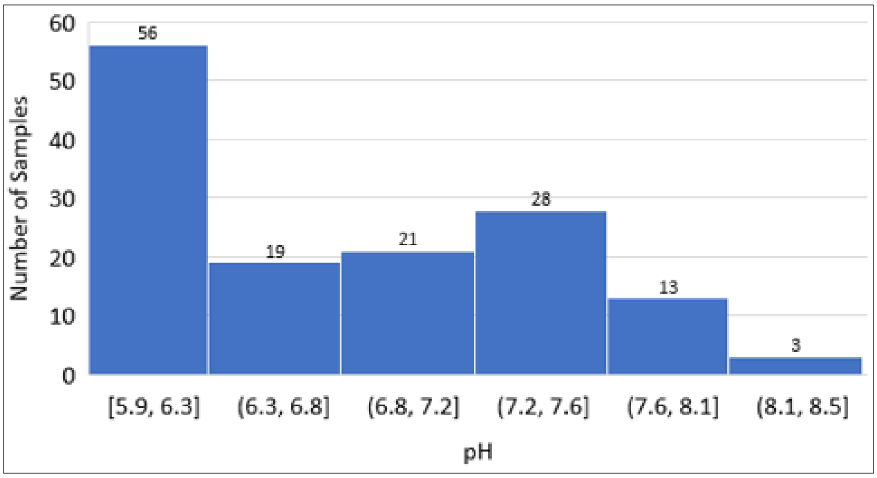

Fig 4: Soil pH in rice growing soils of Jammu plains

Electrical Conductivity (EC)

The electrical conductivity is a measure of soluble salt concentration in the soils. The electrical conductivity of soil water suspension (1:2.5) of soils of Jammu, Kathua and Samba districts ranged from 0.03 to 0.39, 0.04 to 0.33 and 0.07 to 0.31 dS $m^{-1}$with a mean value of 0.18, 0.16 and 0.17 dS m^{-1}, respectively (Table 2 and Fig. 5). Soils under study area were safe from salinity hazards as they have electrical conductivity value less than 1 dS m^{-1}. The very low EC of soils can be attributed to the loss of soluble salts due to surface runoff during monsoon season in this region. Similar results were reported by Jatav *et al*. (2007) [14]. Similar values of electrical conductivity were reported by Rai *et al.* (2018) [32] in Samba district and Spalbar *et al.* (2017) [39] in Jammu district.

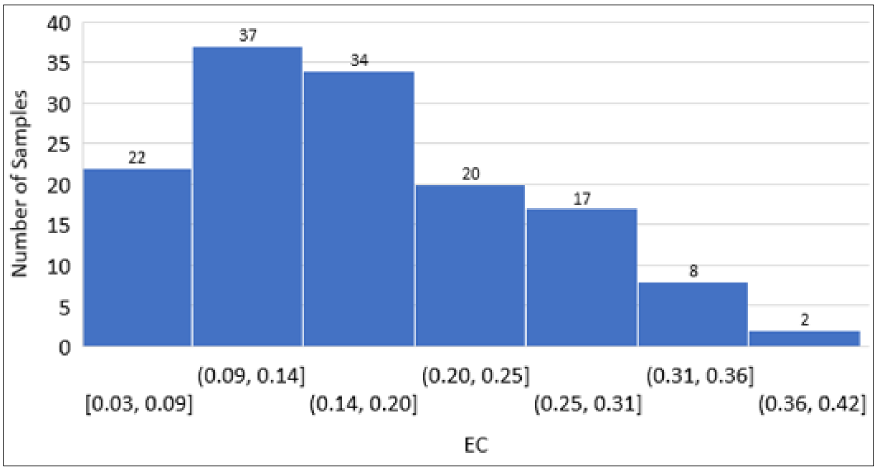

Fig 5: Electrical conductivity (dS m^{-1}) in rice growing soils of Jammu plains

Soil organic carbon

Carbon is an indication of organic fractions in soils formed from the microbial decomposition of residue. The presence of organic matter in soil is a symbol of life in the soil. Soil organic matter acts as a major factor regulating the availability of organic forms of nitrogen, phosphorus, sulphur, and other trace elements in soils (Stevenson, 1991) [40]. Soil organic carbon in Jammu plains varied from low to high. The amount of organic carbon in soils of Jammu, Kathua and Samba districts ranged from 2.10 to 12.90, 3.80 to 9.30 and 3.50 to 6.90 g kg^{-1} with an average value of 7.04, 7.03 and 5.66 g kg^{-1}, respectively (Table 2 and Fig. 6). The lowest mean value of organic carbon was observed in Samba district soils (5.66 g kg^{-1}). In the Samba district, the low organic carbon content may be due to sandy texture of soils and limited application of FYM and other organic sources to the soil as due to relatively small animal populations in the *Kandi* areas, the availability of FYM in this area is limited. Furthermore, warm climatic conditions favor the rapid decomposition of organic matter. Similar results were reported by Sharma *et al.* (2009) [36] in soils of Samba district and Gupta *et al*. (1997) [11] in Jammu soils. These results are also in accordance with those of Tundup *et al.* (2015) [42].

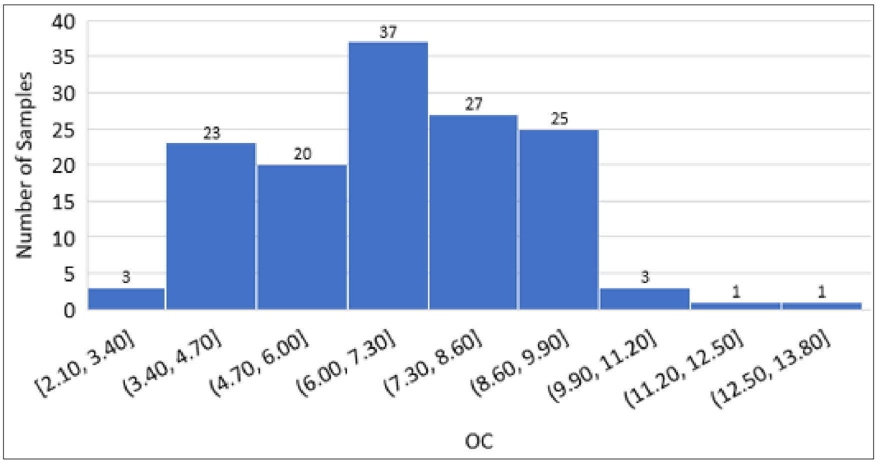

Fig 6: Organic carbon (g kg^{-1}) in rice growing soils of Jammu plains

Cation Exchange Capacity

The cation exchange capacity (CEC) is the capacity of clay to adsorb and exchange cations. The negative charges of clay determine the cation exchange capacity of the soil. The values of CEC content in Jammu, Kathua and Samba districts soils ranged from 6.25 to 15.35,6.59 to 10.45 and 6.84 to 9.54 cmol (p^+) kg^{-1} with an average value of 8.90, 8.33 and 7.72 cmol (p^+) kg^{-1}, respectively (Table 2 and Fig. 7). The highest mean value of CEC was observed in Jammu district soils (8.90 cmol (p^+) kg^{-1}), followed by Kathua and lowest in Samba district soils. This variation in the CEC of the soils appears to be due to variation in the clay content and organic carbon content in the soils of three districts, as clay fraction appears to influence largely the CEC values. Generally the soils which have lower amount of clay content are seen to have lowest CEC values. The cation exchange capacity is controlled primarily by the composition and mineralogy of the soil constituents particularly that of the clay fraction (Coventry *et al*., 2001) [5]. Similar observations were reported by Martel *et al.* (1978) [24] that soils with high organic matter content and clay particles have high values of cation exchange capacity. Similar results were reported by Sharma *et al.* (2009) [36] in soils of Jammu, Samba and Kathua districts.

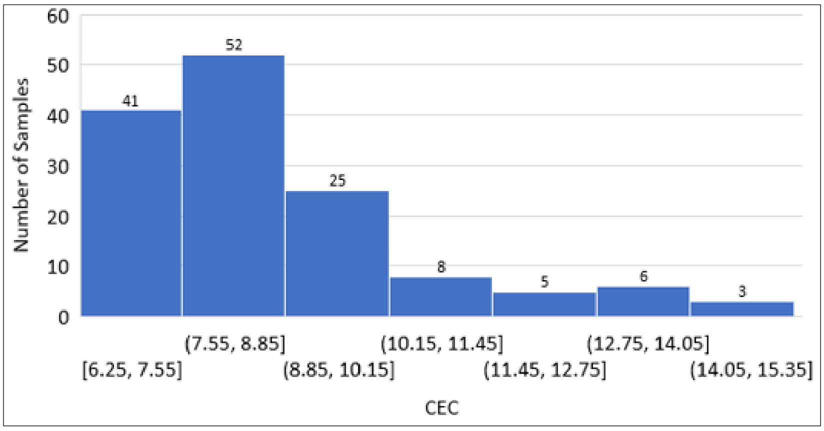

Fig 7: CEC (cmol (p^+) kg^{-1}) in rice growing soils of Jammu plains

Available nitrogen

Available nutrient status of soil is an indication of fertility level of soil and is influenced by various factors like soil pH, organic carbon content, temperature, application of organic manures etc. The available nitrogen content in Jammu, Kathua and Samba districts soils ranged from 119.4 to 440.0, 125.7 to 445.2 and 142.4 to 350.0 kg ha^{-1} with a mean value of 272.44, 293.21 and 238.5 kg ha^{-1}, respectively (Table 2 and Fig. 8). The maximum average value of available nitrogen content was found in Kathua district, followed by Jammu and minimum in Samba district soils. This variation is caused by type of soil particles and amount of organic matter. Overall in all the three districts, available nitrogen content was deficient in maximum soil samples. Similar results were obtained by Mondal *et al*. (2006) [26] and Sharma *et al*. (2009) [36] in soils of Jammu.

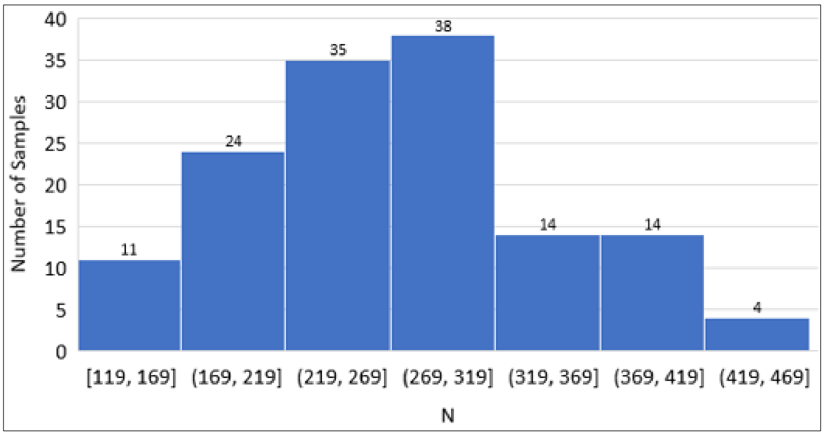

Fig 8: Available nitrogen (kg ha^{-1}) in rice growing soils of Jammu plains

Available phosphorus

The available phosphorus content was low to high in the rice growing soils of Jammu plains and it ranged from 2.0 to 56.1, 10.2 to 63.8 and 6.9 to 22.1 kg ha^{-1} with an average value of 25.13, 24.64 and 14.66 kg ha^{-1} in Jammu, Kathua and Samba districts, respectively (Table 2 and Fig. 9). The available phosphorus content in soils depends on parent material, soil pH, and use of FYM at varying rates, intensity of weathering and with a change in soil condition from reduction to oxidation (Savant *et al*. 1970) [34]. Similar results were obtained by Dabin (1980) [6], Lu *et al.* (1982) [32], Sharma *et al*. (2009) [36] and Jatav *et al.* (2013) [15].

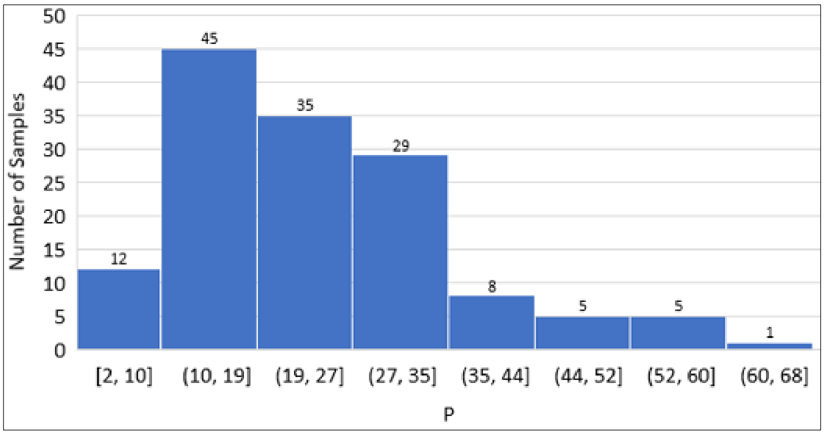

Fig 9: Available phosphorus (kg ha^{-1}) in rice growing soils of Jammu plains

Available potassium

The available potassium content in soils of Jammu, Kathua and Samba districts ranged from 100.0 to 390.0, 76.0 to 372.2 and 109.0 to 202.0 kg ha^{-1} having mean value of 165.45, 201.90 and 144.90 kg ha^{-1}, respectively (Table 2 and Fig. 10). The lower values of available potassium in Samba district may be due to sandy texture and low organic carbon content. These results are in accordance to those of Kour and Jalali (2008) [20] who reported lower values of available potassium in *Kandi* soils of Samba district. On overall basis, maximum numbers of soil samples were medium in available potassium and very few samples contain low available potassium content.

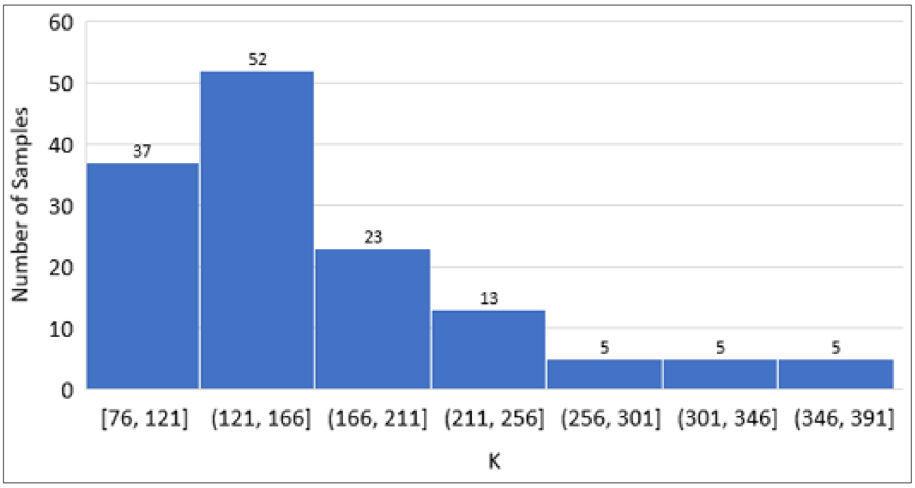

Fig 10: Available potassium (kg ha^{-1}) in rice growing soils of Jammu plains

Available sulphur

The available sulphur content in soils of Jammu, Kathua and Samba districts ranged from 2.5 to 55.0, 5.0 to 51.3 and 5.0 to 27.3 mg kg^{-1} with mean value of 18.15, 15.89 and 14.68 mg kg^{-1}, respectively (Table 2 and Fig. 11). The highest mean sulphur content was found in Jammu district. This may be due to the reason that Jammu district contain high organic matter content and increased organic matter on the surface favored the solubilisation of insoluble sulphur releasing more quantity to the surface as reported by Choudhary *et al.* (2006) [4]. Similar results were reported by Kour and Jalali (2008) [20] in soils of Jammu and Samba districts.

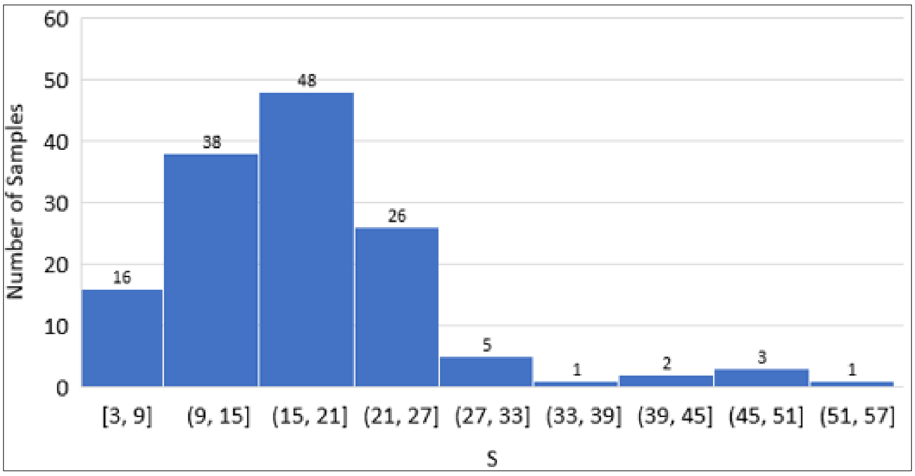

Fig 11: Available sulphur (mg kg^{-1}) in rice growing soils of Jammu plains

Available Silicon

The available silicon content in Jammu, Kathua and Samba district ranged from 10.1 to 632.0, 62.0 to 535.5 and 45.2 to 389.0 mg kg^{-1} with the mean content of 227.6, 261.7 and 226.0 mg kg^{-1}, respectively (Table 2 and Fig. 12). Pati *et al.* (2017) [29] also reported that the plant available silicon extracted by 0.01 *M* $CaCl_2$ ranged from 12.8 to 455.8 mg kg^{-1} in soils of West Bengal. Similarly the plant available silicon content extracted by different extractants in soils of South India ranged from 6.1 to 317.7 mg kg^{-1} (Narayanaswamy and Prakash, 2009) [27] and among the extractants, acetic acid extracted greater amount of silicon than ammonium acetate and calcium chloride.

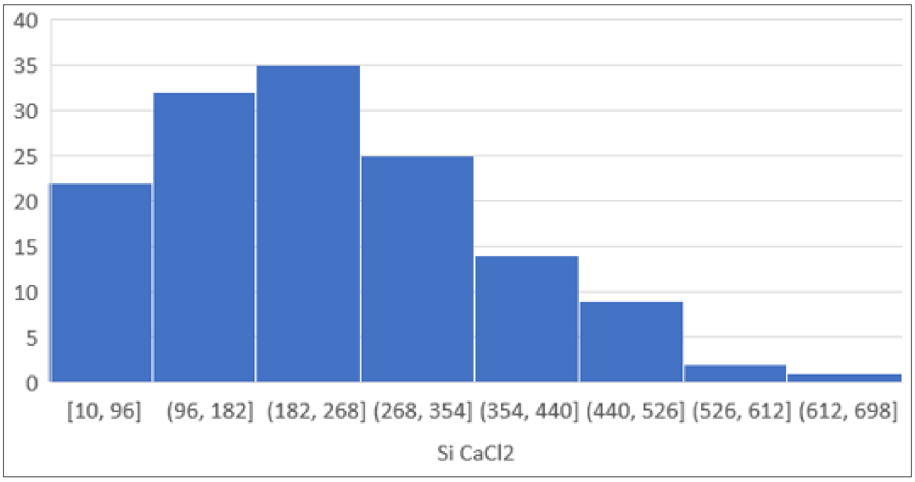

Fig 12: Available silicon extracted by 0.01 *M* $CaCl_2$ (mg kg^{-1}) in rice growing soils of Jammu plains

Relationship between physico-chemical properties of rice growing soils

The relationship between various physico-chemical properties of soils of three districts are presented in table 3. It was observed that the sand was negatively and significantly correlated with silt (r = -0.392**) and clay content (r = -0.571**). Silt was negatively correlated with clay content (r = -0.531**). Soil pH was negatively correlated with clay content although it was non-significant (r = -0.080). EC was positively and significantly correlated with pH (r = 0.476**). Organic carbon was negatively correlated with pH (r = -0.057). The negative correlation of organic carbon with pH might be related with the greater activities of microorganisms. Organic carbon content was positively and significantly correlated with EC (0.186*). Organic carbon was also positively correlated with available N, P, K and S. Similarly results were reported by Singh and Mishra (2012) [37] in Varanasi soils (U.P.). Sharma *et al.* (2009) [36] also reported that available N and P were significantly correlated with organic carbon in Jammu soils. Nitrogen was negatively correlated with pH (r = -0.006) and positively correlated with EC (r = 0.226**) and organic carbon (r = 0.869**). Phosphorus was positively correlated with OC (r= 0.669**), EC (r = 0.211*) and nitrogen (r = 0.639**) and negatively correlated with pH (r = -0.041). Potassium was positively correlated with clay (r = 0.206*), pH (r = 0.077), OC (r = 0.428**), nitrogen (r = 0.525**) and phosphorus (r = 0.364**) and negatively correlated with sand (r = -0.237**). Sinha and Biswas (2003) stated that plant-available potassium showed a positive and significant correlation with clay content and cation exchange capacity in West Bengal soils. Similar results were reported by Sharma *et al.* (2009) [36] in Jammu soils. Sulphur was positively correlated with organic carbon (r = 0.385**), nitrogen (r = 0.317**) phosphorus (r = 0.360**) and potassium (r = 0.205*) and negatively correlated with sand (r = -0.059) and soil pH (r = -0.076).

Table 3: Relationship between different physico-chemical properties and PA-Si content of rice growing soils

	Sand	Silt	Clay	pH	EC	OC	CEC	N	P	K	S	Si
Sand	1											
Silt	-0.392**	1										
Clay	-0.571**	-0.531**	1									
pH	-0.037	0.130	-0.080	1								
EC	-0.155	0.014	0.133	0.476**	1							
OC	-0.253**	-0.265**	0.467**	-0.057	0.186*	1						
CEC	-0.427**	-0.259**	0.624**	-0.020	0.197*	0.820**	1					
N	-0.202*	-0.227**	0.387**	-0.006	0.226**	0.869**	0.705**	1				
P	-0.262**	-0.156	0.380**	-0.041	0.211*	0.671**	0.792**	0.639**	1			
K	-0.237**	0.014	0.206*	0.077	0.226**	0.428**	0.324**	0.525**	0.364**	1		
S	-0.059	-0.196*	0.230**	-0.076	0.138	0.385**	0.365**	0.317**	0.360**	0.205*	1	
Si	-0.214**	0.058	0.145	0.043	0.103	0.397**	0.264**	0.474**	0.221**	0.384**	0.234**	1

**. Correlation is significant at the 0.01% level, *. Correlation is significant at the 0.05% level

Relationship of plant available soil silicon and soil properties

The relationship between clay content and plant available Si indicates that available Si increased with increased clay content in soils of Jammu plains (Table 3). Similar results were reported by Phonde *et al.* (2014) [31] in soils of Maharashtra. Clay soils with higher concentrations of phyllosilicates (minerals that release Si and Al^{3+}) show higher concentration of Si than sandy soils (Dematte *et al.*, 2011) [9]. There was also a positive correlation between soil pH and plant available Si and it indicates that available Si increased with increased pH of soil. Similar results were also reported by Phonde *et al.* (2014) [31] and Liang *et al.* (1994) [21]. Low pH results in less sorption and higher pH in greater sorption of Si (McKeague and Cline, 1963) [25]. There was also a positive correlation between PA-Si and electrical conductivity. The strong positive correlation was obtained between plant available Si and soil organic carbon content. Increased organic carbon content in soil increases water holding capacity as well as exchange capacity and also improves plant available silicon content in soil (Berthelsen *et al*. 2003) [1]. Phonde *et al*. (2014) [31] reported that available Si increases with increasing soil organic carbon. Georgiadis *et al*. (2013) [10] and Vandevenne *et al*. (2015) [43] also reported a positive relationship between easily soluble Si and organic carbon content. Cation exchange capacity was also positively correlated with available Si in the soils of three districts indicating that soils of high CEC and exchangeable cations had good reserves of plant available silicon. Similar results were obtained by Phonde *et al*. (2014) [31] in soils of Maharashtra. The positive and significant correlation was observed between plant available silicon and available nitrogen, available phosphorus, available potassium and available sulphur. Positive and significant correlation was obtained between available soil phosphorus and plant available silicon and indicating high reserves of plant available silicon increased phosphorus availability in soil. The exchange of P anions by silicate anions followed by desorption of phosphorus anions results in increased content of phosphate in soil solution. Similar results were also reported by Phonde *et al*. (2014) [31] and Savant *et al*. (1997) [35]. Dean and Rubins (1947) [8] also observed the ability of silicate ion to replace the phosphate ion from the adsorbed conditions in the soil thus enhancing the availability of phosphorus.

Conclusion
The study shows that there was significant differences in the physicochemical features of rice producing soils in three areas of the Jammu plains. According to the essential limitations for rice producing soils in India, the majority of the rice growing soils in the Jammu plains have sufficient plant accessible silicon concentration. The chemical analysis of the soil samples show that most soils are generally moderately acidic to moderately alkaline in reaction, with limited salt content. The soil organic carbon content in soils varied from low to high in plains of three districts. Plant accessible Si concentration in soil decreased with increasing sand content and increased with increasing pH, clay content, organic carbon, cation exchange capacity, available nitrogen, available phosphorus, and available potassium.

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