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Assessing Silicon Availability in Soils of Rice-Growing Lowlands and Neighboring Uplands in Benin and Nigeria

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Abstract: Silicon (Si) is known as a beneficial nutrient in the cultivation of rice, playing a key role in photosynthesis enhancement, lodging resistance and tolerance to various environmental stress. The present study aimed to examine available Si content in both lowland soils (n = 29) and neighboring upland soils (n = 21) collected from Benin and Nigeria and to evaluate the validity of the assessment results through a pot experiment. Our results revealed that the acetate-buffer method predicted Si concentration in rice straw at the harvest stage (R^2 = 0.68, P < 0.01) better than the anaerobic-incubation method (R^2 = 0.31, P > 0.05), and 76% of the uplands and 38% of the lowlands were deficient (< 50 mg/kg) in acetate-buffer soluble Si. These findings suggest that the Si-deficiency soils prevail across the study area, making rice plants starved for Si and prone to environmental stress.

Key words: *Oryza sativa* L.; silicon; upland field; lowland field

Rice is known as a silicon (Si)-accumulating plant which contains Si at levels up to 10% in dry matter weight (Ma and Yamaji, 2006). Silicon plays beneficial roles in rice plants such as photosynthesis enhancement and lodging resistance (Matoh et al, 1991; Agarie et al, 1992) and helps improve tolerance to biotic and abiotic stress (Savant et al, 1997a; Ma, 2004). Therefore, Si has been long recognized as a key nutrient to improve and stabilize rice yields in Japan (Savant et al, 1997b; Ma and Takahashi, 2002) and has recently been attracting increasing attention in many other Asian countries. Moreover, the plant-available Si in the form of soluble silicate is seriously limited by its low solubility (Sommer et al, 2006). There has been an ongoing need for methods to assess the amount of plant-available Si in the soils of rice-growing regions, and such methods will provide useful information for developing countermeasures for rice Si deficiency and estimating the proper application rate of Si-containing material for soil Si replenishment (Ma and Takahashi, 2002).

Several methods for the assessment of soil-available Si have been developed in Japan to predict the silicon concentration in rice straw, in particular the flag leaf at the harvest stage (Ma and Takahashi, 2002). Of these methods, the acetate-buffer method (Imaizumi and Yoshida, 1958) and the anaerobic-incubation method (Takahashi and Nonaka, 1986) have been widely adopted to lowland paddy soils in Japan and some part of temperate Asia (Ma and Takahashi, 2002). However, much less effort has been devoted to estimating Si availability in tropical paddy soils. Further, very little attention has been paid to measuring Si in upland rice soils (Juo and Sanchez, 1986) despite upland rice ecology being widespread in the tropics such as Latin America and West Africa (Winslow, 1992; Winslow et al, 1997). It is consequently said that no reliable method has been developed so far to predict the need for Si application in tropical soils (Savant et al, 1997a).

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In West Africa, the widespread distribution of highly weathered soils, such as Ultisols, Oxisols and Alfisols (Eswaran et al, 1997; Hirose and Wakatsuki, 2002), represents a potential risk of Si deficiency (Juo and Sanchez, 1986). Si deficiency problems may occur more frequently where rice production is being expanded, as it is in West Africa (Abe and Wakatsuki, 2011). Si deficiency can make rice plants more susceptible to environmental stress (Savant et al, 1997a) and may hamper sustainable rice productivity improvement.

Tsujimoto et al (2014) demonstrated that rice straw having Si concentration below a critical level (5% in dry matter) can be found in 68% of rice fields across west African regions, and that the anaerobic-incubation method has better capacity to assess soil-available Si than the acetate-buffer method. However, they examined much fewer upland rice soils (n = 11) than lowland soils (n = 88) despite the former occupying about one half of rice-cultivated area in the region (Abe and Wakatsuki, 2011). In general, upland rice contains a smaller amount of Si in its body than lowland rice (Winslow, 1992; Winslow et al, 1997) as soil Si availability is affected substantially by the degree of submergence (Takahashi, 1974). Also, it is generally said that about 50% of Si taken up by lowland rice originates from the soil in Japan (Japan Soil Association, 2014). These findings suggest that there are different mechanisms of Si supply between lowland and upland soils.

This background highlights the need for the assessment of Si availability in rice-growing soils of West Africa, as well as the need to develop an appropriate assessment method for soil Si availability which is applicable for both upland and lowland soils. The present study therefore aimed to assess available Si content in lowland soils and neighboring upland soils in Benin and Nigeria and to examine the validity of the assessment methods through a pot experiment.

MATERIALS AND METHODS

Field sampling and soil analysis

Soil samples were collected from the topsoil (0–15 cm)

Table 1. General description of field sampling sites.

Location No.	Location	Country	GPS position		Topography	Land use		Fertilizer use
			Latitude (N)	Longitude (E)		Lowland [a]	Upland	
1	Malanville	Benin	11°52′	3°23′	FP	Rice (60)	–	Yes
2	Wanrarou	Benin	10°10′	2°44′	IV	Rice (5)	Fallow	No
3	Materi	Benin	10°42′	1°02′	IV	Rice (9)	Maize	No
4	Tiele	Benin	10°43′	1°12′	IV	Rice (15)	–	No
5	Kandi	Benin	11°07′	2°55′	IV	Rice (20)	Beans	Yes
6	Tampegre	Benin	10°24′	1°21′	IV	Rice (50)	–	No
7	Sori	Benin	10°42′	2°47′	IV	Rice (7)	Fallow	No
8	Beket-Bourame	Benin	10°18′	1°44′	IV	Rice (20)	–	No
9	Ndali	Benin	9°50′	2°42′	IV	Rice (17)	Maize	No
10	Kommon	Benin	11°16′	2°24′	IV	Rice (40)	Maize	No
11	Korobororou	Benin	9°22′	2°40′	IV	Fallow	Maize	Unknown
12	Kodowari	Benin	9°12′	1°33′	IV	Rice (5)	Maize	No
13	Okutaosse	Benin	8°34′	1°41′	IV	Rice (27)	Maize	No
14	Orokoto	Benin	7°59′	2°13′	IV	Rice (3)	–	No
15	Odochele	Benin	7°49′	2°08′	IV	Rice (10)	Maize	Yes
16	Gome-Ifada	Benin	7°53′	2°13′	IV	Rice (50)	Maize	Yes
17	Loule	Benin	7°50′	2°13′	IV	Rice (50)	Fallow	Unknown
18	Koussin	Benin	7°14′	2°17′	CT	Rice (40)	Maize	Unknown
19	Zongoundou	Benin	7°00′	1°58′	CT	Rice (13)	Maize	No
20	Ayize	Benin	7°09′	2°29′	CT	Rice (10)	Maize	Unknown
21	Tannou	Benin	7°00′	1°43′	IV	Rice (10)	Maize/beans	No
22	Dekandji	Benin	6°47′	1°45′	IV	Rice (30)	Maize/beans	Yes
23	Zadogagbe	Benin	7°05′	2°08′	IV	Rice (11)	–	Yes
24	Zoungo	Benin	7°06′	2°31′	IV	Fallow	–	Unknown
25	Deve	Benin	6°45′	1°38′	FP	Rice (35)	–	Yes
26	Badeggi	Nigeria	9°06′	5°51′	FP	Rice (100)	Soybean	Yes
27	Bida	Nigeria	9°05′	6°01′	IV	Rice (100)	Fallow	No
28	Doko	Nigeria	8°56′	6°05′	IV	Rice (100)	Groundnut	No
29	Ibadan	Nigeria	7°30′	3°54′	IV	Fallow	Maize	Yes

FP, Flood plain; IV, Inland valley; CT, Complex topography.
[a] Years of rice cultivation in parentheses.