Survey of the Silicon Status of Flooded Rice in Louisiana

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Nutrient Cycling & Uptake

ABSTRACT

Low Si content in rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.), and other Si-accumulating crops can adversely affect crop performance by increasing susceptibility to abiotic and biotic stresses. Although it is generally assumed in the United States that soils containing appreciable amounts of silicate clays supply adequate Si to meet crop demands, there is little evidence to support this assumption. A survey was conducted to assess the Si status of rice plants at mid-tiller (Y-leaf) and at harvest (straw) in 97 rice fields located throughout the rice-growing regions of Louisiana. On average, Y-leaves contained 30.5 ± 7.8 g Si kg^{-1}, whereas mature rice straw contained 54.7 ± 12.7 g Si kg^{-1}. Low early season Si assimilation occurred in nearly all rice fields, whereas only 36% contained mature straw with <50 g Si kg^{-1}, a level commonly used to indicate sufficiency. Late-season deficiencies were limited to fields in extreme southwest Louisiana where soils tend to be strongly acidic and have a long history of rice production.

A growing body of evidence indicates that adequate uptake of Si can substantially increase the tolerance of rice, sugarcane, and other crops to abiotic and biotic stresses (Datnoff et al., 2001; Ma and Takahashi, 2002). Although all plants accumulate Si to some degree, the amounts accumulated vary greatly among species. A species accumulating more than 1% of dry mass is considered a Si-accumulator (Epstein, 1994). Many species of wetland grasses, notably rice, accumulate 5% Si or more in their leaf tissue. Plant physiologists generally agree that, although Si accumulates in many species, it is not an essential nutrient because most plants can complete their reproductive cycle in nutrient solutions lacking Si. Even so, it is generally recognized that Si is crucial to the healthy growth of many crops, especially Si accumulators such as rice.

The benefits of Si fertilization on crop yields and quality has been documented extensively in Asia, Africa, South America, and most other regions where rice, sugarcane, and other Si-accumulating crops are commercially grown (Snyder et al., 1986). Although Si fertilization is routine for rice or sugarcane in Japan, China, Brazil and other countries, it is not widely practiced in the United States (Ma and Takahashi, 2002; Korndörfer, 2001). The Everglades Agricultural Area of south Florida is a notable exception. Because the organic mucks and sandy soils offer very low Si availability, many rice and sugarcane fields are treated with silicate slag to increase Si availability (Snyder et al., 1986). Silicon fertilization has largely been overlooked in Louisiana and other rice-growing regions of the United States where most soils contain appreciable amounts of 2:1 layered silicate clay minerals and therefore are presumed to supply adequate amounts of silicates to crops. There is little evidence to support the assumption that these mineral soils supply sufficient Si to fully meet the needs of rice, sugarcane, and other Si-accumulating crops. Similarly, there is little evidence to support the suggestion that the benefits of Si fertilization demonstrated in some rice-growing regions can be obtained where soils supply adequate Si.

The primary goal of this study was to assess the Si status of rice plants at mid-tillering (Y-leaf) and at harvest (straw) throughout the rice-growing regions of Louisiana by comparing tissue concentrations with critical values established for other rice-growing regions where response to Si has been extensively studied. A detailed survey of the Si status of rice grown in the Major Land Resource Areas (MLRA) throughout Louisiana can be used to identify areas where possible Si deficiencies occur and where responses to Si fertilization would most likely result in economic responses. Silicon concentrations at mid-tillering and harvest were compared with flood water Si, pore water Si, field-moist and air-dried pH, and electrical conductivity (EC) to identify possible relationships that may be useful in characterizing Si uptake and availability. This investigation is intended to aid rice and sugarcane researchers in determining whether Si merits further consideration in the south-central region of the United States.

MATERIALS AND METHODS

Survey Strategy

With the help of Louisiana State University AgCenter Extension Agents, representative fields of rice were identified visually in each of the rice growing parishes of Louisiana for

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Abbreviations: EC, electrical conductivity; GCP, Gulf Coast Plains; MLRA, Major Land Resource Areas; SbMVU, Subtropic Mississippi Valley Silty Uplands; SMVA, Southern Mississippi Valley Alluvium; SMVU, Southern Mississippi Valley Silty Uplands.

inclusion in the survey that took place during the growing season of 2007. Silicon uptake appears to be a function of the ability of soils to supply Si and the capacity of rice to uptake available Si. Compelling evidence suggests that factors influencing metabolic activity have a marked effect on the capacity of plants to assimilate Si (Liang et al., 2006). Because the principal objective of this survey was to assess the ability of various fields to supply Si to flooded rice, agents were instructed to select only fields with "good to better" rice, avoiding areas showing strong evidence of insect damage, disease, nutritional deficiency, or other stresses. Fifteen of the sampling sites were located within fields in the state's Rice Verification Program, a program designed to demonstrate best management practices in the principal growing environments using the fields of participating farmers.

Sampling

Once a field was identified, a 10 m by 10 m site was flagged as the sampling area. At mid-tillering, rice fields (97 sites) were sampled for flood water, soil, and the most recent fully expanded leaf (Y-leaf). "Mid-tillering," a commonly recognized growth stage in rice production, is used here to designate the 1- to 2-wk period before panicle initiation when the formation of new plants from seedling tillers is largely complete. Approximately 50 Y-leaves were collected within the sampling area. Flood water samples were collected in clean, screw-cap polypropylene bottles. Bottles were rinsed with the flood water three times before filling and capping. After transport to the laboratory, water samples were stored at 4°C. Soil samples were collected from the surface 15 cm, placed into re-sealable plastic bags, and drained of free water. Bags were placed into a cooler and transported to a laboratory where samples were stored at 4°C until analysis. The geographical coordinates of each sampling site were recorded using a Garmin Vista GPS (Garmin, Ojathe, KS). After harvest, sites were revisited, and samples of straw were collected by cutting 50 mature plants 10 cm above the soil surface. To minimize soil contamination, leaves and straw were washed in 0.2% detergent and thoroughly rinsed with deionized water (Steyn, 1961; Wallace et al., 1980) before oven-drying (65°C for 24 h). Dried tissue samples were ground using an Udy Cyclone Mill (Udy Corp., Ft. Collins, CO) to pass through a 20-mesh screen. Ground samples were re-dried for 48 h (65°C) and placed in snap-cap vials and stored in a desiccator until use.

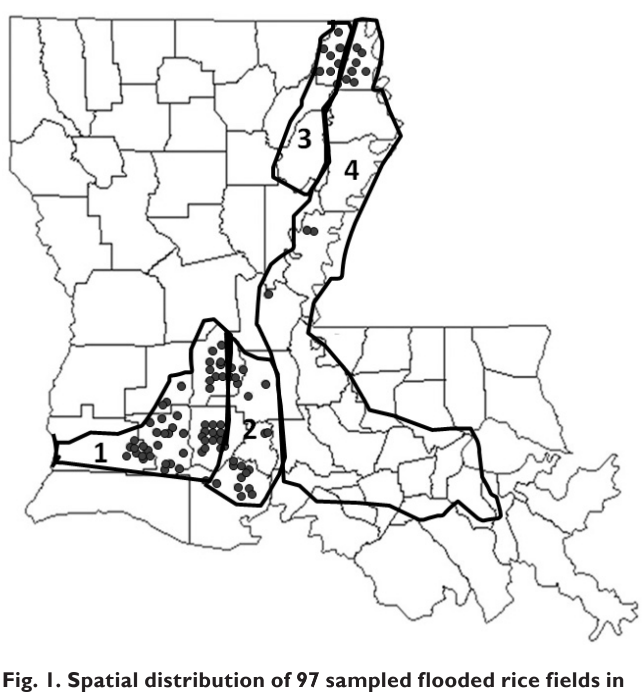

Fig. 1. Spatial distribution of 97 sampled flooded rice fields in Louisiana.

Silicon Analysis

Plant Tissue

Dry, ground tissue samples (100 mg) were digested in polyethylene tubes using strong caustic, and digests were amended with NH_4F before Si determination by molybdenum blue colorimetry as described by Kraska and Breitenbeck (2010).

Soil Pore Water

Samples of pore water were collected by centrifuging samples of field-moist soil. In all cases, sites were flooded at time of sample collection and stored in a state approximating saturation. Pore water was passed through a 0.45-µm filter to remove particulates, and the Si concentration of a 3-mL aliquot was determined by molybdenum blue colorimetry as described by Hallmark et al. (1982).

Flood Water

Flood water Si was determined colorimetrically using filter water by procedures similar to those used to measure soil pore water.

Determining Field-Moist and Air-Dried Soil pH

To assess the pH of field-moist soil samples, a previously calibrated EW-55500-30 AccuFlow electrode (Cole-Parmer, Vernon Hills, IL) with Ag/Cl double-junction reference was placed into the field-moist (saturated) soil sample and allowed to stabilize before recording.

Air-dried pH was determined in 1:2 soil/water suspensions using samples that had been air dried under ambient conditions for 10 d.

Statistical Methods

Data were analyzed using basic descriptive statistics, one-way ANOVA, and frequency tables using a statistical software package (Statistica; Statsoft, Tulsa, OK). Relationships between measured variables were made by plotting simple linear regression comparisons. Forward stepwise multiple linear regression models were used to identify statistically significant ($p < 0.05$) relationships. Geographic information system mapping software (Map Source; Garmin, Salem, OR) was used to create a map showing the spatial distribution of flooded rice fields sampled (Fig. 1).

RESULTS

Geographical, Major Land Resource Areas, and Soil Group Relationships

Figure 1 shows the locations of the 97 sites sampled in this survey. The density of sampling sites approximates the acreage of rice production throughout the state. Rice production traverses the state diagonally from southwest to northeast Louisiana and includes four MLRAs. Rice has been a staple crop in southwest Louisiana since the mid 1800s, and this region continues to produce more than 85% of the state's rice. This region is comprised of two MRLAs: the Gulf Coast Plains (GCP), which include most of the more southerly parishes in extreme southwest Louisiana, and the Subtropic Mississippi Valley Silty Uplands (SbMVU), which lie east of the GCP and west of the Atchafalaya Basin. Many of the soils used for rice in southwest Louisiana lie within the GCP MRLA and were derived largely from sediments deposited by ancestral Mississippi and Red Rivers. Crowley and Vidrine are the dominant soils of the GCP in Louisiana. In the most western parishes, Mowata-Vidrine associations with strongly acid surface horizons predominate. Rice production has declined in recent years in Calcasieu, Allen, and Lafayette parishes (Table 1) as less productive land is retired. East of Crowley, Louisiana, where the GCP transitions into the SbMVU, sugarcane begins to rival rice as the dominant crop. The soils of the SbMVU range from silt loams to heavy clays in the uplands along the western edge of the Atchafalaya Basin. In central and northeast Louisiana, the soils used for rice were derived from alluvial deposits associated with the more recent course of the Mississippi River. Following the Mississippi River is the Southern Mississippi Valley Alluvium (SMVA). Sharkey, a deep, poorly drained clayey alluvium, is the dominant series and is well suited for rice production. Rice production has expanded significantly in Avoyelles and Concordia parishes in recent years (Table 1). West of the SMVA lies the Southern Mississippi Valley Silty Uplands (SMVU), which are dominated by Dundee-Dubbs complex (silty alluvium) and Grenada-Calhoun complex (loamy loess). Although drainage varies greatly, many fields are capable of sufficient water retention to support flooded rice production.

Recommended management practices for rice in Louisiana indirectly consider MRLAs by partitioning the rice-producing acreage into "prairie soils" (GCP and SbMVU) and "delta soils" (SMVA and SMVU). In most respects, management is similar, although rice grown on delta soils generally receives 10 to 20 kg ha^{-1} more N because of higher yields and seldom requires the P and K fertilizers routinely applied to prairie soils. Planting commences in mid-March in southwest Louisiana and progresses over a 5- to 6-wk period as the crop moves northward. No differences in varieties or other production practices are notable except that rice seed is invariably drilled in the Delta, whereas water-seeding is a common practice in southwest Louisiana.

Comparisons of the concentrations of Si in Y-leaves at mid-tillering and with those in straw after harvest indicate that early season assimilation was lower in all fields selected for the survey (Table 2). Even so, rice plants in most fields were able to assimilate substantial amounts of Si by harvest. On average, Y-leaves contained 30.5 ± 7.8 g Si kg^{-1}, whereas mature rice straw contained 54.7 ± 12.7 g Si kg^{-1}. The Si concentrations in Y-leaf ranged from 10.4 to 52.2 g Si kg^{-1}, and those in straw ranged from 21.8 to 80.9 g kg^{-1}. With the exception of two fields in the GCP, the Si content of Y-leaves of young rice was below the 50 g Si kg^{-1} level suggested as sufficient by Dobermann and Fairhurst (2000) for rice at tillering. By harvest, the Si content of straw in only 34% of the fields was <50 g Si kg^{-1}, a level suggested by DeDatta (1981) and commonly used to assess Si sufficiency. Only six fields, all within the GCP, contained <34 g Si kg^{-1}, the level suggested by Korndörfer et al. (2001) to indicate an economic response to Si fertilization. Ranking of the Si contents of straw from various sites according to their respective MLRAs was: SMVA > SMVU > GCP > SbMVA. Parishes showing the lowest seasonal tissue concentrations of Si were Allen, Calcasieu, and Jefferson Davis, all located within the GCP in the southwest corner of Louisiana. In these parishes, 17 of 28 rice fields contained straw with <50 g Si kg^{-1}. Four fields containing <34 g Si kg^{-1} were located in Jefferson Davis Parish, and two were located in Calcasieu Parish, areas where rice production is declining.

Table 1. Average annual rice production (rough rice) for parishes sampled in survey.

Parish	MLRA†	Average annual rice production		
		1980–1989	1990–1999	2000–2007
		thousand Mg		
Acadian	GCP	170.2	225.9	237.1
Allen	GCP	53.4	54.4	45.7
Avoyelles	SMVA	19.6	25.9	38.4
Calcasieu	GCP	55.7	57.2	29.4
Concordia	SMVA	11.4	24.2	33.7
East Carroll	SMVA, SMVU	30.0	47.2	47.9
Evangeline	GCP, SbMVU	94.8	130.1	133.3
Jeff Davis	GCP	169.5	209.7	212.0
Lafayette	GCP, SbMVU	12.2	18.6	16.7
St. Landry	SbMVU	45.4	56.6	61.6
Vermilion	GCP, SbMVU	170.8	214.0	181.4
West Carroll	SMVA, SMVU	10.8	19.2	19.7

† GCP, Gulf Coast Praries; MLRA, Major Land Resource Area; SbMVU, Subtropic Mississippi Valley Silty Uplands; SMVA, Southern Mississippi Valley Alluvium; SMVU, Southern Mississippi Valley Silty Uplands.

Early season tissue Si concentrations were not a reliable indicator of the tissue concentrations in straw at harvest (Fig. 2). In no instance did the Si content decrease with maturity, despite the fact that above-ground biomass increased approximately four times. In a few cases, rice displaying low amounts of Si early in the season remained low until harvest, but most rice fields showing low early season uptake found an adequate supply of Si later in the growing season. The largest increases in Si status occurred in rice growing in the northeast region (MRLAs SMVA and SMVU) where the Si content increased by an average of 248% between mid-tillering and maturity. At mid-tillering, 19% of the sites were deemed "very low" (<24 g Si kg^{-1}), and 56% were deemed "low" (24–34 g Si kg^{-1}). Silicon concentrations suggest that only 3% of the sites contained "sufficient" (45–55 g Si kg^{-1}) or "high" levels' (>55 g Si kg^{-1}) of Si. By harvest, however, 74% of the rice appeared to contain sufficient or high levels of Si. Less than 6% of the rice fields could be considered low or very low in Si in tissue concentration.

Silicon in Flood and Soil Pore Water

The concentrations of Si dissolved in soil pore water collected during mid-tillering averaged 9.9 ± 4.1 mg Si L^{-1} and ranged from 0.7 to 22.7 mg Si L^{-1} (Table 3). Silicon concentrations in irrigation flood water collected at the same time averaged 9.6 ± 6.1 mg Si L^{-1} and ranged from 2.0 to 26.7 mg Si L^{-1}. Despite the similarities in mean Si concentrations and their ranges, no significant relationship was evident between Si concentrations of soil pore water and those of the overlying flood water

Table 2. Average Y-leaf and straw silicon concentrations and percentages of samples below critical levels of 34 or 50 g kg^{-1} in the rice-producing Major Land Resource Areas and parishes.

MLRA†	Parish	N‡	Y-Leaf Mean	Y-Leaf <50 g Si kg^{-1}§	Straw Mean	Straw <34 g Si kg^{-1}¶	Straw <50 g Si kg^{-1}#
			g Si kg^{-1}	%	g Si kg^{-1}	%	%
GCP		58	32.1 ± 8.9	96.6	50.9 ± 13.2	8.6	39.7
	Acadian	16	31.3 ± 8.9	93.8	59.6 ± 9.2	0.0	18.8
	Allen	3	28.3 ± 8.7	100.0	42.5 ± 8.2	0.0	66.7
	Calcasieu	13	26.8 ± 9.2	100.0	41.2 ± 11.2	15.4	53.8
	Evangeline	7	33.6 ± 2.8	100.0	63.3 ± 7.6	0.0	0.0
	Lafayette	1	38.4 ± 0.0	100.0	49.1 ± 0.0	0.0	100.0
	Jeff Davis	12	28.0 ± 9.2	100.0	44.6 ± 12.8	25.0	66.7
	Vermilion	6	38.0 ± 9.8	83.3	55.9 ± 12.4	0.0	33.3
SbMVU		22	30.3 ± 5.5	100.0	49.5 ± 7.6	0.0	40.9
	Evangeline	8	29.2 ± 6.1	100.0	52.5 ± 5.8	0.0	25.0
	Lafayette	1	27.6 ± 0.0	100.0	42.4 ± 0.0	0.0	100.0
	St. Landry	3	29.1 ± 3.0	100.0	46.5 ± 7.8	0.0	100.0
	Vermilion	10	35.4 ± 3.8	100.0	56.5 ± 9.9	0.0	30.0
SMVU		4	24.7 ± 6.5	100.0	62.5 ± 15.1	0.0	25.0
	West Caroll	4	24.7 ± 6.5	100.0	62.5 ± 15.1	0.0	25.0
SMVA		13	27.9 ± 4.7	100.0	66.2 ± 6.9	0.0	0.0
	Avoyelles	1	33.8 ± 0.0	100.0	64.1 ± 0.0	0.0	0.0
	Concordia	2	21.9 ± 5.8	100.0	69.4 ± 5.8	0.0	0.0
	East Caroll	5	27.8 ± 3.9	100.0	67.7 ± 9.2	0.0	0.0
	West Caroll	5	27.9 ± 4.1	100.0	63.6 ± 5.1	0.0	0.0
All		97	30.5 ± 7.8	97.9	54.7 ± 12.7	5.2	34.0

† GCP, Gulf Coast Praries; MLRA, Major Land Resource Area; SbMVU, Subtropic Mississippi Valley Silty Uplands; SMVA, Southern Mississippi Valley Alluvium; SMVU, Southern Mississippi Valley Silty Uplands.

‡ N, number of fields sampled.

§ Doberman and Fairhurst (2000).

¶ Korndörfer (2001).

DeDatta (1981).

(Fig. 3). Even more surprising, no significant relationships were evident between Si concentrations in soil pore or flood water and the concentrations of Si in plant tissue. The correlation coefficient (r) between Y-leaf Si and dissolved Si in pore was −0.17 and between Y-leaf Si and dissolved Si in flood water was only 0.09. Similarly, the correlation coefficients between Si content of straw and dissolved Si in pore and flood water were only −0.10 and −0.13, respectively.

When stepwise linear regression was used to identify measured variables associated with Si in plant tissue, statistically significant relationships ($p < 0.05$) were found between soil pH and Si concentrations in Y-leaf and straw (Fig. 4). The correlation coefficients were greater when tissue Si concentrations were compared with soil pH determined in 1:2 suspensions of air-dried soils than when compared with pH determined in field-moist (saturated) soils. The relationship between soil pH (1:2) and Si in straw was more evident (r = 0.42) than between pH (1:2) and Si in Y-leaves (r = 0.23), although in both instances pH accounted for only a small portion of the variability in tissue Si concentrations. Some of the fields sampled in this survey had become saline due to the use of saline irrigation water and to coastal flooding caused by hurricanes. The EC of flood water ranged from 51 to 1245 μS cm^{-1}, although no relationships were evident among EC and the tissue Si or the amount of Si dissolved in soil pore water or irrigation flood water.

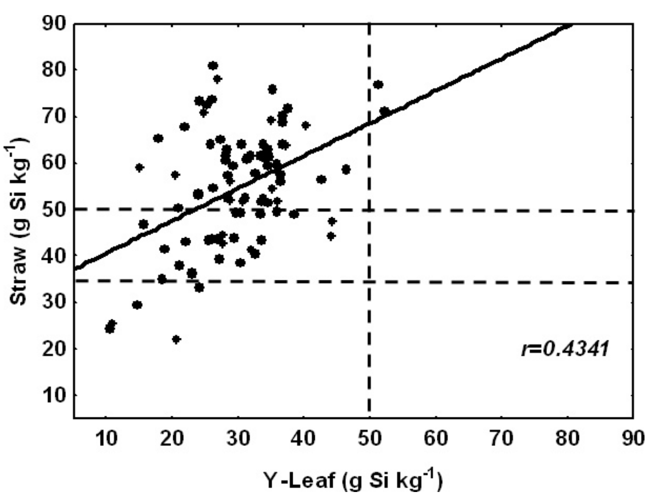

Fig. 2. Comparisons of Si tissue concentrations at mid-tillering (Y-leaf) and at maturity (Straw).

DISCUSSION

Low early season Si concentrations occurred in nearly all rice fields included in this study, although by harvest, only 36% of the fields contained <50 g Si kg^{-1}, a level commonly accepted as indicating sufficient Si for optimum production. These observations suggest that if low Si uptake is adversely affecting rice production in Louisiana, it is most likely due to increased

Table 3. Average silicon content of 97 soil pore water and flood water samples collected at mid-tillering.

Water type	Mean	Median	Minimum	Maximum
	mg Si L^{-1}			
Pore	9.9 ± 6.1	9.2	0.7	22.7
Flood	9.6 ± 4.1	8.9	2.0	26.7

susceptibility to early season diseases, insects, and abiotic factors commonly associated with restricted Si uptake.

Low Si uptake has been shown to increase the susceptibility of rice to blast (*Magnaporthe grisea* (Hebert Barr), leaf blight (*Xanthomonas oryzae* pv. *oryzae* [Ishiyama] Swings et al.), brown spot (*Cochliobolus miyabeanus* [Ito and Kuribayashi in Ito] Drechs ex Dastur), stem rot (*Magnaporthe salvinii* Catt.), scald (*Monographella albescens* Theum), and grain discoloration (Datnoff et al., 1997; Epstein, 1999; Kobayashi et al., 2001; Massey and Hartley, 2006; Mathai et al., 1977; Rafi et al., 1997; Rodrigues et al., 2001; Savant et al., 1997; Volk et al., 1958; Webster and Gunnell, 1992; Winslow, 1992). The specific mechanisms responsible for the ability of Si to increase disease tolerance are not fully understood, although thickening of the Si layer in the cuticle and improved stomata control have been suggested as contributing factors (Okuda and Takahashi, 1961; Yoshida, 1965). Adequate Si uptake also reduces the susceptibility of plants to chewing insects such as stem borer (*Chilo suppressalis* Walker), possibly by rendering plant tissue less digestible and by causing greater damage to the mandibles of feeding insects (Massey and Hartley, 2006). Enhanced Si uptake can also increase the tolerance of rice to excessive soil iron, manganese, and aluminum (Ma and Takahashi, 2002). Ma and Takahashi (2002) convincingly argue that adequate Si uptake can directly increase rice yields through more efficient transpiration and by causing more erect, stronger plants that capture light more efficiently and that resist lodging. The complex relationships among tissue Si levels and the susceptibility of rice to biotic and abiotic stresses, however, complicate the establishment of precise critical levels of Si deficiency and sufficiency. Dobermann and Fairhurst (2000) suggested a critical value of 50 g Si kg^{-1} for Y-leaves during tillering and a similar value for mature rice straw, with 80 to 100 g kg^{-1} as the optimum level. The basis for these widely used recommendations is not discussed. DeDatta (1981) also cites 50 g Si kg^{-1} as the critical concentration of Si for straw collected at maturity based on the work of Tanaka and Yoshida (1970). After their review of extensive field studies in Asia, Lian (1976) concluded no significant increase in yield occurred when mature straw contained >61 g Si kg^{-1} when grown in Japan and Korea and >51 g Si kg^{-1} when grown in Taiwan. India rice varieties growing in tropical regions of Sri Lanka and India appear to respond to Si fertilization at straw concentrations of <37 g Si kg^{-1}. This latter value is similar to value of 34 g Si kg^{-1}, established by Korndörfer et al. (2001), at which the economic response to Si fertilization is possible in the Everglades Agricultural Area of Florida for crops grown on sandy or muck soils. Studies to establish early or late season critical Si values for other rice-growing regions of the United States have not been reported, although the results of this survey suggest that research to assess the influence on Si uptake of rice, especially early season uptake, are merited even in areas where rice is grown on deep mineral soils containing appreciable amounts of clay minerals.

Assuming that a value of 50 g Si kg^{-1} in mature rice straw reflects Si sufficiency in Louisiana, Si uptake was adequate by harvest in nearly all parishes, with the exception of those in the extreme southwestern portion of the state where more than 60% of the fields surveyed failed to meet this criterion. It may be more than coincidental that declining yields and rising production costs have resulted in declining acreage in this area; some fields in southwest Louisiana are suitable candidates for assessing the potential benefits of calcium silicate fertilization on rice productivity.

Between mid-tillering and harvest, tissue concentrations increased an average of 79%, whereas standing biomass increased approximately four times, indicating a increase of

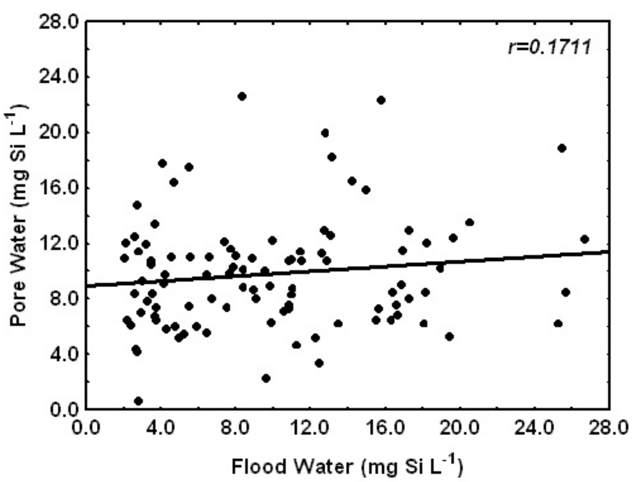

Fig. 3. Comparisons of dissolved Si in soil pore water to that in irrigation flood water in 97 fields sampled during mid-tillering of rice.

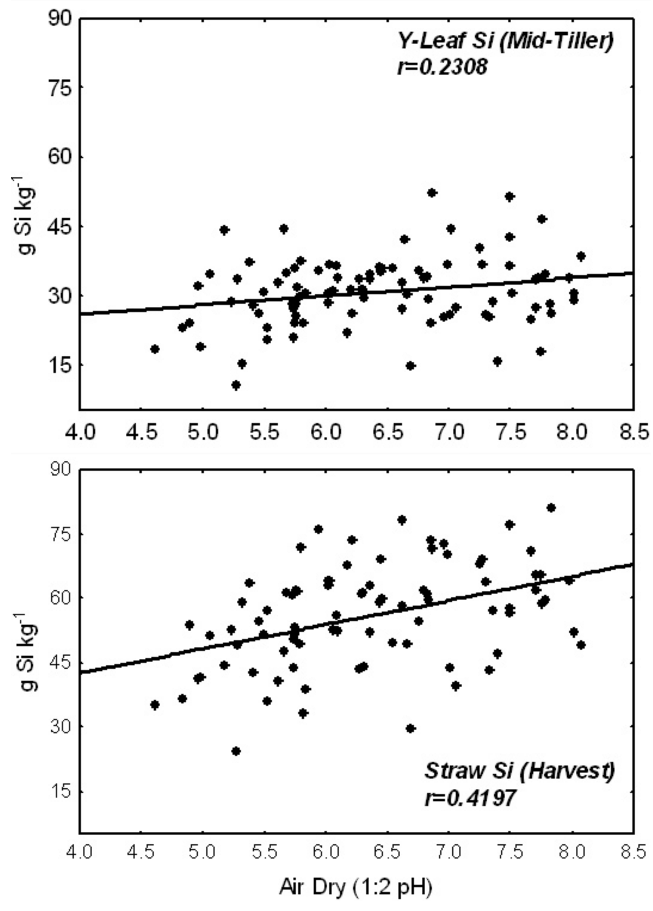

Fig. 4. Linear relationship between air dry 1:2 soil pH and Si concentrations at mid-tiller (Y-leaf) and harvest (straw).

more than six times in the amount of Si assimilated into standing biomass. The low early season uptake observed may have been due to reduced Si availability or reduced capacity of young plants to assimilate Si. Most likely, low early season Si assimilation is the result of a combination of both. Growth chamber studies comparing the effects of low (4°C) and high (25°C) temperatures showed that low temperatures substantially suppressed assimilation of Si by rice and corn (*Zea mays*), as did chemical inhibitors of metabolism (Liang et al., 2006). Increasing solution concentrations of Si, however, increased Si uptake even at low temperatures, indicating that uptake is a combination of metabolic rate and Si availability. Temperatures were not monitored in this study, but the influence of variable early season temperatures may account for the lack of a discernable relationship between Si concentrations at mid-tiller and harvest or between tissue Si concentrations and those in flood water or soil pore water. It is also possible that the marked increase in Si concentrations between tillering and harvest observed in the more northern rice growing regions of Louisiana was due to lower soil, irrigation water, and ambient temperatures.

Silicon is the second most abundant element in mineral soils, although the solubility of Si in clays and in the various other forms present is not well understood (Faure, 1991). In Japan and other Asian countries where rice has been produced on the same land for hundreds (and possibly thousands) of years, it is generally assumed that crop removal has depleted soil reserves of readily soluble Si, and routine fertilization with slag or other silicates is practiced (Ohkawa, 1936–1942; Ishibashi, 1936–1939; Hashimoto et al., 1948; Mitsui et al., 1948; Ma and Takahashi, 2002). Rice has been produced in some fields in southwest Louisiana for more than 150 yr, and it is possible that reserves of more labile silicates have been depleted as well. For example, removing 5500 kg ha^{-1} of rough rice containing 50 g kg^{-1} Si at harvest results in the loss of 275 kg of Si. Additional Si losses occur due to the discharge of flood water. Water-leveling, once widely practiced, undoubtedly led to substantial losses of fine clays and dissolved Si through the discharge of sediment-laden flood water.

Assessing the amounts of potentially available Si in soils remains problematic. Although a number of soil tests to assess Si availability have been proposed, none has found wide acceptance (Haysom and Chapman, 1975; Imaizumi and Yoshida, 1958; Kitada et al., 1992; Ma and Takahashi, 2002; Matichenkov et al., 2001; Mizuochi et al., 1996; Nonaka and Takahashi, 1990; Savant et al., 1997; Sumida and Ohyama, 1988; Sumida, 1991; Takahashi and Nonaka, 1986; Wang et al., 2004). Given the interdependence of the many factors influencing Si uptake, this is not surprising. The poor correlations shown here (Fig. 2 and 3) between dissolved Si in flood or soil pore water and tissue concentrations suggest that development of a soil test that relates to plant uptake will be challenging, although continued efforts are merited. At present, tissue analyses appear to be the most dependable means of assessing Si status. Even so, without supporting research correlating Si status with yields in specific rice growing areas, it is difficult to estimate the economic impact of Si or to predict the benefits of Si fertilization.

CONCLUSIONS

Comparison of Si tissue concentrations measured in this survey with critical values established for other rice-growing areas indicate that Si uptake is adequate by harvest in most rice-growing areas of Louisiana. On the basis of these data, it is unlikely that Si fertilization would benefit rice production, with the possible exception of extreme southwest Louisiana, where tissue Si in harvested straw was <50 mg kg^{-1} in more than 60% of the fields surveyed. Tissue concentrations at mid-tillering were consistently less than the 50 mg kg^{-1} level used to indicate adequacy in some rice-producing regions. The influence of low early season Si uptake on the severity or occurrence of common early season disorders in rice merits further investigation.

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