Chapter 30

The Effect of Silica Rates on the Growth, Silica Deposition and Water Absorption Among Three Turfgrass Species[1]

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ABSTRACT

'Kentucky 31' tall fescue (*Festuca arundinacea* Schreb.) 'Pennstar' Kentucky bluegrass (*Poa pratensis* L.) and common bermudagrass (*Cynodon dactylon* L. Pers.) were cultured in hydroponics at silica rates of 0, 50, and 100 ppm $Si0_2$. The yield and silica content of leaf, stubble, and root tissue were determined for the three species. Turfgrass leaf, stubble, and root yields were not affected by silica rate. No deficiency symptoms or other adverse affects on growth were observed at the zero silica rate. Silica content was consistently highest in stubble tissue for all species. Silica content of the various plant components showed a linear increase with increasing silica concentration in the nutrient solution. The quantity of water transpired by 'Pennstar' Kentucky bluegrass decreased as much as 17.5% at the highest silica rate.

Additional key words: ***Festuca arundinacea, Poa pratensis, Cynodon dactylon.***

INTRODUCTION

Plant species vary considerably in their ability to accumulate silica. Grasses are reported to contain 10 to 20 times the amount of silica found in legumes and other dicotyledons (Jones and Handreck, 1967). The silica content of most grasses has been reported to range from 3 to 10% depending on the grass species, whereas, most dicotyledons have concentrations in the range of 0.1 to 0.5%. Several species of plants including horsetail (*Equisetum arvense* L.) and rice (*Oryza sativa* L.) are considered high silica accumulators containing 10 to 25% $Si0_2$ in stems and leaves (Jones and Handreck, 1967). The essentiality of silica for plant growth has been substantiated in several of the high accumulator species (Van Soest, 1970). However, the role of silica in the low and moderate accumulators is not well documented.

Silica content has also been reported to vary widely among the different parts of the plant. In dicotyledons, the silica content of roots exceeds or equals that of the shoots. In monocotyledons, silica accumulates most readily in the aerial parts or shoots (Jones and Handreck, 1967). Handreck and Jones (1968)

[1]A contribution from the Dept. of Agronomy, The Ohio State Univ. and Ohio Agric. Res. Dev. Ctr., Columbus, OH 43210. Journal Article No.60-81.

reported that the silica content of the leaf blade, leaf sheath, stem and inflorescence of mature oats was 5.30, 4.70, 1.03 and 7.72% respectively. Silica deposition apparently occurs most readily in those plant parts having the greatest potential for water loss.

Blackman (1973) stated that mature and senescent tissue of rye (*Secale cereale* L.) contained two to three times the amount of silica present in young tissue. High levels of silica were also noted in dead tissue. Histochemical studies on high silica accumulators showed that 50% of the total silica in the leaf blade was concentrated in the epidermis and SiO_2 filled the intraspaces of cellulose micelles of the epidermal cells forming a silica-cellulose double layer (Yoshida et al., 1962). A reduction in transpirational water loss was attributed to this double layer. Sangster (1970) noted that senescent leaves, in contrast to younger and mature leaves, typically exhibited extensive extracellular silicification of the mesophyll. Jones et al. (1963) noted that the total silica in plants increased with advancing plant maturity.

In previous studies, silica content and distribution within the plant have been determined after plants reached maturity. Accumulation may vary considerably under turfgrass culture where plants are maintained under a frequent mowing regime. Other turfgrass management variables may also effect silica accumulation and distribution.

Van Soest and Jones (1968) found that silica reduced the digestibility of forage grasses. Smith et al. (1971) reported an inverse relationship between silica content and digestibility of rangeland forages. Silica has been suggested to play a role in thatch accumulation (Street et al., 1980).

The objectives of this study were to determine; (1) the silica content of several turfgrass species at variable silica rates, (2) the distribution of silica among various plant parts, (3) any nutritional role of silica that may have significant field application, and (4) the water-use rate of turfgrass as affected by silica nutritional levels.

MATERIALS AND METHODS

Common bermudagrass (*Cynodon dactylon* L. Pers.,) 'Kentucky 31' tall fescue (*Festuca arundinacea* Schreb.) and 'Pennstar' Kentucky (*Poa pratensis* L.) were seeded in 7.5 l (2-gallon) plastic containers and placed in a controlled environmental chamber. The grasses were cultured throughout the 24-week experimental period on a 0.5X dilution of complete Hoagland's solution. Four weeks after seeding, silica treatments of 0, 50, and 100 ppm SiO_2, applied as sodium silicate, were imposed. Each treatment was replicated three times in a completely randomized design.

The environmental chamber was maintained at a day/night temperature regime of 24/18 C and a photoperiod of 14 hours. The nutrient solution was renewed every 5 to 7 days at which time the containers were rinsed with distilled water. Polyethylene gas dispersion tubes were used to insure adequate oxygen distribution within the system.

Common bermudagrass and Kentucky bluegrass were maintained at a cutting height of 3.8 cm. Tall fescue was maintained at a cutting height of 5.0 cm. Leaf clippings (blades) were collected at 4 to 5-day intervals. Stem (stubble) and root tissues were obtained at the termination of the study. After harvesting, the stem and root tissues were subjected to a series of washings with distilled water to insure freedom from external silica contamination. Leaf, stem, and root components were dried at 70 C. The samples were ground in a micro Willey mill to pass a 60-mesh screen, and stored over P_20_5 in a vacuum desiccator for later analysis.

Silica determinations were made following the procedures described by Jones and Handreck (1967). A sub-sample (0.25 g) of the ground plant material was transferred to a 50-ml nickel crucible and ignited in an electric muffle furnace at 550 C. One gram of anhydrous $NaC0_3$ was mixed with the ash and the mixture fused over an airblast Meker burner for 0.5 hour. The cooled cake was dissolved in distilled water and made up to a 100 ml volume; an aliquot was then analyzed for silica.

Silica was estimated by the reduced silicomolybdate method under the following conditions. A 2-ml aliquot was transferred to a 25-ml standard flask. Distilled water was added to bring the volume to approximately 15 ml. Two ml of a solution containing 5% (w/v) ammonium molybdate in 1N H_2SO_4 was then added. After 10 minutes, the reaction was stopped by addition of 5 ml of 10N H_2SO_4. The silicomolybidic acid was then reduced with 0.5 ml of a solution containing 0.2% 1:2:4 amino-naphtosulphonic acid, 2.4% sodium sulphite, and 12% sodium metabisulphite. Ten minutes after adding the reducing solution, the absorption was determined at 570 mu on a Bausch and Lomb "Spectronic 20" spectrophotometer.

Water use by Pennstar Kentucky bluegrass was determined during the last 5 weeks prior to the termination of the study. The uniformity and density of the bluegrass stand provided for a system low in surface evaporation. The osmotic pressures of all solutions were equalized with sodium phosphate. At each solution change, water remaining in the plastic containers was measured and the percent reduction in water loss relative to the 0 ppm $Si0_2$ treatment was calculated.

RESULTS AND DISCUSSION

Clipping yields of Kentucky 31 tall fescue, Pennstar Kentucky bluegrass and common bermudagrass were unaffected by silica rates during the 24-week experimental period. Thus, leaf yield is only provided for the first and last harvest periods (Tables 1, 2). Dry matter yields of the stubble and roots also were not different among the silica treatments (Tables 3, 4). Visual observations of leaf blades at periodic intervals showed no signs of deficiency symptoms or other alterations in leaf character. Thus, silica would not appear to be a factor in turfgrass nutrition under field conditions since reported soil levels of silica (Jones and Handreck, 1967) are well in the range of those used in this study. It is difficult to discuss the essentiality of silica from the data since silica was present in low concentrations (i.e., 0.8%) in the plant tissue even at the 0 ppm SiO_2 rate.

Table 1. Effect of silica rates on the clipping yield and silica concentration for the initial harvest period at 8 weeks following treatment application.

	Species					
Silica Rate	Tall fescue		Kentucky bluegrass		Bermudagrass	
ppm SiO_2	g pot^{-1}†	%SiO_2	g pot^{-1}	%SiO_2	g pot^{-1}	%SiO_2
0	9.8‡	0.24a§	7.5‡	0.30a§	15.4‡	0.43a§
50	10.1	2.51c	8.2	3.80d	13.1	1.93b
100	11.3	4.71e	7.9	6.22f	13.5	3.48d

† Clippings were combined from several cutting times for each sampling period.
‡ No significant differences in dry matter yield within each species were obtained.
§ Values not having the same letter differ significantly at the 5% level.

Table 2. Effect of silica rates on the clipping yield and silica concentration for the final harvest period at 20 weeks following initial treatment application.

	Species					
Silica rate	Tall fescue		Kentucky bluegrass		Bermudagrass	
ppm SiO_2	g pot^{-1}†	%SiO_2	g pot^{-1}†	%SiO_2	g pot^{-1}†	%SiO_2
0	11.3‡	0.21a§	11.7‡	0.20§	25.7‡	0.21a§
50	13.4	1.83b	10.8	3.88d	24.3	3.09c
100	12.0	3.47cd	9.8	6.88e	25.8	3.90d

† Clippings were combined from several cutting times for each sampling period.
‡ No significant differences in dry matter yields within each species were obtained.
§ Values not having the same letter differ significantly at the 5% level.

The uptake of silica for each species was proportional to the silica level in the nutrient solution (Tables 1, 2). Silica concentration of the leaf blades approached a linear relationship with increasing silica rates. Other investigators (Jones and Handreck, 1967; Handreck and Jones, 1968) have reported similar results with forage species. It is interesting to note that even at the high silica rate, substantial amounts of silica accumulated. This type of accumulation would support the passive movement of monosilicic acid with the transpirational stream that is hypothesized by other investigators.

Pennstar Kentucky bluegrass consistently showed higher silica concentrations in leaf blades when compared to the other species at the same treatment rates. The silica concentration of Kentucky 31 tall fescue and common bermudagrass leaf blades was similar throughout the 24-week experimental period (Tables 1, 2). The average silica concentration for bluegrass, fescue and bermudagrass leaf blades, calculated across all harvest periods was 3.66, 2.39 and 2.40, respectively, at the 50 ppm SiO_2 rate and 6.10, 4.14 and 3.85, respectively, at the 100 ppm SiO_2 rate. Total content of silica in leaf blades from the final harvest period was highest for bermudagrass (Table 5).

The silica concentration of leaf blades showed no consistent variation with time or plant age (Tables 1, 2). Other investigators (Handreck and Jones, 1968), however, have reported the silica content of leaves increased with advancing maturity. Plants in those reports were grown to maturity before harvest. With continuous removal and regrowth of leaf blades under typical turfgrass culture, the physiological age of the harvested leaf blades would not vary greatly from one cutting to the next. Thus, under turfgrass management regimes where frequent mowing is practiced, no significant variation in silica content of leaf blades with time would be expected.

Table 3. Effect of silica rates on the dry matter yield and silica concentration of roots at the final harvest period.

	Species					
Silica rate	Tall fescue		Kentucky bluegrass		Bermudagrass	
ppm	g pot^{-1}	%SiO_2	g pot^{-1}	%SiO_2	g pot^{-1}	%SiO_2
0	8.1†	0.57a‡	6.3†	0.76ab‡	9.1†	0.60a‡
50	8.3	0.87b	6.3	1.43c	10.4	0.57a
100	7.1	1.25c	5.3	2.82d	9.4	0.60a

† No significant differences in dry matter yield within each species were obtained.
‡ Values among species not having the same letter differ significantly at the 5% level.

Table 4. Effect of silica rates on the dry matter yield and silica concentration of stubble at the final harvest period.

	Species					
Silica rate	Tall fescue		Kentucky bluegrass		Bermudagrass	
ppm	g pot^{-1}	%SiO_2	g pot^{-1}	%SiO_2	g pot^{-1}	%SiO_2
0	30.8†	0.80a‡	20.4†	0.16a‡	30.5†	0.71a‡
50	31.2	3.95b	20.3	4.42bc	28.3	4.45bc
100	33.6	5.77cd	20.2	6.34d	29.3	8.02e

† No significant differences in dry matter yield within each species were obtained.
‡ Values among species not having the same letter differ significantly at the 5% level.

The stubble from all three species contained higher percentages of silica than leaf blades and roots when compared within each species (Table 4). Silica concentrations in stubble approached twice the amount found in leaf blades for fescue and bermudagrass. Total content of silica was also considerably higher in stubble than in blades and roots (Table 5). In contrast, Handreck and Jones (1968) reported that the silica concentration of oat stems was one percent compared to five and four percent for the leaf blade and leaf sheath, respectively. They considered silica uptake to be passive and silica deposition to occur in greatest quantities in those plant parts from which water is lost in greatest quantities.

Cutting frequency most likely played a significant role in silica distribution. Residual leaf surfaces were available for transpiration after the leaf blades were harvested. Thus, the potential for upward silica movement was maintained. Silica would be expected to concentrate in the xylary system of the stubble prior to leaf blade regrowth. As the silica content in the xylary stubble increases, it is possible that silicic acid molecules moved from the xylem toward the outer epidermal cells or intercellular spaces by mass flow and/or diffusion. Silica precipitation in the epidermal cells and in other cell types would maintain a gradient in favor of further accumulation. Over time, higher silica levels in the stubble could occur.

Table 5. Silica distribution among various plant parts under different silica nutritional rates †.

		Species		
Silica rate	Plant part	Tall fescue	Kentucky bluegrass	Bermudagrass
		g pot^{-1}		
0 ppm SiO_2	Blades‡	0.02	0.02	0.05
	Stubble	0.25	0.03	0.22
	Roots	0.05	0.05	0.06
	Total	0.32	0.10	0.33
50 ppm SiO_2	Blades‡	0.26	0.42	0.75
	Stubble	1.23	0.90	1.26
	Roots	0.07	0.09	0.06
	Total	1.56	1.41	2.07
100 ppm SiO_2	Blades‡	0.42	0.67	1.01
	Stubble	1.94	1.28	2.35
	Roots	0.09	0.15	0.06
	Total	2.45	2.10	3.42

† All data are means of three replicates.
‡ Total silica content of leaf blades is provided for only the final harvest period.

Stubble components (e.g., leaf sheaths, stems and nodes) are considered to be significant contributors to thatch development. Street et al. (1980) previously reported a depressing effect of silica on decomposition of turfgrass tissue. Stubble tissue in the latter study constituted only 25% of their total decomposition sample. The remaining 75% of their decomposition sample was composed of leaves and roots. In the present study, the concentration and total uptake of silica in stubble were considerably higher than in leaves and roots. The inclusion of more stubble in the decomposition sample may have shown a more depressing effect of silica on turfgrass (thatch) decomposition than was reported (Street et al., 1980).

The concentration and total uptake of silica in the roots for all three species was lower than that found for leaf blades and stubble (Tables 3, 5). The lower accumulation of silica in roots is in agreement with the findings of other investigators (Handreck and Jones, 1968; Jones et al., 1963). The silica content of roots was highest in Kentucky bluegrass and lowest in bermudagrass.

Water use by Pennstar Kentucky bluegrass as affected by silica rate is shown in Table 6. The amount of water transpired by Kentucky bluegrass decreased at the higher silica rates. The percent reduction ranged from 10.2% initially to 17.5% at the final sampling date. The differences cannot be attributed to osomotic pressure variations since the osomotic pressures of the nutrient solutions were equalized.

The reduction in water utilization at the higher silica rates cannot be attributed to variations in vegetative growth since no yield differences were obtained among silica treatments. The cause of the reduction in water use can

Table 6. Water use by Kentucky bluegrass as affected by the silica nutritional level in hydroponic solution.

	Water utilized				
Silica rate	7-25†	8-1	8-13	8-20	8-27
(ppm SiO_2)			ml pot^{-1}		
0	1937b‡	2117b	2376b	3000b	2097b
50	1873ab	1994ab	2280ab	2734ab	1904ab
100	1740a	1858a	2080a	2537a	1730a
Difference	197	259	287	427	367
% reduction§	10.2	12.2	12.1	14.2	17.5

† Date of measurement.
‡ Values within each sampling date not having the same letter differ significantly at the 5% level.
§ Expressed as a % of 0 rate.

only be speculative at this point. In rice, lower transpirational rates at higher silica levels were attributed to increased silica deposition within the cell wall and between the cell wall and cuticle (Yoshida et al., 1962). Sangster (1970) has reported deposition of silica in cell walls of the epidermal cells of oats and in the walls and lumina of guard cells and subsidiary cells of the stomatal cells of grasses became non-functional with a resultant reduction in transpiration. Thus, the lower transpirational rates observed in this study may result from (1) a physical obstruction or (2) a loss of stomatal function.

CONCLUSION

Silica did not have any noticeable effects on turfgrass growth and development. Under field conditions, it would not appear to have any important role in fertilization programs. Silica concentration was highest in stubble and lowest in roots for all three species. Total content of silica was likewise highest in stubble. Stubble components are key contributors to thatch. Silica is known to cause a depressing effect on grass digestibility and/or decomposition. The magnitude of its effect in depressing turfgrass decomposition and, in turn, promoting thatch accumulation needs to be further assessed since earlier work used only a small fraction of stubble in decomposition samples. Water use was also lowered at the higher silica rates. Water use may, therefore, vary from site to site depending on silica content of various soil media.

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