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Growth and Wear Tolerance of Creeping Bentgrass as Influenced by Silica and Potassium Fertilization

Yong Seon Kim[1]* and Ki Sun Kim[2]

[1]Turfgrass & Environment Research Institute, Samsung Everland Inc., Gunpo 435-737, Korea
[2]Department of Plant Science, Seoul National University, Seoul 151-921, Korea

ABSTRACT. The study was conducted to know whether turfgrass wear tolerance, growth, and quality could be improved by the application of silicon and potassium. First, turf responses to silicate and potassium were evaluated by several parameters such as, turf visual quality, root length, shoot density, and dry weight under the field condition. Second, turf responses to traffic frequencies were examined by turf growth (root) length, shoot density and dry weight) and soil hardness under the field condition. Finally, under traffic stress condition, the effects of silica and potassium application on wear tolerance were evaluated through the methods described above. Creeping bentgrass (*Agrostis stolonifera*) rooting were significantly improved by silica. The root length was enhanced by an increase in potassium silicate application. Certain level of light traffic is beneficial while frequent traffic cause serious adverse effect on visual quality of bentgrass. Under a traffic stress condition with 10 times of footing a day for 30 days, silica and potassium increased turf visual quality by 6.38% and 10.25% respectively when compared to the control. Silica and potassium treatment on trafficked plot increased turf visual quality by 11.4% and 10.2% respectively in comparison with the control with significant reduction of wear injury from the traffic. A co-application of potassium silicate with potassium sulfate provided the enhanced visual quality of turf as compared to application of silica or potassium fertilizer, respectively.

***Key words*:** Creeping bentgrass(*Agrostis stolonifera* L.), Potassium silicate, Silica, Traffic, Wear tolerance

Introduction

Injury from traffic is one of the predominant abiotic stresses to affect turfgrass growth and quality on recreational sites. Wear injury to shoot tissue is manifested by abrasion, tearing, or stripping of the leaf tissue, resulting in chlorophyll degradation and subsequent reduction in photosynthesis. Secondary effects due to this injury can include increased susceptibility to insect or fungal attack at the sites of injury or increased weed pressure due to loss of turf density. The overall effect of the injury is a cessation of turf growth, loss of density, and premature senescence of shoot or root tissue. Rates of recovery vary based on inherent growth rate and degree of injury severity.

Greater shoot density and quantity of verdure tissue may increase wear tolerance and speed recovery from wear injury (Trenholm et al., 1999). Shoot tissue quantity may be due to inherent growth rate, which may vary between or within species (Beard, 1973) or may result from specific turfgrass fertility or management practices. Adequate nitrogen (N) fertilization can increase shoot density and hasten recovery from wear, but applications of high rates of N typically reduce wear tolerance, due to increased tissue succulence. Potassium fertilization has been shown to increase wear tolerance, primarily due to effects on stomatal control and leaf turgidity (Carrow, 1995).

As with any plant grown for the use or benefit of people, understanding the nutritional requirements of turfgrasses is among the most important factors in their successful culture. Inadequate soil nutrient levels, insufficiently or excessively applied nutrients, and improperly applied nutrients can each lead to problems in the general health, vigor, and quality of a turfgrass stand. As the use or quality expectations of a turfed area increase, so does the importance of adequate soil fertility and a proper fertility program. In extreme cases, poor or improper fertility can lead to the decline and eventual loss of major portions of a turfgrass stand.

In classical plant nutrition literature, 16 elements are generally considered essential for plant growth. These include: C, H, O, N, K, P, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B, and Cl. In reality, however, plant growth requires far more than 16 elements. Of the elements, not included in the 16 but proven a quantitatively major inorganic constituent of plants, is silicon (Si). Silicon is the second most abundant element on

*Corresponding author; Tel: +82-31-460-3402
E-mail : y_s_k@naver.com
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the surface of the earth and accounts for up to 31% of the earth's crust by weight, 3 to 17 ppm in soil solution. Si may be beneficial to some plants in some situations, but have not been shown at this time to be absolutely essential according to strict classical definitions. It is most commonly found in soil solution as a form of silicic acid, H_4SiO_4, which is readily absorbed by plants. The form in which Si is taken up by plants is monosilicic acid, $Si(OH)_4$ (Chen et al., 2000).

Increasingly, chemical companies are promoting silica-amended products to enhance turfgrass wear tolerance, reportedly due to effects of silicification on leaf rigidity. However, the authors are unaware of any scientific studies related to the influence of Si on wear tolerance.

Silicification of tissue may impart additional rigidity to leaf blades, which could influence wear tolerance. Silica may be deposited intra- or extracellularly (Sangster, 1970). Especially, epidermal cells and xylem cell walls are the places where the silica is highly accumulated (Mengel and Krikby, 1987). Silica deposition lowers cuticular water loss (Mengel, 1987) and has also been shown to impede fungal penetration of the cuticular layer (Miyake and Takahashi, 1983).

Silicon's activity in the soil matrix has been proven to improve micronutrient uptake (boron, copper, iron, manganese, zinc), and reduce toxic metal uptake (aluminum and sodium) (Chen and Caldwell, 1998).

Creeping bentgrass (Agrostis stolonifera L.) cv. ‘Penncross’ had increased dry weight in response to Si application at 50 or 100 mg/ L (Gussack et al., 1998). Silicon deficiency decreases plant height, tillering, and production of green and dry matter (Mengel and Krikby,1987).

In recent several years, It has been noticed that silica is promoted for use on rice (Kang et al., 1997). Although the effects of silica on turfgrasses have been studied for some time, their effects on turfgrass growth have not been well documented. Knowledge of the roles of silica in turfgrasses would help identify traits to improve wear tolerance.

The objectives of this study were to determine whether foliar silica application could improve wear tolerance of bentgrass and to examine whether silica might be involved in physiological responses of the turfgrass. This research was undertaken to determine the influence of silica application on growth, quality, and wear tolerance in creeping bentgrass.

Materials and Methods

Influece of silica and potassium on the growth & quality of creeping bentgrass

Field experiment was carried out at the Anyang Benest Golf Club Research Field located in Gunpo-si, Kyounggido, Korea. The experiment was conducted on 'Dominant'('Providence' 50% + 'SR1020' 50% blend) creeping bentgrass (*Agrostis stolonifera* L.) turf from May through June, 2001. Fertilizers used in the study were soluble potassium silicate (Kasil #1, 20.8% SiO_2 and 8.3% K_2O, PQ Corp., Chester, PA) and potassium sulfate (50%, K_2O., Kyounggi Chemical Co.)

Table 1. Listing of treatments applied in experiments.

Treatments	Amount (m^2)
Control	no applied
Potassium silicate(K_2SiO_3)	3 ml
Potassium silicate	6 ml
Potassium silicate	10 ml
Potassium silicate + Potassium sulfate	3 ml + 3 g
Potassium sulfate(K_2SO_4)	3 g
Potassium sulfate	6 g
Potassium sulfate	10 g

Silicon was used in the form of the potassium (K) salt. A total of 8 treatments were comprised of the untreated control (no fertilizer application), 3 rates of potassium silicate, 3 ml/m^2, 6 ml/m^2, 10 ml/m^2, three rates of potassium sulfate, 3 g/m^2, 6 g/m^2, 10 g/m^2, and a mixture of potassium silicate 3 ml/m^2 and potassium sulfate 3 g/m^2 (Table 1).

Fertilizers were applied by hand sprayer capable of accurate and uniform delivery. The sealed mix tank was vigorously shaken prior to application. The amount of delivery was based on 1 L/m^2 water for all treatments. The same treatment was replicated three times in a randomized complete block design. A plot size was 1 m × 1 m. Fertilizers were applied twice a month in the field.

Turf visual quality, root length, shoot density, and dry weight were investigated under field conditions for 7 treatments (including control) at 25 days after each treatment. Visual quality assessments were based on color, and uniformity, using a scale of 9 to 1(9 = best, 6 = minimum acceptable, and 1 = poorest quality).

Growth response of traffic stress

The experiment was conducted on creeping bentgrass turf. Traffic treatments were applied for thirty days from May 11 to June 10 in 2001. A plot size was 1 m × 1 m. One person in a weight of 70 kg made traffic treatments as 0, 2, 7, 15, 25 passes daily. Data were collected at thirty days after treatment was initiated. The parameters measured were the same as mentioned in the first experiment.

Turf visual quality, root length, shoot density, dry weight, and soil hardness were investigated under field conditions for 5 treatments (including control) at 30 days after each treatment.

Visual quality assessments were based on color, and uniformity, using a scale of 9 to 1(9 = best, 6 = acceptable, and 1 = poorest quality). Soil hardness was measured by soil hardness tester (SHM-1, TAKEMURA, Japan).

Effects of silica and potassium application under traffic stress conditions

A field experiment was carried out to determine whether or not foliar silica and potassium application could improve wear tolerance of bentgrass. The experiments were conducted on creeping bentgrass turf from May through June, 2001. A total of 4 treatments were comprised of the untreated control (no fertilizer application), potassium silicate 3 mL/m^2, potassium sulfate 3 g/m^2 and a mixture of potassium silicate 3 mL/m^2 and potassium sulfate 3 g/m^2. Fertilizers were applied by hand sprayer capable of supplying accurate and uniform delivery. The amount of delivery was based on 1 L/m^2 water for all treatments. The sealed mix tank was vigorously shaken prior to application. The traffic treatments were replicated three times in a randomized complete block design. A plot size was 1 m × 1 m. One person in a weight of 70 kg made traffic treatments as 10 passes daily. Data were collected at thirty days after treatment was initiated. Data were collected at thirty days after treatment as mentioned in the first experiment.

Chemical analysis of soil and leaf tissue

Chemical analyses for soil and leaf tissue were completed in 10 and 25 days after individual treatment. A total of 3 treatments were comprised of the untreated control (no fertilizer application), potassium silicate 5 ml/m^2, and potassium sulfate 5 g/m^2. Soil samples were taken at every 5 cm depth by 10 and 25 days after treatment was over.

Analysis followed the common chemical methods (NASTI, 1983). K, Ca, Mg, Fe were extracted with 1M ammonium acetate solution and determined by inductively coupled plasma spectrophotometer (Spectro Analytical Instrument, SPECTRO CIROS CCD. Germany). Total nitrogen was extracted with H_2SO_4 and determined by the micro Kjeldahl method. Available phosphorus was determined by Lancaster method. Available silicon was determined by Kolthoff and Hesse method. Electical conductivity (EC) and pH were determined with distilled water filtrate (soil to water 1:5 W/V). Organic matter was determined by Turin method. Cation exchange capacity (CEC) was determined by Polemio and Rhoade (1977).

Statistical analysis

Data were analyzed as a randomized complete block design with analysis of variance, using the General Linear Model procedures and the Statistical Analysis System (SAS Institute, Cary, NC, USA, 1990).

Results and Discussion

Turf visual quality

Visual quality ratings of creeping bentgrass in response to fertility treatments were not significantly different from untreated control (Table 2). There is no K or Si effect on turf visual quality.

The result from qualitative responses to Si treatments were less consistent than responses to K. Enhanced turf quality scores due to the treatment could be in response to either the K or Si within the treatment. Information on the role of Si in turf visual quality is limiting. Si could possibly improve turf quality through any of the following physiological responses: 1) improved water relations within leaf tissue due to reduced cuticular water loss, 2) increased photosynthetic capacity due to increased rigidity and erectness of leaf blades, resulting in less shading of leaves and enhanced interception of photosynthetically active radiation (PAR), and 3) increased photosynthetic capacity due to increased chlorophyll content as found in strawberry plants(Wang, 1998).

Christians et al. (1979) found that as the K level increased,

Table 2. Visual quality[z] of creeping bentgrass in response to potassium silicate and potassium sulfate fertilizers.

Treatment	Rates	10 DAT[y]	25 DAT
		Visual quality	
Control	no applied	4.97	5.67
Potassium silicate	3 ml/m^2	4.90	5.50
Potassium silicate	6 ml/m^2	4.97	5.50
Potassium silicate	10 ml/m^2	5.03	5.33
Potassium silicate + Potassium sulfate	3 ml/m^2 + 3 g/m^2	4.90	5.50
Potassium sulfate	3 g/m^2	4.97	5.67
Potassium sulfate	6 g/m^2	4.77	6.00
Potassium sulfate	10 g/m^2	5.00	6.33
LSD (alpha = 0.05)	-	NS	NS

Treatments applied biweekly over three replications in field studies.
[z]Visual quality : 9 to 1(9 = best quality, 6 = lowest acceptable quality, and 1 = poorest quality).
[y]DAT : days after treatment.
[NS]Not significantly different at $P = 0.05$ probability level.

less N was needed for maximum turfgrass quality. They concluded from their study that K may play a more important role in maintenance of turf quality, with the N/K balance of particular importance.

Root length

Root length of creeping bentgrass in response to fertility treatments was increased in comparison to the untreated control (Table 3). Root length of creeping bentgrass in response to potassium silicate at 25 days after treatment was enhanced by 4.7% to 9.9% with increasing application rates from 3 ml/m^2 up to 10 ml/m^2. Gussack (1998) stated that creeping bentgrass shows increased growth in response to Si application.

Juska et al.(1965) reported greater stimulation of root growth than top growth by K additions. Root length of creeping bentgrass in response to potassium sulfate at 25 days after treatment was enhanced 11.4% to 15.7% with increasing K application rates from 3 g/m^2 up to 10 g/m^2.

Shoot density

Shoot density of creeping bentgrass in response to fertility treatments were not different from the untreated control (Table 4). However, the best shoot density of creeping bentgrass in response to potassium sulfate was found at the plot treated with 10 g/m^2 of K application rates at 25 days after treatment. The treatments applied with potassium sulfate had higher shoot density than those applied with potassium silicate. Shoot density of creeping bentgrass in response to potassium sulfate at 25 days after treatment was enhanced 15.4% to 28.8% with increasing K application rates from 3 g/m^2 up to 10 g/m^2.

Dry weight

Dry weight of creeping bentgrass in response to fertility treatments were not different from that of untreated control (Table 5). Gussack (1998) reported the dry weight of creeping bentgrass (*Agrostis palustris* Huds.) cv. 'Penncross' increased in response to Si application at 50 or 100 mg/ L. In contrast, Si application did not appear to improve the dry weight in this experiment.

Growth response of traffic stress.

Turf visual quality in response to 2 time-passing traffic a

Table 3. Root length (cm) of creeping bentgrass in response to potassium silicate and potassium sulfate fertilizers.

Treatment	Rates	25 DAT^z
Control	no applied	11.67 c
Potassium silicate	3 ml/m^2	12.22 bc
Potassium silicate	6 ml/m^2	12.78 ab
Potassium silicate	10 ml/m^2	12.83 ab
Potassium silicate + Potassium sulfate	3 ml/m^2 + 3 g/m^2	13.28 a
Potassium sulfate	3 g/m^2	13.00 ab
Potassium sulfate	6 g/m^2	13.39 a
Potassium sulfate	10 g/m^2	13.50 ab
LSD (alpha = 0.05)	-	0.78**

Treatments were applied biweekly with three replications in field studies.
^{z}DAT : days after treatment.
**Mean separation within column by least significant difference.
^{NS}Not significantly different at the 0.05% probability level.

Table 4. Shoot density (plant/cm^2) of creeping bentgrass in response to potassium silicate and potassium sulfate fertilizers.

Treatment	Rates	25 DAT^z
Control	no applied	17.33
Potassium silicate	3 ml/m^2	18.16
Potassium silicate	6 ml/m^2	18.22
Potassium silicate	10 ml/m^2	18.67
Potassium silicate + Potassium sulfate	3 ml/m^2 + 3 g/m^2	19.78
Potassium sulfate	3 g/m^2	20.00
Potassium sulfate	6 g/m^2	21.56
Potassium sulfate	10 g/m^2	22.33
LSD (alpha = 0.05)	-	NS

Treatments were applied biweekly with three replications in field studies.
^{z}DAT : days after treatment.
^{NS}Not significantly different at P = 0.05 probability level.

Table 5. Dry weight (g) of creeping bentgrass in response to potassium silicate and potassium sulfate fertilizers.

Treatment	Rates	25 DAT[z]
Control	no applied	0.65
Potassium silicate	3 ml/m^2	0.62
Potassium silicate	6 ml/m^2	0.61
Potassium silicate	10 ml/m^2	0.64
Potassium silicate + Potassium sulfate	3 ml/m^2 + 3 g/m^2	0.66
Potassium sulfate	3 g/m^2	0.58
Potassium sulfate	6 g/m^2	0.65
Potassium sulfate	10 g/m^2	0.58
LSD (alpha = 0.05)	-	NS

Treatments applied biweekly over three replications in field studies.
[z]DAT : days after treatment.
[NS]Not significantly different at $P = 0.05$ probability level.

Table 6. Turf visual quality, root length, shoot density, dry weight, and soil hardness at 30 days after wear treatment.

Treatment	Visual quality[z]	Root length (cm)	Shoot density (ea/cm^2)	Dry weight (g)	Soil hardness (kg/cm^2)
Control	4.50 b[y]	11.10	16.7	0.71	3.0 d
2 passes	5.83 a	10.90	17.7	0.72	3.6 c
7 passes	5.00 b	11.07	20.3	0.76	3.8 bc
15 passes	3.83 c	10.60	16.2	0.66	4.0 b
25 passes	2.67 d	10.40	14.8	0.60	4.3 a
LSD (alpha = 0.05)	4.37**	NS	NS	NS	3.77**

Wear treatments applied daily over three replications in field studies for May 11 to June 10, 2001.
[z]Visual quality : 9 to 1(9 = best quality, 6 = lowest acceptable quality, and 1 = poorest quality).
[y]Means within column followed by the same letters are not significantly different according to the Duncan's Multiple Range Test.
**Mean separation within column by least significant difference, $P = 0.01$ probability level.
[NS]Not significantly different at the 0.05% probability level.

day was the highest rather than other trafficking with various passing frequencies. A two time-passing traffic was the best condition in order to measure visual quality. Turf visual quality of 7 time-passing plot was higher than that of non-traffic plot. But, visual quality of the turf treated with a 15 time-passage plot was considerably deteriorated (Table 6). Therefore, it was assumed that certain level of light traffic is beneficial while frequent traffic cause serious adverse effect on visual quality of turfgrass. There is no traffic effect on shoot density, root length and dry weight. Soil surface hardness increased over time in the study. Soil surface hardness increase in this experiment occurred with increasing traffic frequency up to 25 passes.

Effects of silica and potassium application under traffic stress conditions

All of the treatments increased visual quality relative to the control, with significant reduction of wear injury from the treatments. This agreed with findings of Beard (1973), who stated that application of adequate K increased wear tolerance due to greater leaf turgidity.

Under the traffic stress conditions, potassium silicate application increased turf root length considerably in comparison to the control. Shearman and Beard (1975) reported bentgrass wear tolerance improved significantly with annual K additions in the range of 27 to 36 g/m^2.

Shoot density of creeping bentgrass in response to fertility treatments on traffic-treated plots was not different from the untreated control (Table 7). Dry weight of creeping bentgrass by fertility treatments on traffic-treated plots was not different from the untreated control (Table 7).

Chemical analysis of treated soil and leaf tissue

Soil chemical characteristics with depth at 5 cm before fertilization were shown in Table 8. K and available SiO_2 content were very low. Nitrogen, potassium, Ca, Mg, Fe, CEC, and available SiO_2 content was reduced at 10days after potassium silicate (5 ml/m^2) fertilization. However, soil pH and available P content was increased at 10days after potassium silicate (5 ml/m^2) fertilization. EC and organic matter content were not different at 25 days after fertilization.

Leaf tissue concentrations of K and Si were significantly different at 10 days after treatment, but not different at 25 days after treatment. Potassium leaf tissue concentration was

Table 7. Visual quality[z], root length, shoot density, and dry weight of creeping bentgrass in response to potassium silicate or potassium sulfate treatments.

Treatment	Rates	Visual quality[z]	Root length (cm)	Shoot density (ea/cm^2)	Dry weight (g)
Control	no applied	5.17 c[y]	11.22 c	20.22	0.91
Potassium sulfate	3 g/m^2	5.50 b	11.33 c	23.67	0.92
Potassium silicate	3 ml/m^2	5.70 a	12.50 a	20.11	0.81
Potassium silicate + Potassium sulfate	3 ml/m^2 + 3 g/m^2	5.80 a	11.89 b	21.89	1.02
LSD (alpha = 0.05)	-	5.54 **	11.74 **	NS	NS

The plots were trafficked 10 times a day for 30 days.
[z]Visual quality : 9 to 1(9 = best quality, 6 = lowest acceptable quality, and 1 = poorest quality).
[y]Means within column followed by the same letters are not significantly different according to the Duncan's Multiple Range Test.
[**]Mean separation within column by least significant difference, $P = 0.01$ probability level.
[NS]Not significantly different at $P = 0.05$ probability level.

Table 8. Chemical properties of soil in experiment field before and at 10 days after potassium silicate (5 ml/m^2) fertilization.

DAT	pH (1:5)	EC (dS/m)	N (%)	Avail. P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	CEC (me/100g)	OM (%)	Avail. SiO_2 (mg/kg)
0	5.8	0.02	0.021	59.54	23.7	154.3	23.9	146.6	1.32	0.2	7.46
10	5.9	0.02	0.019	75.16	19.1	142.6	20.8	134.6	1.20	0.2	6.47

Table 9. Chemical contents of leaf tissue at 10 and 25 days after treatment.

Treatment	Rates	K (%)		Si (%)	
		10 DAT[z]	25 DAT	10 DAT	25 DAT
Control	no applied	1.69 b	1.92	1.02 b	1.48
Potassium silicate	5 ml/m^2	1.70 b	1.94	1.14 a	1.63
Potassium sulfate	5 g/m^2	1.99 a	1.98	0.99 b	1.51
LSD (alpha = 0.05)	-	0.11*	NS	0.05**	NS

[z]DAT : days after treatment.
[**]Mean separation within column by least significant difference, $P = 0.01$ probability level.
[*]Mean separation within column by least significant difference, $P = 0.05$ probability level.
[NS]Not significantly different at the 0.05% probability level.

greatest in the potassium sulfate treated plots at 10 days after treatment. Silica leaf tissue concentration was greatest in the potassium silicate treated plots at 10 days after treatment.

Waddington et al. (1978) obtained creeping bentgrass tissue K levels as low as 0.58% of K, with some chlorosis occurring, whereas no chlorosis was observed on the date on plots with 1.04% tissue of K.

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규산 및 칼리 시비에 따른 벤트그래스 생육 및 내답압성 반응

김용선 · 김기선

삼성에버랜드(주) 잔디 · 환경연구소, 서울대학교 식물생산과학부

요 약: 본 연구는 규산과 칼리 시용이 골프장 그린용 크리핑 벤트그래스 잔디의 생육과 품질 그리고 내답압성에 미치는 영향을 알아보기 위해 실시되었다. 먼저 규산과 칼리 시용에 따른 잔디반응을 살펴보기 위해서 필드조건에서 잔디품질, 뿌리길이, 잔디밀도와 건물중을 평가하였다. 다음으로 답압빈도에 따른 크리핑 벤트그래스의 잔디생육(뿌리길이, 잔디밀도, 건물중)과 잔디품질 및 토양경도를 조사하였다. 마지막으로 30일간의 답압처리조건에서 규산과 칼리의 내답압성 시비효과를 평가하였다. 규산 및 칼리 처리에 따른 잔디뿌리생육에 있어서 규산을 증가함에 따라 뿌리길이가 증가하였다. 크리핑 벤트그래스의 답압빈도에 따른 잔디품질은 1일 2회 처리구가 가장 우수하였으며, 7회 처리구는 무답압 처리구보다 우수하였다. 그러나 15회 이상 답압 처리구는 잔디품질이 월등히 저하하였다. 30일간의 답압처리시 규산 및 황산칼리의 시비효과는 잔디품질 향상 및 뿌리생육 증진효과가 있었다. 규산과 칼리를 처리하였을 때 잔디품질이 대조구보다 각각 6.38%, 10.25% 상승하였으며 규산과 칼리를 혼용 살포하였을 때 가장 잔디품질이 좋았다. 잔디 뿌리길이는 규산을 살포하였을 때 가장 길었으며 대조구보다 11.4%가 길었다. 따라서 답압이 예상되는 골프장 그린용 벤트그래스에서 잔디의 내답압성 증진을 위해서는 규산과 칼리의 시비가 효과적이었다.

주요어: 크리핑 벤트그래스, 규산, 규소, 답압, 내답압성