Spinach leaf quality and yield is improved by supplemental gypsum application in two soil types in semi-arid South Texas

Donald J. Makus

U. S. Dept. Agriculture, Agricultural Research Service , Weslaco, Texas 78599
Current address: USDA, ARS SJVASC, WMU 9611 S. Riverbend Ave. Perlier, California 93648

Email: donald.makus@ars.usda.gov

ABSTRACT

Light textured soils in semi-arid areas can be deficient in sulfur (S). Spinach (*Spinacia oleracea* L.), a nutrient -rich greens, was used in the present study to evaluate the effects of genotype (smooth vs semi-savoy types), a light and heavier textured soils, and gypsum application rates between 0 and 2000 kg/ha on soil and mineral nutrients, particularly S, and on yield and leaf mineral nutrient concentrations, particularly leaf tissue S. Field-grown spinach, cultivars Lazio and Samish, were direct seeded into raised beds at a site near Weslaco, TX (Lat. 26° 08'). Gypsum (23% Ca and 16.5% S) at rates of 0, 500, 1000, and 2000 kg/ha were applied and incorporated prior to direct seeding in order to determine the effects of added soil sulfur (as gypsum) on soil and leaf mineral nutrients. Results indicated that soil test S was improved up to 2.7 to 5.5 fold 91 days after gypsum application, depending on soil type. Agronomic responses such as plants / m of row, plant marketable weight, marketable leaves, and marketable leaf area were improved linearly with increasing gypsum rates. Yield / ha was significantly improved when 0 kg / ha of gypsum (no applied gypsum) was contrasted to all other gypsum rates. Increased gypsum rates also improved leaf S concentrations (linearly), and leaf chlorophyll and total carotenoids were generally increased with increased gypsum application. Results suggest that levels of spinach leaf tissue S and the carotenoid pool can be increased in relatively low S soils with the application of gypsum. Additional benefits include improved plant marketable quality, greener and larger spinach leaves.

Additional Index Words: Spinacia oleracea, low sulfur soils, sulfur fertility

Spinach is an excellent source of fiber, mineral nutrients and vitamins for the human diet (U. S. Dept. Agriculture, 2011) and human health compounds containing sulfur (Jez and Fukagawa, 2008). Glutathione levels, for example, were found to be ranked 9th in spinach tissues (dry wt. basis) compared to 30 other vegetables tested; cysteine levels in spinach ranked 10th (Mills, et al., 1997). Plants provided an abundance of sulphate have the capacity to store excess inorganic S into the organic S pool in the form of glucosinolates, glutathione, cysteine, and other sulfur-containing health compounds (Marschner, 1995). Other important sulfur-containing compounds include the vitamins biotin and thiamine (Vit B1) . Spinach plants deprived of sulphate have reduced nitrogen up-take (via nitrate reductase) and subsequently reduced protein synthesis (Prosser, et al., 2001). Nitrogen is necessary for chlorophyll synthesis and sulfur (sulfolipids) for thylakoid membrane integrity (Hell, et al., 2010). Because carotenoids function as electron scavengers in photosystem II, they correlate with leaf greenness (chlorophyll concentration) in several vegetables, including spinach (Reif, et al., 2013). Carotenoids, such as lutein and B-carotene, were increased in winter-grown spinach as much as 40% by the application of S, as K2SO4 (Reif, et al., 2012).

Soils used in vegetable production in south Texas vary greatly in chemical nutrients and physical properties. The range in soil sulfur can be 20 fold, from ca. 10 to 200 kg/ha (Makus and Lester, 2002). Annual rain-fall and cultural practices all can affect soil sulfur concentrations in soils in addition to plant productivity. Semi-arid climates generally receive S as SO42- aerosols in the form of precipitation (Franzen and

Grant, 2008), which has been declining in south Texas and elsewhere since 1981 (Nilles and Conley, 2001; Lehmann, et al., 2007). Sulfur deficiencies in crops have been reported worldwide, especially in Western European countries (Scherer, 2009).

Gypsum, as calcium sulfate, is an inexpensive and fairly rapid paired-ion sulfur delivery system, which can provide sulfur and calcium to soils depleted in these nutrients (Hickman and Whitney, 2004). Gypsum can also improve soil properties by reducing soil compaction and salinity, and improving water infiltration and storage (Baumhardt, et al., 1992; Hamza and Anderson, 2003).

The objective of the present study was to evaluate the effects of cultivar type (flat vs. semi-savoy leaf types), two soils (light textured vs. heavy textured), and gypsum rate (0, 500, 1000 and 2000 kg/ha) on soil properties and mineral nutrients, particularly S, leaf greenness, and on spinach yield and leaf mineral nutrient concentrations, particularly tissue S.

MATERIALS AND METHODS

Two distinct soils were used. The light textured soil, Hebbronville, is composed of 47% sand, 42% silt and 11% clay. Nutrient levels, with the exception of Fe, test lower than the heavier Raymondville soil, which has a soil texture of 20% sand, 34% silt, and 46% clay. The soil S levels were 20 fold lower in the lighter textured Hebbronville soil (Makus and Lester, 2002).

Two spinach cultivars were used. 'Lazio' is generally grown for fresh markets and 'Samish' for processing. Seeds 'Lazio' and 'Samish' were planted with a Stanhay Model S870 planter at a rate of 6.6 kg/ha into both soil types on 6 Nov. and 10 Nov. 2009, respectively. Three days prior to seeding, gypsum (23 % Ca and 16.5% S; 200 mesh) was broadcast at rates of 0, 500, 1000, and 2000 kg/ha, incorporated and bedded. Seeding was on raised beds approx. 35 cm wide with double rows, and a bi-wall trickle tape centered on the bed surface to supply supplemental irrigation water. The split-split plot experimental row lengths were 6.4 m long and 2.03 m wide. Each bed was on 1 m centers. Soil samples (0-15 cm) were taken on 1 Feb. (reps 1 and 2) and on 2 Feb. 2010 (reps 3 and 3) 91 days after gypsum application.

Rainfall was supplemented by surface trickle irrigation to planted beds when soil moisture was depleted to approximately -40 kPa at 15 cm. Irrigation water was provided by a reverse osmosis system which delivered and average 0.24 mS/m water throughout the experiment. A total of 50 kg N×ha-1 (as 20-20-20; Scotts, Marysville, OH) were added by trickle irrigation at the 20 kg rate on 14 Dec. and 28 Dec. and then at 10 Kg N / ha on 18 Jan. 2010. Ammonium nitrate was the N form. Temperature (°C) and solar radiation (400 – 1100 nm, in kW×m-2), UV A+B (280 – 400 nm), were recorded hourly (CR-10X , Campbell Scientific, Logen, UT) with a thermister (Vasiala HMP-35), a pyranometer (LI-200SA; Li-Cor Instruments, Lincoln, NE), a UV sensor (PMA1107-WP; Solar Light, Glenside, PA), and a tipping bucket rain gauge, respectively, by a weather station located within 100 m of the experimental plots.

Stand counts were made on 15 Dec. 2009. Leaf samples for nutrient analysis were collected from 20 plants per plot (6-8th leaf from the base of the plant) on 26 Jan. 2010. Both cultivars were harvested for yield (1 linear meter of row) on 27 Jan.; plant subsamples for yield components were made on 28 Jan. (reps 1 and 2) and 29 Jan. (reps 3 and 4). Yield attributes consisted of biomass (in kg) / ha, plant number per meter, yield per ha (t), marketable plant weight (g), marketable leaf number per plant, total leaf area per plant (cm-2) and average leaf area (cm-2). A LI-1800 (Li-Cor Instruments) was used to determine leaf area. The 26 Jan. leaf sub-samples were frozen, freeze-dried, and passed through a 40 mesh (0.36 mm2) screen and stored at -20 ºC until analysis. Leaf mineral nutrients (K, P, Ca, Mg, S, Na, Fe, Mn, Zn, B, and Cu) were determined, after HNO3 digest, by ICP spectroscopy (Plank, 1992) (Midwest Laboratories, Omaha, NE). Leaf total-N was determined by dry combustion (Elementar Vario Max, Mt. Laurel, NJ).

The experimental design was a split-split plot, where soil type was the main plot, cultivars were subplots, and gypsum rates were sub-subplots in a randomized complete block design (N = 4). Gypsum rate was fitted to a polynomial regression model to determine any linear, quadratic, or cubic relationships. For several attributes, single degree contrasts were made between 0 kg gypsum / ha and all other rates. Differences between response means were tested using the PDIFF option of the LSMEANS statement of PROC GLM of SAS Version 9.1 (SAS Institute, Cary, N.C.).

RESULTS AND DISCUSSION

Environment. Rainfall of 179 mm was supplemented with 52 mm of water by surface trickle irrigation during the 78 to 82 day growing season. Samish used 2.1% less irrigation water than Lazio and Raymondville soil had 4.3% less water applied than the Hebbronville treatments. Average mean season temperature was 17.7 °C and cumulative total solar radiation over the 78 to 82 day growing period (sowing to final harvest) averaged 804 MJ/m2, 13.4 % of which was in the UV A+B range.

Influence of soils. On 15 Dec., plant stand 25 DAP 'Lazio' and 29 DAP 'Samish' was higher in plants sown in Raymondville soil (P=0.046; data not shown). At harvest, these differences were not apparent (Table 1.) Plant attributes, which included yield / ha were lower in cultivars grown in the Raymondville (heavier) soil. Generally heavier soils improve plant yields over lighter soils, but the Raymondville site experienced 4 days of water pooling in the furrows after a significant rain event. These anoxic soil conditions may have impacted yields.

Both Plant leaf chlorophyll and total carotenoid levels were higher in cultivars grown in Hebbronville soil, but these observations were confounded with significant soil by cultivar and soil by cultivar by gypsum interactions (Table 2.). Overall, total carotenoid levels were 9% higher in Hebbronville-grown spinach than spinach grown in Raymondville soil.

Soil type influenced all leaf nutrients tested except P, Fe, and Zn. Total N, Mg, Na, and Cu were higher in cultivars grown in Hebbronville soil, whereas K, Ca, Mn, and B were higher in cultivars grown in Raymondville soil (Table 3.). Ninety-one days after gypsum application, Raymondville soil tested higher in Mg, Fe, and B and had higher K:Mg and Ca base saturation (%) than did the Hebbronville soil, but soil test Zn, Ca:Mg, and Mg base saturation (%) were lower.

Influence of cultivars. Early season stand was slightly higher in 'Samish' (P=0.04) and also higher at harvest than was 'Lasio'. Not unexpectedly, 'Samish', a processing type, was higher yielding at harvest, but had fewer leaves per plant and, probably because of the savoy nature of the leaf, leaf area expressed on a total plant basis, but also on an individual leaf basis, were lower in 'Samish' compared to 'Lazio' (Table 1.).

'Samish' was higher in both chlorophyll and total carotenoids (dry wt. basis), regardless of the soil grown in, compared to 'Lazio' (Table 2.). Cultivars differed in all leaf nutrients tested except Na (Table 3.). Soil by cultivar interactions occurred for Total N, K, Na, and Fe; otherwise leaf Ca, Mg, Zn, and Cu were higher in 'Samish' and P, Mn, and B were higher in 'Lazio'. 'Samish' leaves were higher in S than were 'Lazio' leaves in both soils (Table 4.).

Influence of gypsum rate. Gypsum applications improved plant number per m at harvest. Yield was increased quadratically (Q) and, based on sub-sampled plants, marketable plant weight, leaves, total plant leaf area, and leaf size (cm2) was increased linearly (L) by

Table 1. Agronomic responses of two spinach cultivars planted in light (Hebbronville) and heavy (Raymondville) textured soils and four rates of gypsum: 0, 500, 1000 and 2000 kg / ac. Mkt = marketable.

			Based on three sub-sampled plants			
Effects	Plant No.	Yield/ha	Mkt Plant weight	Mkt leaves	Mkt plant leaf area	Mkt leaf Area
	(per m)	(t)	(g)	(No.)	(cm^2)	(cm^2)
Soil	NS[z]	0.016	0.009	NS	0.006	0.009
Gypsum	0.04	NS	0.0005	0.043	0.0005	0.0006
Soil X gypsum	NS	NS	NS	NS	NS	NS
Cultivar	<0.0001	0.042	NS	<0.0001	0.003	NS
Soil X cultivar	NS	NS	NS	0.010	NS	NS
Gypsum X cultivar	0.023	NS	NS	NS	NS	NS
Soil X gypsum X cultivar	NS	NS	NS	NS	NS	NS
Soil:						
Hebbronville	23.3 a	14.6 a	80.8 a	15.5 a	1302 a	83.3 a
Raymondville	23.0 a	11.2 b	62.5 b	14.8 a	980 b	65.6 b
Cultivar:						
Lazio	21.7 b	12.5 b	71.3 a	16.1 a	1229 a	75.4 a
Samish	24.6 a	13.3 a	72.0 a	14.3 b	1054 b	73.4 b
Gypsum:						
0 kg / ha (1)	21.6 b	11.8 a	56.8 b	14.4 b	929 b	64.1 c
500 kg / ha (2)	23.1 ab	13.2 a	64.9 b	14.7 b	1054 b	71.7 bc
1000 kg / ha (3)	23.7 a	13.8 a	78.4 a	15.8 a	1245 a	78.3 ab
2000 kg / ha (4)	24.2 a	13.0 a	86.5 a	15.8 a	1338 a	83.7 a
Polynomial fit:	L**	Q^{07}	L**	L**	L**	L**
Contrast: 1 vs. 'others'	0.002	0.001	<0.0001	0.025	<0.0001	<0.0001

[z] NS = not significant. Where significant ($P \leq 0.05$), probabilities of a > 'F' value are shown. Aphameric mean separations shown at $P = 0.05$. L and Q = linear and quadratic, respectively.

Table 2. Interactive effects between gypsum addition, soil type and cultivar on spinach leaf pigments grown during winter 2009 – 2010.

Effects	Total chlorophyll (mg/g)	Chlorophyll a:b ratio	Total carotenoids (mg/g)
		Hebbronville	
Gypsum level:	NS	NS	NS
Cultivar:			
Lazio (L)	9.3 b	2.07 a	2.30 b
Samish (S)	11.4 a	1.85 b	2.65 a
Interaction:			
L - 0 kg/ha rate	9.3 c	2.05 a	2.30 d
L - 500 kg/ha rate	8.9 c	2.06 a	2.21 d
L - 1000 kg/ha rate	9.3 c	2.06 a	2.32 d
L - 2000 kg/ha rate	9.6 c	2.09 a	2.40 cd
S - 0 kg/ha rate	10.8 b	1.90 b	2.55 bc
S - 500 kg/ha rate	12,2 a	1,79 c	2.81 a
S - 1000 kg/ha rate	11.1 b	1.88 b	2.59 bc
S - 2000 kg/ha rate	11.3 ab	1.84 bc	2.64 ab
Polynomial fit:			
'Lazio'	—	L^{**}	$L^{0.11}$
'Samish'	Q^{*}	—	—
	Raymondville		
Gypsum level:	NS	NS	NS
Cultivar:			
Lazio (L)	8.4 b	2.07 a	2.18 b
Samish (S)	9.4 a	1.94 b	2.37 a
Interaction:			
L - 0 kg/ha rate	7.6 c	2.06 a	1.96 c
L - 500 kg/ha rate	8.6 b	2.08 a	2.20 b
L - 1000 kg/ha rate	8.7 ab	2.06 a	2.27 a
L - 2000 kg/ha rate	8.7 ab	2.09 a	2.28 a
S - 0 kg/ha rate	9.3 ab	1.94 bc	2.38 a
S - 500 kg/ha rate	9.6 a	1.96 b	2.40 a
S - 1000 kg/ha rate	9.1 ab	1.95 bc	2.29 ab
S - 2000 kg/ha rate	9.5 ab	1.90c	2.40 a
Polynomial fit:			
'Lazio'	L^{*}, Q^{*}	—	L^{*}, Q^{*}
'Samish'	—	Q^{*}	—

[Z] Aphameric mean separations shown at $P = 0.05$. L and Q = linear and quadratic, respectively.

increasing gypsum application rates. The contrast between no gypsum and the other rates of gypsum applied was highly significant in all the aforementioned agronomic responses (Table 1.). Ammonium sulfate has been successfully used to improve both yield and greenness when applied to winter-grown spinach planted into a Roxanna fine sandy loam (Wells, et al., 1992).

Leaf chlorophyll and total carotenoid levels were influenced by cultivar, soil type, and gypsum rate and the response to gypsum application was not consistent, but generally increased with application rate (Table 2.). Reif, et al. (2013) suggested that "the strong correlations between carotenoids and chlorophylls indicate that the depth of green leaf coloration could help estimate the approximate carotenoids contents within a botanical family".

Table 4. Effect of soil type, spinach cultivar and gypsum rate on leaf total sulfur concentration (% dry wt. basis). There were no cultivar X gypsum interactions.

Main effects		Sulfur	
		Soil type	
		Hebbronville	*Raymondville*
Cultivar:			
'Lazio'		0.458 b	0.471 b
'Samish'		0.539 a	0.521 a
Prob. > 'F' value		<0.01	<0.01
Gypsum rate:			
0 kg / ha	(1)	0.474 b	0.456 b
500 kg / ha	(2)	0.502 ab	0.499 ab
1000 kg / ha	(3)	0.489 b	0.482 b
2000 kg / ha	(4)	0.531 a	0.546 a
Prob. > 'F' value		0.0149	0.0366
Contrast:			
1 vs. others		0.012	0.0069
Polynomial fit:			
'Lazio'		$L^{0.17}$	L*
'Samish'		L**, C*	$L^{0.06}$

[Z] * and ** = significant at P=0.05 and P=0.01, respectively. Aphameric mean separations shown at $P = 0.05$. L and C = linear and cubic, respectively.

Leaf nutrients, with the exception of S, were not affected by gypsum rates, nor were there gypsum by soil, gypsum by cultivar, or soil by cultivar by gypsum interactions (Table 3.). Total leaf S was increased

Table 3. Experiment-wise main effects and their interactions of leaf mineral nurients as affected by soil type, cultivar and gypsum level. Cultivar differences separated by soil type. Sulfur responses appear in Table 4.

Effects	Total N	K	Ca	Mg	P	Na	Fe	Mn	Zn	B	Cu
	%						ppm				
Soil type	<0.0001[Z]	0.024	0.008	0.002	NS	<0.0001	NS	0.0002	NS	0.023	0.0004
Cultivar	0.0005	0.052	<0.0001	0.0009	0.002	NS	<0.0001	0.005	<0.0001	<0.0001	<0.0001
Gypsum	NS	0.061	NS	NS	NS	NS	NS	0.026	NS	0.07	NS
Soil X cultivar	0.012	0.013	NS	NS	NS	0.004	0.03	NS	NS	NS	NS
Soil X gypsum	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cultivar X gypsum	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Soil X Cv X gypsum	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
						Hebbronville					
Cultivar:											
Lazio	4.13 b	7.01 a	1.19 b	0.90 b	0.59 a	1.69 b	114 b	73 a	36 b	36 a	8.5 b
Samish	4.50 a	6.49 b	1.44 a	0.99 a	0.52 b	1.89 a	145 a	66 b	52 a	32 b	9.8 a
Prob. > 'F' value	0.002	0.016	0.001	0.021	0.006	0.039	<0.0001	0.003	<0.0001	<0.0001	0.002
						Raymondville					
Cultivar:											
Lazio	3.30 a	7.70 a	1.46 b	0.63 b	0.58 a	0.34 a	119 b	123 a	28 b	41 a	7.2 b
Samish	3.37 a	7.78 a	1.63 a	0.68 a	0.55 a	0.25 b	136 a	115 a	44 a	36 b	8.2 a
Prob. > 'F' value	NS	NS	0.006	0.007	NS	0.010	0.006	0.09	<0.0001	0.0003	0.003

[Z] Probability of a > 'F' value. NS = not significant. LSMEANS separation at $P = 0.05$.

(generally linearly) in both cultivars by increased gypsum application. Contrasts of no gypsum to all other rates applied were highly significant for leaf S.

When soil nutrients were analyzed over both soil types, increasing gypsum application rates linearly increased soil test S, Mn, K:Mg ratio, Ca base saturation (%) and decreased soil pH, Mg, Zn, Cu, and Mg base saturation (%) (Table 5.). The soil S increases between 0 and 2000 kg gypsum / ha rates were 2.7 and 5.5 fold in Raymondville and Hebbronville soils, respectively.

Table 5. Effect of gypsum on soil pH and nutrients 88 days after application to Hebbronville and Raymondville soils.[z]

Main Effect	pH	Mg	S	Zn	Fe	Mn	Cu	B	Ca:Mg ratio	K:Mg ratio	Base saturation Mg	Ca
		ppm									%	
Soil type:												
Heb	8.19	143	44.8	1.09	4.25	2.44	1.19	0.68	16.4	2.36	8.7	85.0
Ray	8.12	321	33.7	0.94	9.69	3.00	1.09	1.10	11.8	1.83	11.6	82.0
Prob. > 'F' value	0.09	0.0001	NS	0.04	0.007	NS	NS	0.0005	0.0004	0.004	0.001	0.0004
Gypsum rate:												
0 kg/ha	8.19	248	19.6	1.10	6.88	2.50	1.34	0.91	12.9	1.95	10.9	82.7
500 kg/ha	8.16	234	26.5	1.08	6.75	2.50	1.11	0.95	13.8	2.07	10.3	83.3
1000 kg/ha	8.19	226	33.0	0.94	6.50	2.88	1.08	0.96	14.4	2.13	9.9	83.7
2000 kg/ha	8.10	220	77.9	0.94	7.75	3.00	1.02	0.94	15.5	2.26	9.5	84.2
Prob. > 'F' value	0.004	0.01	0.02	0.07	NS	0.05	0.10	NS	0.002	0.008	0.007	0.01
Polynomial fit:	L**	L**	L**	L**	--	L*	L*	--	L**	L**	L**	L**
Hebbronville												
Gypsum rate:												
0 kg/ha	8.22	162	17.8	1.22	4.75	2.00	1.45	0.62	14.5	2.14	9.8	83.8
500 kg/ha	8.20	146	30.2	1.10	4.25	2.25	1.15	0.68	15.7	2.31	9.0	84.7
1000 kg/ha	8.25	136	32.8	1.00	4.00	2.75	1.10	0.75	16.8	2.37	8.5	85.4
2000 kg/ha	8.10	127	98.5	1.02	4.00	2.75	1.05	0.68	18.7	2.66	7.7	86.0
Prob. > 'F' value	0.02	0.11	NS	NS	NS	0.12	0.08	NS	0.02	0.03	0.06	0.08
Polynomial fit:	L**	L**	L*	--	--	L*	--	Q*	L**	L**	L**	L**
Raymondville												
Gypsum rate:												
0 kg/ha	8.15	334	21.5	0.98	9.00	3.00	1.22	1.20	11.4	1.75	12.0	81.6
500 kg/ha	8.12	322	22.8	1.05	9.25	2.75	1.08	1.22	11.8	1.82	11.6	81.9
1000 kg/ha	8.12	316	33.2	0.87	9.00	3.00	1.05	1.18	12.0	1.88	11.4	82.0
2000 kg/ha	8.10	313	57.2	0.85	11.50	3.25	1.00	1.20	12.2	1.86	11.3	82.3
Prob. > 'F' value	NS	NS	0.007	NS	0.10	NS	NS	NS	0.11	NS	0.10	0.16
Polynomial fit:	L*	L*	L**	L^{08}	L*	--	L^{07}	--	L*	--	L*	L*

[z] NS, *, ** = not significant, significant at P=0.05 and P=0.01, respectively. L and Q = linear and quadratic, respectively.

One reason for including and documenting field experiment light data in the UV A and B range is the recent awareness that this area of the visible light spectrum has on improving vitamins such as C, β-carotene (pro-Vitamin A), lutein, and the anti-oxidative capacity in spinach, particularly glasshouse-grown spinach (Heuberger, et al. 2004; Schirrmacher, et al., 2007). Other environmental constraints, such as latitude, photoperiod, minimum / maximum day temperatures, and cumulative incident light, can have a significant effect on spinach vitamins (Lester, et al., 2013.)

CONCLUSIONS

Both light and heavy-textured soils respond to supplemental S application with gypsum; and both cultivars evaluated behaved similarly in their response to gypsum. By improving low or deficient S soils with gypsum, benefits to spinach production systems can include improved yield potential, greener leaves, leaves with improved bio-constituent pools of total carotenoids and sulphur, and plants with improved market quality attributes, which include higher individual plant weights and plants with larger leaves.

ACKNOWLEDGMENTS

The skillful assistance of C. Salinas and V. Valladares are greatly appreciated.

Received for publication on November 4, 2013. Mention of trademark, proprietary product, or vendor does not constitute a guarantee by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

LITERATURE CITED

Baumhardt, RL, C Wendt and J Moore. 1992. Infiltration in response to water quality, tillage, and gypsum. Soil Sci. Soc. Amer. J. 56:261-166.

Franzen, D and CA Grant. 2008. Sulfur Response Based on Crop, Source and Landscape Position. pp.105- 116. In: (Jez, J, ed.) Sulfur: A missing link between soils, crops, and nutrition. ASA Agronomy Monograph 50, Madison, WI.

Hamza, MA and WK Anderson. 2003. Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. Aust. J. Agric. Res. 54:273-282.

Hell, R, Wirtz, M and Khan MS. 2010. Cellular biology of sulfur and its functions in plants. Plant Cell

Monographs. 17:243-279.

Heuberger, H, Praeger, U, Georgi, M, Schirrmacher, G, Grassmann, J, Schnitzler, W. H. 2004. Precision stressing by UV-B radiation to improve quality of spinach under protected cultivation. Acta Hort. 659: 201−206.

Hickman, JS and DA Whitney. 2004. Soil Conditioners. North Central Regional Ext. Pub. 265. 4 pp.

Jez, JM and NK Fukagawa. 2008. Plant sulfur compounds and human health. In: (Jez, J, ed.)Sulfur: A missing link between soils, crops, and nutrition. ASA Agronomy Monograph 50, Madison, WI.

Lehmann, CMB, VC Bowersox, RS Larson and SM Larson. 2007. Monitoring long-term trends in sulfate and ammonium in US precipitation: Results from the National Atmospheric Deposition Program/National Trends Network. Water Air Soil Pollut: Focus 7:59-66.

Lester, GE, Makus, DJ, Hodges, DM, and Jifon, JJ. 2013.Summer (Subarctic) versus winter (Subtropic) production affects spinach (*Spinacia oleracea* L.) leaf bionutrients: Vitamins (C, E, folate, K1, provitamin A), lutein, phenolics, and antioxidants. J. Agric. Food Chem. 61:7019-7027.

Makus, DJ and Lester, GE. 2002. Effect of soil type, light intensity, and cultivar on leaf nutrients in mustard greens. Subtropical Plant Science. 54:23-28.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. pp 255-265. 2nd Ed. Academic Press. San Diego, CA 92101.

Mills, BJ, CT Stinson, MC Liu and CA Lang. 1997. Glutathione and cyst(e)ine profiles of vegetables using high performance liquid chromatography with dual electrochemical detection. J. Fd Comp. and Anal. 10:90-101.

Nilles, MA and BE Conley. 2001. Changes in the chemistry of precipitation in the United States, 1981-1998. Water, Air, and Soil Pollut. 130:409-414.

Plank, CO. 1992. Plant analysis reference procedures for the Southern Region of the United States. So. Coop. Ser. Bull. 368. Ga. Agri. Exp. Sta., Athens.

Prosser, IM, Purves, JV, Saker, LR and Clarkson, DT. 2001. Rapid disruption of nitrogen metabolism and nitrate transport in spinach plants deprived of sulphate. J. Experi. Bot. 52(354):113-121.

Reif, C, Arrigoni, E, Neuweiler, R, Baumgartner, D, Nystrom, L, and Hurrell, RF. 2012. Effect of sulfur and nitrogen fertilization on the content of nutritionally relevant carotenoids in spinach (*Spinacia oleracea*). J. Agric. Food Chem. 60:5819-5824.

Reif, C, Arrigoni, E, Scharer, H, Nystrom, L, and Hurrell, FR. 2013. Carotenoid data base of commonly eaten Swiss vegetables and their estimated contribution to carotenoids intake. J. Food Comp. and Analysis. 29:64-72.

Scherer, HW. 2009. Sulfur in soils. J. Plant Nutr. Soil Sci. 172:326-335.

Schirrmacher, G, Schnitzler, WH and Grassmann, J. 2007. Influence of UV-light on the antioxidative capacity of extracts from *Spinacia oleracea* L. and *Gynura bicolor* (Willd.) DC. Acta Hort. 747:357-364.

U.S. Department of Agriculture. 2011. Agricultural Research Service, USDA National Nutrient Database for Standard Reference, Release 24, Nutrient Data Laboratory, http://www.ars.usda.govSP2UserFiles/Place/12354500DataSR24sr2411.pdf.

Wellburn, AR and Lichtenthaler, H. 1984 Formulae and program to determine total carotenoids and chlorophyll a and b of leaf extracts in different solvents, p. 9-12 In: (C. Sybesma, ed.) Advances in photosynthesis research. Vol. 2, Kluwer. The Hague.

Wells, BR, Morelock, TE and Motes, DR. 1992. Response of 'Fall Green' spinach to rates of nitrogen and sulfur fertilizer. Ark. Agric. Expt. Sta. Res. Series. 421, pp 115-117. [See also Ark. Far Res. 38(5):8.]

.

Tribute to Dr. Donald Joel Makus (1944 – 2014)

On Thursday May 26, 2014, Don Makus passed away suddenly in California. For many years, he was an active member of the Society, serving on its board in various capacities including the President in 2004. He was also a regular contributor to the journal, and the current volume contains his 17th and last paper.

Donald Joel Makus was born to Frank and Helen Makus in Chicopee MA on June 11, 1944.

Don graduated from high school in Clifton NJ in 1962. He finished his bachelor's degree at Delaware Valley College in Doylestown PA. He earned a Master of Science degree in Horticulture in 1966 from Michigan State University. He then served two years in the US Army assigned to duties in Germany. Following his return, Don earned his Ph.D. degree in Plant Physiology in 1972 at N. Carolina State University.

After his Ph.D., Don accepted a position as Assistant Professor at the University of Idaho in Moscow ID. There he met Judy Derr. The couple was married on July 6, 1979. In January 1981, Don and Judy moved to Booneville AR, where Don worked for the US Department of Agriculture (USDA). In 1995 Don was transferred to the Rio Grande Valley where he worked at the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center in Weslaco. When this center was closed in 2012, Don transferred to the Agricultural Research Center in Parlier CA in 2012.

While doing research for the USDA in Arkansas, Don determined ways to improve production of white asparagus and blueberries. In Texas he studied production of various vegetables and cotton. At Parlier he was working on improving the nutritional value of pomegranates. Don loved his research and almost all topics related to growing and eating healthy food. He could talk knowledgeably about a vast array of these topics.

He is survived by his wife Judy and their three children – Michelle, Joel and Dennis. The Subtropical Agriculture and Environments Society expresses its condolences to the Makus family. He was a much loved and respected colleague and he will be greatly missed.