ASCORBIC ACID AND GLYCOALKALOID CONTENT OF ATLANTIC AND SUPERIOR POTATO TUBERS AS AFFECTED BY SUPPLEMENTAL IRRIGATION AND SOIL AMENDMENTS

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Abstract

Atlantic and Superior potato (*Solanum tuberosum* L.) tubers were collected at harvest from two field experiments in Maine during 1993 and 1994. Tubers were analyzed for ascorbic acid (ASC) and total glycoalkaloid (TGA) concentration within one month of harvest and after 4 to 5 months of storage at 10 C. ASC concentration was significantly higher in Superior than Atlantic at harvest and after storage. TGA concentration was consistently higher in Atlantic than Superior. Irrigation tended to slightly reduce ASC and increase α-solanine concentrations when applied too late in the season for yield benefits. Storage decreased tuber ASC content, but no specific pattern was observed for TGA changes. Soil amendment programs using compost and manure (22 Mg ha^{-1} potato compost + 45 Mg ha^{-1} manure) did not dramatically affect tuber ASC or TGA concentrations. ASC content of the tubers declined dramatically in storage, but no consistent pattern was found for tuber TGA changes. We conclude that genotype, growing environment, and storage time play much stronger roles in determining tuber ASC and TGA levels than do irrigation and soil management programs. We observed a negative relationship between the average tuber size of the assayed samples and ASC concentration in fall samplings; however, this relationship was not observed from storage. Average tuber size and TGA content generally displayed a negative relationship.

Compendio

Se recolectaron en Maine tubérculos de las variedades Atlantic y Superior (*Solanum tuberosum* L.) a la cosecha en dos experimentos de campo durante 1993 y 1994. Los tubérculos fueron analizados para determinar la concentración de ácido ascórbico (CAA) y el total de glicoalcaloides (TGA) a un mes

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de la cosecha y después de 4 a 5 meses de almacenamiento a 10 C. La CAA fue significativamente mayor en la variedad Superior que en Atlantic tanto a la cosecha como después del almacenamiento. La concentración de TGA fue consistentemente mayor en Atlantic que en Superior. La irrigación tendió a reducir ligeramente la CAA y a aumentar las concentración de solanina cuando fue aplicada demasiado tarde en la temporada para beneficiar el rendimiento. El almacenamiento disminuyó el contenido de ácido ascórbico de los tubérculos; sin embargo, no se observó ningún patrón específico para los cambios de TGA. Los programas de enmiendas de suelo empleando abono y estiércol (22 t ha^{-1} de abono de papa + 45 t ha^{-1} de estiércol) no afectaron en forma dramática las concentraciones de AA o TGA; sin embargo, no se encontró ningún patrón consistente para los cambios de TGA en los tubérculos. Concluímos que el genotipo, el ambiente de crecimiento y el tiempo de almacenamiento cumplen papeles más decisivos en la determinación de la CAA y TGA de los tubérculos que los programas de irrigación y manejo de suelos. Observamos una relación negativa entre el promedio del tamaño del tubérculo de las muestras analizadas y la concentración de AA en las muestras de otoño; sin embargo, no se observó esta relación en el almacenamiento. El promedio del tamaño del tubérculo y el contenido de TGA mostraron por lo general una relación negativa.

Introduction

Among their many positive nutritional attributes, potatoes are an excellent dietary source of ascorbic acid (ASC) or vitamin C (Kolasa, 1993; Storey and Davies, 1990). The ASC content of potato tubers differs dramatically among varieties (Hyde, 1962; Mullin *et al.*, 1991; Shekhar *et al.*, 1978). ASC content tends to increase during tuber growth, reaches a peak, and then declines if harvest is delayed (Augustin *et al.*, 1975; Mazza *et al.*, 1983; Perkins, 1993; Shekhar *et al.*, 1978). ASC concentration typically ranges from 15 to 25 mg 100 g^{-1} fresh weight in freshly harvested tubers (Hyde, 1962; Storey and Davies, 1990) and typically declines dramatically with time during storage (Augustin, 1975; Augustin *et al.*, 1978; Perkins, 1993; Shekhar *et al.*, 1978). In addition to cultivar and storage time, cultural practices and growing location can have strong effects on tuber ASC concentration, possibly by affecting tuber maturity (Hyde, 1962; Augustin *et al.*, 1978; Shekhar *et al.*, 1978; Mullin *et al.*, 1991). Lending support to this hypothesis, a study by Murphy *et al.* (1945) indicated that ASC content of tubers tended to be higher during warm, dry seasons than cool, wet seasons (*e.g.* 28.4 vs. 14.1 mg 100 g^{-1} fresh weight).

Glycoalkaloids, which are mainly present as α-solanine and α-chaconine in the tubers of most commercial potato cultivars, are of potential concern because high concentrations can have adverse health effects and can be detrimental to potato flavor (Maga, 1980; Sinden *et al.*, 1984). Potato tubers with total glycoalkaloid (TGA) levels above 20 mg 100 g^{-1} fresh weight are considered undesirable for human consumption because of their bitterness and toxicity (Sinden *et al.*, 1984; Storey and Davies, 1990); however, the normal TGA concentration of potato tubers is typically low, usually ranging from 1 to 15 mg 100 g^{-1} fresh weight (Sinden *et al.*, 1984).

Major differences in tuber TGA concentration exist among varieties (Sinden *et al.*, 1984; Sinden and Webb, 1972; Cronk *et al.*, 1974). Exposure to light is a major factor affecting tuber TGA levels (Gull and Isenberg, 1960; Wolf and Duggar, 1946); however, other factors that affect growth and maturity can also affect tuber TGA concentration (Sinden and Webb, 1972; Sinden *et al.*, 1984). Climate, altitude, soil type and moisture, fertilization, air pollution, time of harvest, vine-killing, pesticides, and tuber greening all reportedly affect tuber TGA levels at harvest (Hutchinson and Hilton, 1955; Sinden and Webb, 1972; Maga, 1980; Sinden *et al.*, 1984). Environmental effects on TGA concentrations can be quite large. For example, Russet Burbank tubers ranged from 3 to 39 mg TGA 100 g^{-1} fresh weight among environments (Sinden and Webb, 1972) and from 3.8 to 18.6 mg 100 g^{-1} fresh weight in a study by Carmen *et al.* (1986). Tuber TGA levels can decrease (Linnemann *et al.*, 1985; Perkins, 1993), remain constant (Perkins, 1993), increase several fold (Love *et al.*, 1994), or increase slightly over time in storage (Cronk *et al.*, 1974; Perkins, 1993).

Soil amendments, such as compost and manure, can improve soil fertility and physical properties, including soil structure and water holding capacity (Alford *et al.*, 1996). Potato growers in the northeastern U.S. have been increasingly interested in management practices which reduce agricultural chemical usage and also those which might increase productivity and quality of the crop. Little information is available regarding how soil amendment use might affect tuber quality, including ASC and TGA concentrations. In the few published reports available, Mondy *et al.* (1984) reported that sewage sludge, applied as a soil amendment, had no effect on tuber TGA concentration, while Lee *et al.* (1980) reported an increase in tuber ASC content from sludge applications. Whether the latter effect was due to changes in nutrient supply or soil physical properties is unknown. This research was conducted to determine if soil amendment application and supplemental irrigation affect tuber nutritional quality, specifically tuber ASC and TGA concentrations of two cultivars that are commonly grown in the eastern U.S.

Materials and Methods

Cultural Practices and Site Characteristics—The samples collected for tuber quality analyses were from two field experiments conducted during 1993 and 1994 on the University of Maine's Aroostook Research Farm in Presque Isle, Maine. The two field experiments were: (1) the University of Maine potato ecosystem study; and (2) a study of irrigation and soil management practices. Experimental details for the potato ecosystem study are presented by Alford *et al.* (1996). The potato ecosystem study compares three pest management systems, two cultivars, and two soil management systems; however, we chose to focus only on the cultivars and the soil management systems. The experiment was a split-plot, randomized complete block design, with pest management systems as the mainplot. Samples were collected from only one of the three pest management systems (*i.e.* the reduced-input pest management system). Subplots were a full factorial combination of two soil management systems (unamended vs. amended), two potato varieties (Atlantic vs. Superior), and two crop rotation entry points (rotation crop vs. potato). In the unamended soil management system, potatoes were grown after a grain crop (barley underseeded with medium red clover), fertilizers were applied at planting (1344 kg ha^{-1} of 10-10-10) and additional N (50 to 59 kg ha^{-1}) was applied at tuber initiation. In the amended plots, green manure (a mixture of peas, oats and hairy vetch) was used as the rotation crop in place of the grain crop, and potato compost and cattle manure were applied each spring prior to primary tillage at rates of 22 and 45 Mg ha^{-1}, respectively. At-planting fertilizers were applied at one-half the rate applied to the unamended plots. During 1994, the amended plots did not receive sidedressed N. Each treatment combination was replicated four times.

Tuber samples were also collected from an experiment examining the effects of supplemental irrigation, using overhead sprinklers, and soil management strategies using organic amendments and green manure rotation crops. Details of this experiment are provided by Opena (1995). Mainplots (486 m^2 each, 18 x 27 m) within this split-plot, randomized complete block design experiment consisted of supplemental irrigation treatments: (1) non-irrigated check; (2) infrequent irrigation (5.6 cm in 1993 and 4.7 cm in 1994); (3) moderate irrigation (14.7 cm in 1993 and 9.1 cm in 1994). The timing of the irrigation treatments was from July 30 to September 1 in 1993, and July 18 to August 20 in 1994. Subplots (121.5 m^2 each, 9 x 13.5 m) consisted of a complete factorial combination of soil amendment (with and without soil amendment) and crop rotation (oats or a green manure mixture of oats, peas, vetch and clover). Amendment treatments were the same as those described above for the potato ecosystem experiment; however, in this study N fertilizer (a combination of diammonium phosphate, ammonium nitrate, and ammonium sulfate) was applied at two rates: 134 and 202 kg N ha^{-1}. Phosphate and potash rates were held at 134 kg ha^{-1} each in 1993 and 202 kg ha^{-1} each in 1994, regardless of the amendment and rotation crop treatments. In order to focus on the effects of irrigation and soil management strategy, samples were taken only from the "non-irrigated check" and "moderate irrigation" treatments with a full factorial combination of soil amendment and crop rotation treatments. Our samples were taken only from the subplots receiving 202 kg N ha^{-1}.

Each of these studies utilized hand-cut seedpieces with an average weight range of 50-64 g. They were machine planted at a 23-cm, within-row seedpiece spacing in rows spaced 0.9 m apart. At-planting fertilizers were applied in dual bands 5 cm below and to each side of the seedpieces. Planting dates for the potato ecosystem study were May 26-28, 1993 and May 27 to June 3, 1994. The irrigation x soil management study was planted on June 9, 1993 and May 31, 1994. Herbicides, fungicides, and insecticides were applied with standard boom-type, tractor-mounted sprayers using rates and materials recommended by the University of Maine Cooperative Extension.

Sampling Procedure—Harvest dates for the experiments are presented in Table 1. In total, 16 plots from the potato ecosystem study and 32 plots from the irrigation x soil amendment study were sampled. A random sample, typically 23 kg of 5- to 10-cm diameter tubers, was collected from each plot at harvest and placed in storage at 10 C and 90% relative humidity. Tuber samples were extracted for ASC and glycoalkaloids within one month of harvest and again approximately 4 to 5 months after harvest. No glycoalkaloid concentrations were determined for the 1993 fall-sampled tubers due to the failure of our initial glycoalkaloid extractions. The time schedule for the lab extraction and analysis is presented in Table 1.

Ascorbic Acid Analyses—Six average-sized tubers were chosen from each sample. Each was individually weighed, washed, peeled and cut into quarters along its longitudinal axis. One quarter slice from each tuber was chopped, weighed fresh, and weighed again after drying at 60 C for determination of tuber dry matter content. A second set of quarter slices from each tuber was chopped, mixed, weighed and then immediately homogenized and extracted using a modification of the method described by Bushway *et al.* (1988). Average tuber weight of each homogenized sample was calculated from the fresh weights of the six individual tubers. Instead of centrifugation, one to two ml aliquots of each homogenate were passed through a 0.45 μm nylon filter into an injection vial for HPLC analysis. Duplicate aliquots of each ASC extract were assayed on

TABLE 1.—*Harvest and sample extraction schedule.*

	1993 Experiments		1994 Experiments	
	Ecosystem	Irrigation	Ecosystem	Irrigation
Harvest Date[1]**:**	Sept. 21-24 117-120 DAP	Oct. 7 120 DAP	Sept. 23-27 115-119 DAP	Sept. 23 115 DAP
Fall Extraction Date:				
Ascorbic acid	Oct. 8, 22	Oct. 26, 29	Oct. 3 Nov. 5, 8	Oct. 4-5
Glycoalkaloids	none	none	Oct. 7	Oct. 13-14
Storage Extraction Date:				
Ascorbic acid	Feb. 27, 1994	March 7, 1994	Jan. 26, 1995	Jan. 24-26, 1995
Glycoalkaloids	Apr. 15, 1994	Apr. 8, 1994	Jan. 31, 1995	Feb. 1-2, 1995

[1]DAP=days after planting.

the day of extraction using the procedure of Bushway *et al.* (1988) with a Hewlett Packard 1050 Series HPLC system (Hewlett Packard, Inc.; Wilmington, DE) consisting of an autosampler, quaternary pump, and variable wavelength detector connected to a microcomputer. Peaks from the extracts were compared to a 0.1 mg ml^{-1} standard prepared using L-ascorbic acid (Sigma Chemical Co., St. Louis, MO) and 3% metaphosphoric acid. The approximate retention time was 12 minutes.

Glycoalkaloid Analyses—Tuber sampling and initial processing was similar to that described for ASC analyses except that each set of quarter slices for homogenization was cut into 1-cm cubes, pooled, and mixed well. One hundred grams was removed and glycoalkaloids (α-chaconine and α-solanine) were extracted and assayed by HPLC using a modification of the method published by Bushway *et al.* (1986). Homogenization in a blender took place for one minute rather than three minutes. Approximately 50 ml of the resulting extract were filtered through 15-cm diameter, 315-grade fluted filter paper (VWR Scientific; Boston, MA). A 10-ml aliquot of filtrate was cleaned by passing through a preconditioned C-18 Sep-Pak (Waters Chromatography Division; Milford, MA) as described by Bushway *et al.* (1986); however, the final step was modified so that glycoalkaloids were eluted with 2 mls of a tetrahydrofuran, water, and acetonitrile mixture (50:30:20,v/v/v). The samples were stored in a standard freezer until they could be assayed within several weeks by HPLC. Each C-18 Sep-Pak was re-used four times and was reconditioned prior to each use.

The HPLC system used was described above, however, a C6 (150 mm x 4.6 mm i.d. 5 μ particle size) reversed-phase column (Phenomenex Ultrmex; Torrance, CA) was used. The mobile phase (0.5 ml min^{-1}) was made up of 40 ml buffer, 240 ml water, 160 ml of acetonitrile, 16 ml of tetrahydrofuran. The buffer was 0.1 M ammonium phosphate dibasic with pH adjusted to 3.5 using 85% *o*-phosphoric acid. The injection volume was 5 μl and glycoalkaloid (solanine and chaconine) concentrations were quantified by absorbance at 210 nm. Peaks from the extracts were compared to glycoalkaloid standards prepared by mixing α-solanine (Department of Food Science, University of Maine, Orono, ME) and α-chaconine (Sigma Chemical Co., St. Louis, MO) with the mobile phase. The concentrations of α-solanine and α-chaconine standard used were 0.21 and 0.14 mg ml^{-1}, respectively. The total run time was about 10 minutes with α-solanine eluting first after 5 to 6 minutes and α-chaconine eluting immediately after with nearly baseline separation. TGA was calculated as the sum of the α-solanine and α-chaconine concentrations.

Statistical Analysis—Analysis of variance (AOV) was conducted using single degree of freedom F-tests for variety, soil amendment, rotation and irrigation effects (ANOVA and GLM procedures; SAS Institute, 1990). Storage and growing season effects were evaluated with t-tests. Relationships between average tuber fresh weight of the homogenized samples, ASC, and TGA concentrations were evaluated using SAS correlation procedures (SAS Institute, 1990).

Results and Discussion

Tuber Ascorbic Acid Concentration—A highly significant varietal difference in tuber ASC concentration was found in the fall samples and after approximately 4 (1994) and 5 (1993) months of storage at 10 C (Table 2). The ASC concentration of the fall-sampled Atlantic tubers was 26 to 28% lower than Superior. Because Atlantic had significantly higher tuber dry matter content during both growing seasons (22.4 vs 20.3% in 1993, $p<0.01$; 25.1 vs 22.0% in 1993, $p<0.01$), fall ASC content of Superior tubers, expressed on a dry weight (d.w.) basis, was 35% higher than Atlantic (Table 2). The average fresh weight of the sampled tubers was not significantly different among varieties (Table 2) indicating that the varietal differences in ASC concentration were not due to differences in tuber size.

Significant varietal differences in tuber ASC content have been observed by others (Hyde, 1962; Murphy *et al.*, 1945; Mullin *et al.*, 1991; Shekhar *et al.*, 1978); however, we were unable to find any published reports comparing the ASC content of these two commercially important varieties. ASC content of our fall samples compared well with other reports despite differing analytical methods [*e.g.* 9.0 to 30.3 mg 100 g^{-1} after 1 mo storage at 4.4 C (Hyde, 1962); 5.7 to 27.7 mg 100 g^{-1} after 7 wk of storage at 5 C (Mullin *et al.*, 1991); 20 to 40 mg 100 g^{-1} (Murphy *et al.*, 1945)]. On a d.w. basis, our Atlantic data were similar to the data of Shekhar *et al.* (1978) for Kennebec and Russet Burbank; however, our Superior ASC content was higher.

After approximately 4 to 5 months storage, ASC concentration in both varieties decreased (Table 2). Averaged over varieties, ASC concentration on a f.w. basis declined 33% during 1993 and 58% during 1994 ($p<0.0001$ and 0.0002, respectively). Even after storage, ASC concentrations in Superior tubers remained 23 to 30% higher than those of Atlantic on a f.w. basis and 31 to 38% higher on a d.w. basis. A similar decline in ASC concentration of Superior tubers during storage was observed in the irrigation x soil management experiment (Table 3). Averaged over treatments, ASC concentration on a f.w. basis declined 28% during 1993 and 56% during 1994 ($p<0.0001$ for both years). These decreases during storage are in agreement with the observations of others (Augustin, 1975; Shekhar *et al.*, 1978; and Perkins, 1993).

Growing season effects on the ASC concentration of fall-sampled tubers were quite large in our potato ecosystem (ASC content averaged 41% higher during 1994 vs. 1993, $p<0.0003$, Table 2) and irrigation x soil management studies (46% higher during 1994 vs. 1993, $p<0.0001$, Table 3). Total May through September rainfall was higher in 1993 (48.1 cm) than in 1994 (43.8 cm) and the rainfall distribution patterns differed [*e.g.* August rainfall was 7.6 cm during 1993 (20% below normal) and 3.2 cm during 1994 (67% below normal)]. From this, it appears that the drier conditions experienced during 1994 resulted in elevated tuber ASC concentrations. Murphy *et al.* (1945) had

TABLE 2.—*Ascorbic acid content of Atlantic and Superior tubers from the University of Maine Potato Ecosystem study.*

Treatment	1993 Experiment[2] (mg 100 g^{-1} tuber tissue)				1994 Experiment[3] (mg 100 g^{-1} tuber tissue)			
	Fall Samples		Storage Samples		Fall Samples		Storage Samples	
	f.w. basis	d.w. basis	f.w. basis	d.w. basis	f.w. basis	d.w. basis	f.w. basis	d.w. basis
Variety:								
Atlantic	14.7	65.6	10.3	45.9	21.0	83.9	8.5	34.0
Superior	20.5	101.6	13.4	66.1	28.4	128.7	12.1	55.1
Soil Mgt. System:								
Unamended(-)	17.6	84.6	11.9	56.9	25.3	108.7	10.4	44.8
Amended(+)	17.6	82.6	11.8	55.1	24.2	103.9	10.3	44.2
AOV Results[1]:								
Variety	**	**	**	**	**	**	**	**
Soil Mgt. Sys.	ns	ns	ns	ns	ns	ns	ns	ns
Var. x Soil Mgt.	ns	ns	ns	ns	ns	ns	ns	ns

[1]Analysis of variance (AOV) results: ns=not significant; +, *, ** significance at α=0.1, 0.05, and 0.01, respectively.
[2]The average tuber fresh weights of the processed samples were 183 g in the fall and 158 g from storage. These fresh weights did not differ significantly for variety, soil management system, and variety x soil management system effects.
[3]The average tuber fresh weights of the processed samples were 148 g in the fall and 145 g from storage. These fresh weights of the processed samples did not differ significantly for variety, soil management system, and variety x soil management system effects.

previously suggested that dry conditions can lead to a higher tuber ASC levels. ASC concentration also differed significantly among growing seasons for the storage samples (potato ecosystem exp, $p<0.0347$; irrigation x soil management experiment, $p<0.0008$). From storage, the 1994 ASC contents averaged 12 to 13% lower than 1993 (Tables 2 and 3). Similarly, Augustin *et al.* (1978) noted that high ASC tubers tended to lose ASC more rapidly in storage than those with low concentrations. After 8 months storage, they found that ASC values varied little regardless of variety or growth location.

Irrigation did not significantly affect ASC during 1993 (Table 3). The 1993 growing season was relatively moist (26.8 cm of rainfall, June through August) and yields were not affected by supplemental irrigation during 1993 (Opena, 1995). During the drier 1994 growing season, a 10 t ha^{-1} yield increase (36%) was observed due to irrigation (Opena, 1995) and irrigation tended to decrease ASC when viewed on a f.w. basis (-18% for the fall samples, $p<0.1$; -4% for the storage samples, ns; Table 3). Our results show relatively small effects of sprinkler irrigation on tuber ASC content and are generally in agreement with observations of Augustin (1975). However, effects of irrigation on ASC content might still be expected in situations when irrigation strongly affects crop maturity (*e.g.* similar to the cool, moist seasons reported by Murphy *et al.*, 1945). Augustin (1975) reported that tuber ASC content tended to be higher on sandy loam than loamy soils suggesting some impact of moisture and/or nutrient supply. Irrigation significantly affected tuber dry matter content during 1993 (19.4 non-irrigated vs. 19.1% irrigated, $p<0.05$) and 1994 (22.6 non-irrigated vs. 20.2% irrigated, $p<0.05$). Despite these effects on tuber dry matter, relative treatment effects on ASC were generally similar whether the results were viewed on a f.w. or d.w. basis.

There were no soil management system effects on tuber ASC concentration in the potato ecosystem study (Table 2), where fertilizer rates were dramatically reduced to partially account for nutrients applied in the soil amendments. The irrigation x soil management study was managed differently in that fertilizer rates were held constant as nutrient supply was increased with the green manure rotation crop and soil amendment applications. Despite these major differences in management, soil amendment and rotation treatments had few significant effects on tuber ASC concentration (Table 3); however, the 1994 storage samples displayed a significant decline in ASC content due to the amendment treatments (Table 3). Significant three-way interactions among irrigation, amendment, and rotation were observed during 1993 (fall samples only) and 1994 (storage samples only). The patterns of these interactions were very different for the two samplings (Figs. 1A and B). In the 1993 fall samples, the non-irrigated treatment with no soil amendments and oats as the rotation crop had unusually high ASC content on a d.w. basis (Fig. 1A). With the exception of this irrigation x crop rotation combination, amendments tended to slightly increase ASC content. The patterns were similar when viewed

TABLE 3.—*Ascorbic acid content of Superior tubers from the Supplemental Irrigation x Soil Management experiment.*

Treatment	1993 Experiment[2] (mg 100 g^{1} tuber tissue)				1994 Experiment[3] (mg 100 g^{1} tuber tissue)			
	Fall Samples		Storage Samples		Fall Samples		Storage Samples	
	f.w. basis	d.w. basis	f.w. basis	d.w. basis	f.w. basis	d.w. basis	f.w. basis	d.w. basis
Irrigation:								
Non-irrigated	18.8	96.6	13.3	68.7	29.9	133.1	12.2	54.7
Irrigated	18.5	97.3	13.7	71.6	24.6	122.6	11.7	58.4
Rotation Crop:								
Oats	19.2	99.4	13.2	68.3	27.3	128.5	11.8	55.7
Green Manure	18.2	94.6	13.8	72.0	27.2	127.3	12.1	57.4
Soil Amendment:								
Unamended(-)	19.2	98.4	13.8	70.7	27.4	128.1	12.4	58.3
Amended(+)	18.1	95.5	13.2	69.5	27.1	127.7	11.5	54.8
AOV Results[1]:								
Irrigation	ns	ns	ns	ns	+	ns	ns	+
Crop Rotation	ns	ns	ns	ns	ns	ns	ns	ns
Soil Amendment	ns	ns	ns	ns	ns	ns	*	+
Rotation x Amend.	ns	ns	ns	ns	ns	ns	ns	ns
Irrig. x Amendment	ns	ns	ns	ns	+	ns	**	*
Irrig. x Rotation	ns	ns	ns	ns	ns	ns	ns	ns
Irrig. x Rot. x Amend.	*	*	ns	ns	ns	ns	*	*

[1]Analysis of variance (AOV) results: ns=not significant; +, *, ** significance at α=0.1, 0.05, and 0.01, respectively.

[2]The average tuber fresh weights of the processed samples were 193 g in the fall and 140 g from storage. The average fresh weights of the fall-processed tubers did not differ significantly among irrigation, crop rotation and interactions. Average tuber fresh weight differed significantly among soil amendment treatments (185 g unamended vs. 202 g amended, $p<0.05$). For the samples processed from storage, average tuber fresh weight did not differ significantly between crop rotations and there were no significant interactions among main effects. Average tuber fresh weight differed significantly between irrigation (146 g non-irrigated vs. 135 g irrigated, $p<0.01$) and soil amendment treatments (127 g unamended vs. 154 g amended, $p<0.05$).

[3]The average tuber fresh weights of the processed samples were 151 g in the fall and 133 g from storage. Average tuber fresh weight of the all-processed samples did not differ significantly between crop rotations and there were no significant interactions among main effects. Average tuber fresh weight differed significantly between irrigation (144 g non-irrigated vs. 158 g irrigated, $p<0.10$) and soil amendment treatments (141 g unamended vs. 161 g amended, $p<0.10$). For the samples processed from storage, average tuber fresh weight did not differ significantly among irrigation, soil amendment, and crop rotation treatments and there were no significant interactions among main effects.

on a f.w. basis. In the 1994 storage samples, soil amendments tended to reduce ASC content, except in the non-irrigated treatment with oats as the rotation crop (Fig. 1B). On a d.w. basis, ASC content tended to be higher in the irrigated than the non-irrigated treatment, except when the oat rotation crop was used with soil amendments. ASC levels were not higher in irrigated versus non-irrigated when the data were viewed on a f.w. basis (data not shown).

In both experiments, soil amendments significantly increased soil organic matter content, cation exchange capacity, micronutrient availability, and soil test levels of potassium, calcium, and magnesium (Alford *et al.*, 1996; Opena, 1995). Two-year average yields were increased by 3.7 t ha^{-1} (12%) in the amended soil management system in the potato ecosystem study (Alford *et al.*, 1996) and by 8.4 t ha^{-1} (26%) due to amendments in the irrigation x soil management study (Opena, 1995). Despite higher nutrient availability due to soil amendments (*i.e.* calcium, magnesium, potassium, and micronutrients) and crop rotation (*i.e.* nitrogen), we observed few soil management effects on ASC content even though others have reported that N fertilizer can increase (Mondy *et al.*, 1979) or decrease ASC content (Augustin, 1975; Shekhar *et al.*, 1978) and that other fertilizers can increase ASC content of potato tubers (Mondy and Munshi, 1993; Munshi and Mondy, 1988, and Mondy *et al.*, 1993).

Correlation of Ascorbic Acid Concentration and Tuber Fresh Weight—Within the potato ecosystem experiment, Superior produced a higher percentage of tubers within larger size classes than Atlantic and the amended soil management system produced larger-sized tubers than the unamended system (Alford *et al.*, 1996). Soil amendments increased the percentage of larger-sized tubers within the irrigation x soil management experiment (Opena, 1995). Irrigation increased tuber size in 1994, but not during 1993. The goal of the present study was to study management effects on tuber ASC and TGA concentrations. We hoped to avoid the complications caused by management practice effects on tuber size by sampling "average-sized" tubers from each treatment. Our sampling procedure eliminated tuber size (measured as the average tuber f.w. of each homogenized sample) as a differential factor among treatments in the potato ecosystem study (Table 2). We were less fortunate in the irrigation x soil management experiment where tuber samples from the irrigation and soil amendment treatments sometimes differed in the average tuber size (Table 3). We did not measure the ASC concentration of individual tubers; however, correlation analysis was utilized to determine if the average tuber size of a sample was an important factor affecting ASC concentration in this experiment. Average tuber size ranged from 105 to 197 g for Atlantic and 92 to 244 g for Superior. Over the two-year study, fall-sampled Atlantic tubers displayed a significant negative correlation between average tuber size and ASC ($r = -0.64$, $p<0.01$, $n=16$); however, no correlation was observed from storage ($r = -0.003$, ns, $n=16$). For Superior, fall-sampled tubers displayed a significant negative correlation between average tuber size and ASC ($r = -0.55$, $p<0.01$, $n=80$), while

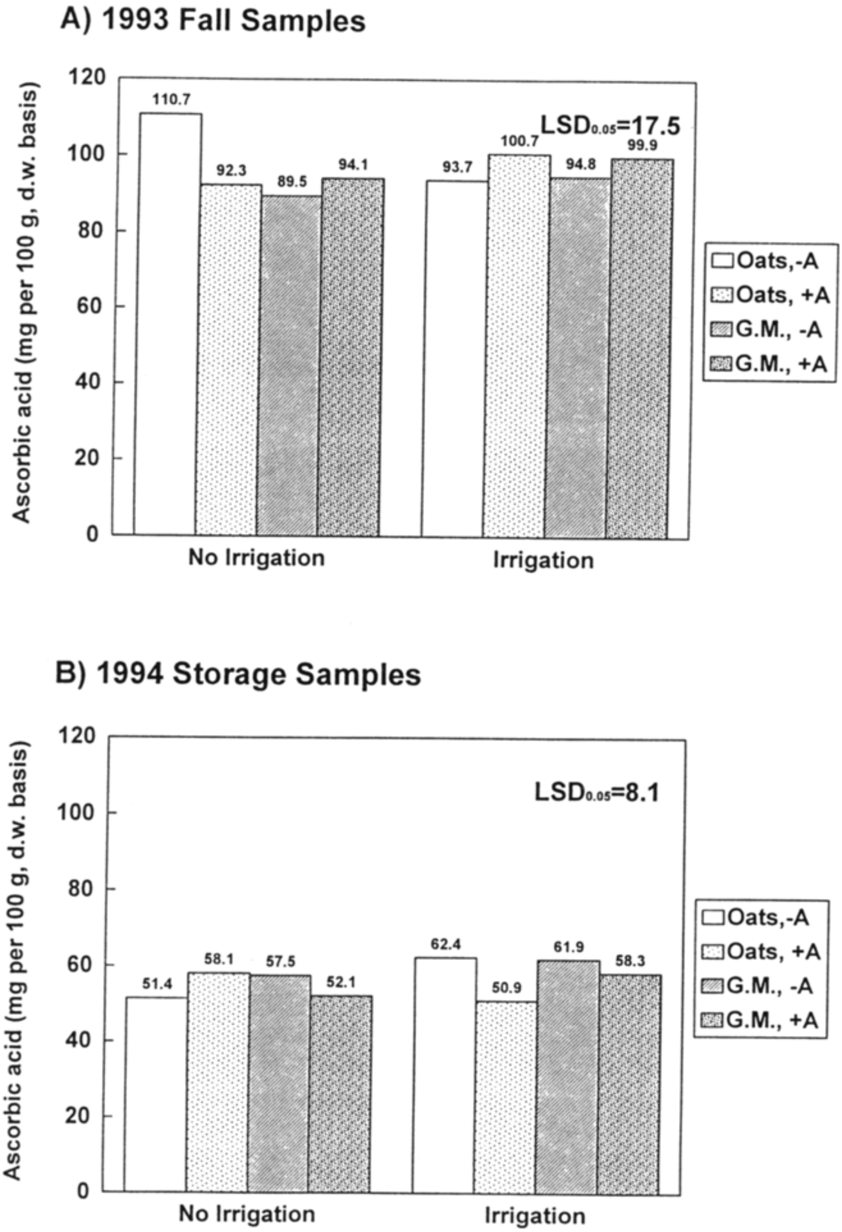

FIG. 1. Ascorbic acid content of Superior tubers as affected by irrigation, crop rotation [oats vs. an oat, pea, vetch green manure crop (G.M.)], and soil amendment treatments [unamended (-A) vs. amended (+A) with manure and compost]: A) 1993 fall samples; B) 1994 storage samples. The irrigation x rotation x amendment interaction was significant ($p<0.05$) for these samplings, but not for the remaining sample dates.

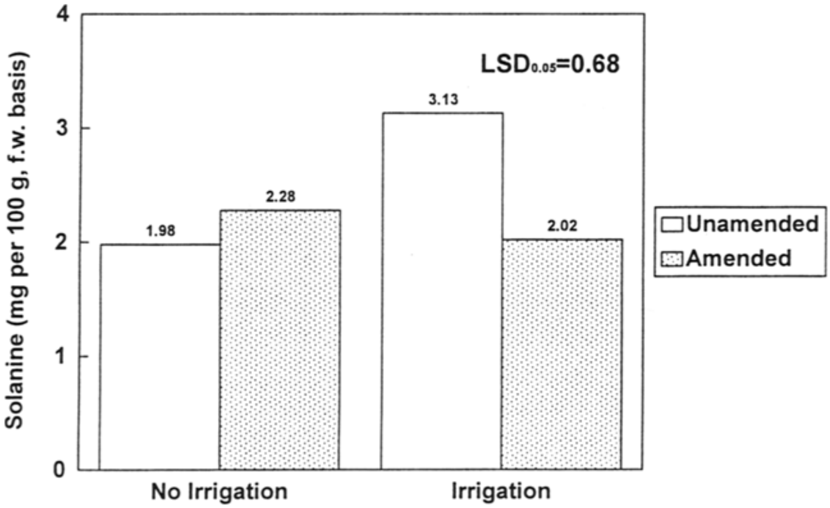

FIG. 2. Tuber α-solanine concentration of Superior as affected by irrigation and soil amendment treatments [unamended (-A) vs. amended (+A) with manure and compost] during 1993. The irrigation x amendment interaction was significant ($p<0.01$).

no correlation existed from storage ($r=-0.06$, ns, $n=80$). Over this size range, average tuber fresh weight can be an important factor affecting ASC concentration just after harvest; however, the relationship disappears over time in storage. Murphy *et al.* (1945) did not find a relationship between tuber size and ASC content.

Tuber Glycoalkaloid Content—In two of our three samplings, we observed that Atlantic contained significantly higher tuber TGA concentrations than Superior (Tables 4 and 5). TGA in Atlantic was 86% higher than that of Superior during 1993 and 60% higher at the 1994 fall sampling. Atlantic tubers were significantly higher in both α-solanine and α-chaconine concentration. Some of these differences, but probably not all, could have been caused by significant tuber size differences among the varieties. The Atlantic tubers sampled were 15 and 19% smaller (f.w. basis) than those of Superior during the two respective samplings (Tables 4 and 5). No differences between the varieties were detected from storage during 1994 (Table 5). In both varieties, α-chaconine was present in greater concentrations than α-solanine. Treatment effects were similar whether the results were viewed on a f.w. or d.w. basis.

Superior TGA concentrations in our study fell well below the 20 mg per 100 g^{1} limit which is considered safe for human consumption (Sinden *et al.*, 1984; Storey and Davis, 1990). These results were comparable with those of Carman *et al.* (1986) who reported a TGA concentration of 6.2 mg 100 g^{-1} for unpeeled Superior tubers.

TABLE 4.—*Glycoalkaloid content of Atlantic and Superior tubers from the 1993 University of Maine Potato Ecosystem study.*

Treatment	Storage Samples[2] (mg 100 g[1] tuber tissue)					
	f.w. basis			d.w. basis		
	sola-nine	chaco-nine	total	sola-nine	chaco-nine	total
Variety:						
Atlantic	3.83	5.57	9.40	17.11	24.87	41.98
Superior	1.62	3.42	5.04	7.99	16.90	24.89
Soil Mgt. System:						
Unamended(-)	2.82	4.59	7.41	13.11	21.52	34.63
Amended(+)	2.63	4.41	7.04	11.99	20.25	32.24
AOV Results[1]:						
Variety	**	**	**	**	**	**
Soil Mgt. Sys.	ns	ns	ns	ns	ns	ns
Var. x Soil Mgt.	ns	ns	ns	ns	ns	ns

[1]Analysis of variance (AOV) results: ns=not significant; +, *, ** significance at α=0.1, 0.05, and 0.01, respectively.
[2]The average tuber fresh weight of the storage-processed samples was 171 g. These average fresh weights did not differ significantly between soil management systems and there was no significant variety x soil management system interaction. Average tuber fresh weight differed among the varieties (157 g for Atlantic vs. 185 g for Superior, p<0.10).

Conclusions concerning growing season effects on tuber TGA concentrations are not possible from this study because the tubers were not peeled during 1993, while they were peeled during 1994. Peeling the tubers would be expected to reduce their TGA concentration because glycoalkaloids tend to be more concentrated in the outer tuber layers (Gull and Isenburg, 1960; Wolf and Duggar, 1946). As expected, our TGA concentrations were significantly higher in the unpeeled 1993 samples than the peeled 1994 samples (Tables 4 to 7; $p<0.0001$ for both experiments).

In general, α-solanine concentrations increased slightly after 4 mo storage, while α-chaconine concentrations tended to increase in the potato ecosystem experiment and decrease in the irrigation x soil management experiment (Tables 5 and 7). TGA concentration did not change significantly during storage in the potato ecosystem experiment ($p<0.17$, Table 5), but decrease by 21% in the irrigation x soil management experiment ($p<0.0167$, Table 7). Others have reported inconsistent effects of storage on tuber TGA concentrations (Linnemann *et al.*, 1985; Perkins, 1993; Cronk *et al.*, 1974). Love *et al.* (1994) observed a significant increase in tuber TGA after 3 and 9 months of storage.

Irrigation effects on TGA concentration were inconsistent and relatively small in these experiments. A significant irrigation effect on α-solanine concentration (d.w. basis, $p<0.05$) was observed during the 1993 storage season.

TABLE 5.—*Glycoalkaloid content of Atlantic and Superior tubers from the 1994 University of Maine Potato Ecosystem study.*

Treatment	Fall Samples[2] (mg 100 g^{-1} tuber tissue)						Storage Samples[3] (mg 100 g^{-1} tuber tissue)					
	f.w. basis			d.w. basis			f.w. basis			d.w. basis		
	sola-nine	chaco-nine	total	sola-nine	chaco-nine	total	sola-nine	chaco-nine	total	sola-nine	chaco-nine	total
Variety:												
Atlantic	1.34	2.83	4.17	5.33	11.30	16.63	1.46	2.88	4.34	5.82	11.45	17.27
Superior	0.73	1.87	2.60	3.33	8.51	11.84	1.09	2.31	3.39	4.96	10.52	15.48
Soil Mgt. System:												
Unamended(-)	1.11	2.45	3.56	4.62	10.30	14.92	1.24	2.60	3.84	5.26	11.03	16.29
Amended(+)	0.91	2.17	3.08	3.86	9.25	13.10	1.29	2.59	3.88	5.49	10.95	16.44
AOV Results[1]:												
Variety	**	**	**	*	*	*	ns	ns	ns	ns	ns	ns
Soil Mgt. Sys.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Var. x Soil Mgt.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]Analysis of variance (AOV) results: ns=not significant; +, *, ** significance at a=0.1, 0.05, and 0.01, respectively.
[2]The average tuber fresh weight of the fall-processed samples was 142 g. There were no significant differences in average tuber fresh weight among soil management systems and there was no significant variety x soil management system interaction. Average tuber weight of the fall-processed samples differed significantly among the varieties (126 g for Atlantic vs. 156 g for Superior, $p<0.05$).
[3]The average tuber fresh weight of the storage-processed samples was 136 g. Variety, soil management system, and the variety x soil management system interactive effects were not significant.

Tuber α-solanine concentration under irrigation was 23% higher than non-irrigated on a d.w. basis and 21% higher ($p<0.1$) on an f.w. basis. However, the irrigation effect was not consistent between the soil amendment treatments (Table 6). Irrigation increased α-solanine concentration in the unamended soil management treatments, but not when amendments were applied (Fig. 2). Irrigation did not significantly affect glycoalkaloid concentrations during 1994 (Table 7). In the case of the irrigation main effects and interactions, average tuber size of the extracted samples was similar among the treatments (Tables 6 and 7); therefore, treatment effects on tuber size were not the cause of these irrigation effects.

Soil management system did not have any significant effects on TGA within the potato ecosystem experiment (Tables 4 and 5). Aside from the irrigation x soil management interaction described above, no significant soil amendment or rotation effects on tuber TGA concentration were found within the irrigation x soil management experiment (Tables 6 and 7).

Cool, moist growing conditions have been implicated in increasing the TGA levels of potato tubers through effects on tuber maturity (Sinden and Webb, 1972). Gosselin *et al.* (1988) reported that potatoes irrigated by micro-

TABLE 6.—*Glycoalkaloid content of Superior tubers from the 1993 Supplemental Irrigation x Soil Management experiment.*

Treatment	Storage Samples[2] (mg 100 g^{-1} tuber tissue)					
	f.w. basis			d.w. basis		
	solanine	chaconine	total	solanine	chaconine	total
Irrigation:						
Non-irrigated	2.13	4.13	6.26	10.97	21.24	32.21
Irrigated	2.58	4.94	7.52	13.45	25.87	39.32
Rotation Crop:						
Oats	2.22	4.24	6.46	11.53	21.97	33.50
Green Manure	2.48	4.83	7.32	12.89	25.14	38.02
Soil Amendment:						
Unamended(-)	2.56	4.66	7.22	13.14	23.95	37.09
Amended(+)	2.15	4.41	6.56	11.29	23.15	34.44
AOV Results[1]:						
Irrigation	+	ns	ns	*	ns	+
Crop Rotation	ns	ns	ns	ns	ns	ns
Soil Amendment	ns	ns	ns	ns	ns	ns
Rotation x Amend.	ns	ns	ns	ns	ns	ns
Irrig. x Amendment	**	ns	ns	*	ns	ns
Irrig. x Rotation	ns	ns	ns	ns	ns	ns
Irrig. x Rot. x Amend.	ns	ns	ns	ns	ns	ns

[1]Analysis of variance (AOV) results: ns=not significant; +, *, ** significance at α=0.1, 0.05, and 0.01, respectively.
[2]The average tuber fresh weight of the processed samples was 97 g. Irrigation, crop rotation, soil amendments, and the interactions among main effects were not significant.

jet mist were significantly higher in tuber TGA concentration than non-irrigated potatoes, while TGA concentrations did not differ between non-irrigated and sprinkler-irrigated potatoes. They, as did Sanders *et al.* (1972), felt that the micro-jet irrigation system delayed tuber maturation. Their lack of sprinkler irrigation effect on TGA was consistent with our 1994 experiment; however, we observed an increase in α-solanine during 1993 when irrigation was applied without the use of soil amendments. Although irrigation does appear to increase TGA levels under some conditions (*e.g.* when tuber maturity is delayed), these conditions were apparently not present during our 1994 study. Irrigation applications during 1994 were well-timed during a very dry August period and they significantly increased yields without negative effects on external quality (Opena, 1995). During the wetter 1993 growing season, our irrigation applications were applied later than desirable and resulted in high tuber decay incidence without any increase in tuber yields (Opena, 1995). We conclude that irrigation did delay tuber maturity during 1993.

TABLE 7.—*Glycoalkaloid content of Superior tubers from the 1994 Supplemental Irrigation x Soil Management experiment.*

Treatment	Fall Samples[2] (mg 100 g^{-1} tuber tissue)						Storage Samples[3] (mg 100 g^{-1} tuber tissue)					
	f.w. basis			d.w. basis			f.w. basis			d.w. basis		
	solanine	chaconine	total	solanine	chaconine	total	solanine	chaconine	total	solanine	chaconine	total
Irrigation:												
Non-irrigated	0.62	2.24	2.86	2.74	9.93	12.67	0.83	1.45	2.28	3.63	6.39	10.02
Irrigated	0.56	1.89	2.45	2.81	9.52	12.34	0.79	1.13	1.92	3.92	5.62	9.54
Rotation Crop:												
Oats	0.62	2.13	2.75	2.91	10.03	12.93	0.87	1.28	2.15	4.05	5.96	10.00
Green Manure	0.56	2.00	2.56	2.65	9.42	12.07	0.74	1.30	2.04	3.50	6.05	9.55
Soil Amendment:												
Unamended(-)	0.61	2.20	2.81	2.83	10.32	13.15	0.79	1.28	2.07	3.64	5.90	9.54
Amended(+)	0.57	1.93	2.50	2.73	9.13	11.86	0.82	1.29	2.11	3.91	6.11	10.02
AOV Results[1]:												
Irrigation	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Crop Rotation	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Soil Amendment	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rotation x Amend.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrig. x Amendment	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrig. x Rotation	+	ns	ns	+	ns	ns	ns	ns	ns	ns	ns	ns
Irrig. x Rot. x Amend.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]Analysis of variance (AOV) results: ns=not significant; +, *, ** significance at α=0.1, 0.05, and 0.01, respectively.

[2]The average tuber fresh weight of the fall-processed samples was 141 g. Irrigation, crop rotation, soil amendment, and the interactions among main effects were not significant.

[3]The average tuber fresh weight of the storage-processed samples was 124 g. Average tuber fresh weight did not differ significantly among crop rotations and soil amendments. Most interactions among main effects were not significant; however, average tuber fresh weight was different among irrigation treatments (117 g non-irrigated vs. 131 g irrigated, $p<0.05$) and the irrigation x soil amendment interaction was significant.

Soil amendment and rotation treatments increased the availability of N and other nutrients in these experiments (Alford *et al.*, 1996; Opena, 1995), yet they did not significantly affect TGA concentrations. This latter observation is similar to that of Mondy *et al.* (1984) who concluded that sewage sludge had no effect on tuber TGA content. Others have reported that increased N availability can increase tuber TGA levels (Cronk *et al.*, 1974; Love *et al.*, 1994; Mondy and Munshi, 1990); however, sometimes concentrations decrease or are unaffected (Cronk *et al.*, 1974; Nowacki *et al.*, 1975; Love *et al.*, 1994). The results of the current study indicate that nutrients supplied in the form of compost, manure, and green manures do not delay tuber maturity of Superior and, thus, do not affect TGA levels. It remains possible that these amendments might delay maturity and increase TGA levels in an indeterminate variety, such as Russet Burbank.

Correlation of TGA Concentration with Tuber Fresh Weight—Even though we chose "average-sized" tubers for our analysis and had similar-sized tubers for many treatments (Table 4 to 7), average tuber fresh weight of the homogenized samples varied significantly among treatments in several experiments. Correlation analysis was utilized to determine if average tuber size was an important factor affecting TGA concentration. Average tuber size of the TGA samples ranged from 98 to 181 g for Atlantic and 41 to 227 g for Superior. For Atlantic, tuber size and TGA were not significantly correlated in the fall sampling ($r = -0.61$, ns, $n=7$), but were positively correlated from storage ($r=.53$, $p<0.05$, $n=15$). For Superior, a negative correlation existed between tuber size and TGA concentration in the fall ($r = -0.35$, $p<0.05$, $n=40$) and from storage ($r = -0.36$, $p<0.01$, $n=78$). Although we generally observed a negative relationship between average tuber size and TGA concentration in this series of studies, the relationship was not strong over this range of tuber sizes; therefore, variations in average tuber size among treatments should have little influence on TGA concentration of the samples. Others have reported that smaller tubers typically have higher TGA concentrations (Cronk *et al.*, 1974; Wolf and Duggar, 1946), because the outer tuber layers are higher in TGA than the pith and because smaller tubers have a higher surface to volume ratio (Gull and Isenberg, 1960; Lampitt *et al.*, 1943).

Summary

In conclusion, Superior tubers are significantly higher in ASC and lower in TGA than Atlantic. Irrigation tended to slightly reduce tuber ASC and increase α-solanine concentrations when applied too late in the season for yield benefits. Soil amendment programs using compost and manure did not dramatically affect either tuber ASC or TGA concentrations. ASC content of the tubers declined dramatically in storage, but no specific pattern was found for TGA. We conclude that genotype, growing environment, and storage time play much stronger roles in determining tuber ASC and TGA levels than do irrigation and soil management programs. We observed a negative relationship between average tuber size of the homogenized samples and ASC concentration in the fall; however, this relationship was not observed from storage. In general, average tuber size and TGA content were negatively correlated.

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