Sweet Corn Nutrient Uptake and Removal

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SUMMARY. **Current emphasis on writing comprehensive nutrient management plans for crop production in the mid-Atlantic region of the United States requires accurate crop nutrient removal values for vegetable crops. Therefore, studies were conducted to measure nutrient uptake in harvested fresh sweet corn (*Zea mays*) ears in 2003 on a sandy loam soil and in 2004 on a silt loam soil, in New Jersey. Nine varieties were included in the study to represent early, mid-, and late-season hybrids. Corn production practices followed local extension recommendations. The crop was seeded by hand and thinned to ensure a uniform within-row spacing of 9 inches and a population of 23,231 plants/acre. Nutrient concentrations were determined on ear and stover samples oven-dried at 70 °C for 72 hours. Mean nutrient uptake values for full-season varieties based on a typical sweet corn yield of 150 cwt/acre (about 18,396 ears/acre) would be projected to remove (in lb/acre) 51 N, 9.1 P, 34 K, 3.7 S, 2.0 Ca, 3.9 Mg, 0.024 B, 0.09 Fe, 0.044 Mn, 0.014 Cu, and 0.072 Zn. Values for N, P, and K are similar to reference values in *Knott's Handbook for Vegetable Growers* (4th ed.). Due to smaller ear size, nutrient removal values were generally lower for early and mid-season varieties. In 2004 only, nutrient removal by harvesting the crop residue was also determined by assuming a harvest of 23,231 plants/acre, minus the upper ear for the average full-season hybrid. This biomass was found to remove (in lb/acre) 126 N, 13.4 P, 173 K, 11.6 S, 20.6 Ca, 13.6 Mg, 0.05 B, 0.37 Fe, 0.30 Mn, 0.05 Cu, and 0.13 Zn.**

The mandate for comprehensive nutrient management plans in the mid-Atlantic region of the United States (Pennsylvania State Conservation Commission, 1997; Simpson, 1998; Sims, 1999) makes it necessary to re-evaluate crop nutrient removal values for vegetable crops such as sweet corn. To be relevant, the nutrient removal values must be based on current cultural practices and production technology. Although production guides often publish values for crop nutrient removal, the original studies upon which those values are based are generally not cited (Heckman et al., 2003).

Over the course of the growing season, a crop will accumulate, in its biomass, certain amounts of each of the essential plant nutrients. Amounts of nutrient uptake and removal vary with crop species and variety, yield level, and production practice. Higher-yielding crops and crops that produce large amounts of harvestable material remove greater amounts of nutrients from the soil. Knowing the typical amounts of nutrient removal by a crop provides useful information for sustainable soil fertility management.

In sustainable agriculture, nutrient management planning should ideally provide, over the long-term, a balance between nutrient inputs and outputs. In the establishment of a sustainable system, soil nutrient levels that are deficient are built up to levels that will support economic crop yields. To sustain soil fertility levels, nutrients that are removed from the system by crop harvest, or other losses, must be replaced annually or at least within the longer crop rotation cycle. Values for crop nutrient removal are useful for providing estimates of the amount of nutrients that must be applied to maintain soil fertility when levels have already been built up to the optimum range. These values are also useful for selecting crops of high nutrient removal for production on soils that have excessive nutrient supplies, such as P, and where is a desire to draw down the fertility level (Sims et al., 1998). Thus, accurate values for crop nutrient removal are an important component of nutrient management planning and crop production.

Application of fertilizers without regard to sustainable nutrient management is coming under increased scrutiny with concerns raised over nutrient runoff and water-quality deterioration (Daniel et al., 1998; Sims, 1998). Evidence in New Jersey suggests that a significant number of soils have built up excessive levels of P. On the basis of samples collected in 2004 from commercial grower fields, and received by the Rutgers Soil Testing Laboratory, 39% of soil samples had soil test P ratings in the very high (above optimum) range. Also, personal communication with Rutgers Cooperative Extension (RCE) county agriculture agents suggests that New Jersey soils that are used for vegetable crop production have substantially more than 39% of soil test P ratings in the very high range. Although at present there is much emphasis on controlling P application in nutrient management planning, other nutrients may receive greater attention in the future.

The objective of this study was to measure nutrient (N, P, K, S, Ca, Mg, Zn, Mn, Cu, B, Fe) removal by fresh sweet corn ears for a range of varieties grown in two site years on New Jersey soils.

Materials and methods

Sweet corn varieties were grown on a Freehold sandy loam soil near Adelphia, N.J., in 2003 and on a Quakertown silt loam soil near Pittstown, N.J., in 2004 to represent soils of both the coastal plain and the piedmont. Soil samples were collected in the spring from the 0- to 15-cm depth by randomly collecting

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
45.3592	cwt	kg	0.0220
112.0851	cwt/acre	$kg \cdot ha^{-1}$	0.0089
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
1	ppm	$mg \cdot kg^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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Table 1. Mean fresh and dry weights, water content, mineral concentrations, least significant difference (LSD), and cv (CV) of marketable sweet corn ears from the variety trial in 2003 on a Freehold sandy loam soil near Adelphia, N.J., and the 2004 trial on a Quakertown silt loam near Pittstown, N.J. (nutrient concentrations are expressed on a dry weight basis).

	Sweet corn variety	Ear fresh wt[z] (lb/ear)[x]	Ear dry wt[y] (lb/ear)[x]	Water (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (ppm)[w]	Fe (ppm)[w]	Mn (ppm)[w]	Cu (ppm)[w]	Zn (ppm)[w]
2003 Harvest	Early Choice	0.50	0.091	82	1.67	0.31	1.22	0.050	0.11	0.10	5.35	31.3	8.88	2.53	18.1
	Temptation	0.59	0.13	78	1.52	0.27	1.03	0.037	0.10	0.11	5.97	27.8	7.37	1.47	18.6
	Sensor	0.75	0.12	84	2.00	0.30	1.07	0.055	0.11	0.10	8.88	23.8	8.23	2.85	21.7
	Brocade	0.88	0.14	84	1.64	0.32	1.16	0.060	0.12	0.10	8.28	28.1	9.50	2.93	18.2
	Silver King	0.81	0.13	84	1.85	0.31	1.22	0.048	0.11	0.10	6.30	24.0	11.3	5.95	20.9
	Argent	0.76	0.12	84	1.67	0.32	1.19	0.058	0.11	0.10	9.30	29.3	11.0	2.80	19.9
	Terrific	0.73	0.14	80	2.10	0.29	1.24	0.055	0.10	0.091	9.08	24.5	8.20	2.38	17.7
	Significance	*	***	*	***	NS	NS	NS	*	**	NS	NS	*	**	NS
	$LSD_{0.05}$[v]	0.10	0.14	0.031	0.0028				0.0015	0.0015			0.59	0.026	
	CV (%)[u]	6.7	12.3	16.3	1.8	15.5	7.3	8.6	15.4	7.1	9.0	41.2	11.6	14.6	79.0
2004 Harvest	Early Choice	0.57	0.094	84	1.51	0.28	1.01	0.065	0.14	0.13	5.13	26.4	19.9	5.15	25.0
	Double Choice	0.81	0.18	78	1.35	0.32	1.05	0.065	0.14	0.13	6.18	37.7	20.6	6.08	31.3
	Sensor	0.88	0.16	82	1.47	0.29	0.98	0.070	0.15	0.14	10.4	27.3	16.5	4.98	34.7
	Brocade	0.98	0.19	81	1.47	0.29	1.06	0.083	0.14	0.13	7.63	31.3	19.4	5.08	25.6
	Silver King	0.83	0.21	74	1.52	0.29	1.05	0.070	0.15	0.14	7.15	32.6	19.0	5.58	26.6
	Argent	0.84	0.21	75	1.47	0.28	0.99	0.073	0.14	0.14	7.98	37.8	19.3	5.08	25.6
	Terrific	0.79	0.23	71	1.43	0.24	1.00	0.063	0.12	0.11	5.35	26.9	15.3	4.70	20.6
	Brilliance	0.72	0.19	74	1.41	0.28	1.09	0.065	0.14	0.15	5.73	33.2	19.1	5.88	22.9
	Significance	***	***	***	NS	***	NS	NS	***	***	NS	**	**	***	***
	$LSD_{0.05}$[v]	0.049	0.014	0.13		0.0022			0.0011	0.0014		0.77	0.36	0.077	0.44
	CV (%)[t]	4.2	4.2	0.95	11.2	4.2	5.2	13.7	4.4	5.8	44.7	13.2	10.4	7.8	8.9

[z]Ear fresh wt = weight of fresh sweet corn ears at time of harvest for optimal maturity for eating, determined by taking the mean ear weight of eight ears per plot.
[y]Ear dry wt = weight of mature sweet corn ears after drying, determined by taking the mean ear weight of eight harvested oven-dried ears per plot.
[x]1 lb = 0.4536 kg.
[w]1 ppm = 1 $mg \cdot kg^{-1}$.
[v]$LSD_{0.05}$ = Fisher's protected least significant difference among varieties (α = 0.05).
[u]CV = coefficient of variance.
NS,*,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Nutrient removal values estimated for different sweet corn maturity groups based on data collected in 2003 and 2004 growing seasons; expressed on a fresh weight basis and presented in different units of yield measurement.

	Nutrient removal						
	Early season[z]		Mid-season[y]		Late season[x]		
Nutrient	(lb/1000 ears)[w]	(lb/cwt)[v]	(lb/1000 ears)[w]	(lb/cwt)[v]	(lb/1000 ears)[w]	(lb/cwt)[v]	(lb/crate)[wu]
N	1.47	0.272	2.18	0.312	2.75	0.340	0.138
P	0.276	0.051	0.451	0.0645	0.493	0.0609	0.0246
P_2O_5 (phosphate)	0.633	0.117	1.03	0.148	1.13	0.139	0.056
K	1.03	0.191	1.59	0.227	1.84	0.227	0.092
K_2O (potash)	1.24	0.229	1.90	0.272	2.21	0.273	0.110
S	0.108	0.0200	0.188	0.0269	0.201	0.0249	0.0101
Mg	0.113	0.0210	0.181	0.0259	0.212	0.0262	0.0106
Ca	0.0532	0.0098	0.077	0.0111	0.107	0.0132	0.0053
B	0.00048	0.000090	0.00092	0.00013	0.0013	0.00016	0.000066
Cu	0.0036	0.000066	0.00057	0.000082	0.00074	0.000091	0.000037
Fe	0.0027	0.00049	0.0050	0.00071	0.0049	0.00060	0.00024
Mn	0.0013	0.00025	0.0021	0.00030	0.0024	0.00030	0.00012
Zn	0.0020	0.00037	0.0038	0.00054	0.0039	0.00048	0.00019

[z]Early season = 66 d to maturity, variety 'Early Choice'.
[y]Mid-season = 70–74 d to maturity, varieties 'Temptation' and 'Double Choice'.
[x]Late season = 75–86 d to maturity, varieties 'Sensor', 'Brocade', 'Silver King', 'Argent', 'Terrific', and 'Brilliance'.
[w]1 lb = 0.4536 kg.
[v]1 lb/cwt = 1%.
[u]1 crate = 50 ears of a late-season variety.

12 cores (2.25-cm diameter) from each replicate. The samples were analyzed at Brookside Laboratory, New Knoxville, Ohio, using the Mehlich-3 method (Mehlich, 1984). At both field sites, soil-test P levels were above optimum and K levels were in the optimum range. RCE defines Mehlich-3 soil-test P range ratings for general crops as below optimum (<36 ppm), optimum (36–69 ppm), and above optimum (>69 ppm) and Mehlich-3 soil-test K range ratings as below optimum (<73 ppm), optimum (73–139 ppm), and above optimum (>139 ppm). RCE recommendations guided cultural practices. Before planting, 42 lb/acre of K as potassium sulfate and 1 lb/acre of B were broadcast and incorporated. Starter fertilizer at the sites supplied 30 lb/acre N, 13.2 lb/acre P, and 24.9 lb/acre K. Individual plot size consisted of three 20-ft rows with spacing between rows of 30 inches. Planting was performed by hand-seeding and thinning to ensure a uniform, within-row, spacing of 9 inches for a population of 23,231 plants/acre. Yields in 2003 and 2004 and above ground biomass in 2004 only were measured on the day of maturity for fresh eating of each sweet corn variety from a harvest area of one 6-ft row in the middle of each of four replicated plots. Yields were measured for both fresh and dry weights. Hand-harvested sweet corn ears included the cob, kernels, and flag and wrapper leaves just as they would appear in a fresh market. Representative plant samples were oven-dried at 70 °C for 72 h and ground in a Wiley mill (Thomas Scientific, Swedesboro, N. J.) to pass through a 1-mm sieve. Brookside Laboratory analyzed ear and plant samples that were collected from each plot. Total N in the ear and plant samples was determined by combustion method P-2.2 (Gavlak et al., 2003). Concentrations of P, K, Ca, Mg, S, Zn, Mn, Cu, Fe, and B in these samples were determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) after samples were digested with nitric acid and hydrogen peroxide (Gavlak et al., 2003).

All nutrient concentrations in ear and plant samples are expressed on a dry weight basis, but nutrient removal values for the ear are expressed on a fresh harvest basis. Mean nutrient concentrations, fresh weight, dry weight, and water content in the ear and plant material of each variety were calculated. Data were analyzed using the analysis of variance methods of SAS (version 8.0; SAS Institute, Cary, N.C.). Mean separations were obtained by Fisher's protected least significant difference (LSD).

Results and discussion

Mineral nutrients in fresh ears varied significantly among sweet corn varieties for concentrations of Mg, S, Mn, and Cu in both years and for concentrations of N, P, Fe, and Zn in one of the two site years (Table 1). The mean P concentration in the ear was nearly the same in the two site years, but the concentrations of some other nutrients varied substantially. The concentration of Mn among site years, for example, varied more than 2-fold. The concentration of K varied slightly among site years, and, as may be predicted, K varied inversely with concentrations of Ca and Mg (Dibb and Thompson, 1985). With the current emphasis in nutrient management on P, it is fortunate, for the purpose of writing nutrient management plans, that this nutrient appears to have relatively stable P concentrations in the ear. This stability in P concentration enables Certified Crop Advisors writing comprehensive nutrient management plans to more accurately predict P removal for different sweet corn varieties. Previous research (Heckman et al., 2003) found field corn grain samples to be much more variable in P concentration than the current study with sweet corn ears. Fresh sweet corn ears, which are harvested at an earlier growth stage than field corn grain, may not exhibit the variability in P concentration associated with late-season P accumulation during field corn seed fill (Karlen et al., 1988).

Fresh sweet corn ear size was, on average, ≈10% larger in 2004, and

Table 3. Mean fresh and dry weights, water content, mineral concentrations, least significant difference (LSD), and cv (CV) of sweet corn crop stover[z] after harvest of the uppermost marketable ear from the variety trial conducted in 2004 on a Quakertown silt loam near Pittstown, N.J. (nutrient concentrations in sweet corn stover are expressed on a dry weight basis).

Sweet corn variety	Stover fresh wt[zy] (lb/stover)[wy]	Stover dry wt[xy] (lb/stover)[wy]	Water (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (ppm)[v]	Fe (ppm)[v]	Mn (ppm)[v]	Cu (ppm)[v]	Zn (ppm)[v]
Early Choice	0.796	0.099	87	1.99	0.237	2.35	0.34	0.21	0.18	8.7	86.7	71.8	7.8	27.3
Double Choice	0.883	0.126	86	2.29	0.231	2.74	0.37	0.25	0.22	10.0	76.6	71.4	12.6	35.8
Sensor	1.601	0.210	87	1.96	0.230	2.98	0.38	0.24	0.22	11.6	56.1	59.4	9.9	30.1
Brocade	1.406	0.169	88	2.23	0.265	3.17	0.41	0.28	0.19	9.0	57.2	67.5	10.0	26.5
Silver King	1.941	0.306	84	2.31	0.261	3.16	0.35	0.24	0.22	10.7	63.1	49.3	10.5	23.0
Argent	1.856	0.305	84	2.25	0.236	2.85	0.35	0.24	0.19	7.1	56.5	45.9	8.3	21.4
Terrific	1.559	0.285	82	1.99	0.194	2.79	0.33	0.21	0.19	7.0	69.6	42.2	9.1	20.3
Brilliance	1.161	0.203	82	2.49	0.215	3.26	0.35	0.22	0.21	8.0	81.7	54.1	9.6	19.2
Significance	***	***	***	***	***	***	***	***	***	*	***	***	***	***
$LSD_{0.05}$[u]	0.18	0.018	0.93	0.14	0.022	0.30	0.038	0.021	0.019	2.96	10.80	12.72	1.11	4.59
CV (%)[t]	8.6	5.8	0.74	4.3	6.3	7.1	7.3	6.2	6.3	22.4	10.7	15.0	7.7	12.3

[z]Stover = aboveground biomass of a single sweet corn plant minus the uppermost marketable ear.
[y]Stover fresh weight determined by taking the mean weight of eight fresh stovers at harvest.
[x]Stover dry weight determined by taking the mean weight of eight oven-dried stovers per plot.
[w]1 lb = 0.4536 kg.
[v]1 ppm = 1 $mg \cdot kg^{-1}$.
[u]$LSD_{0.05}$ = Fisher's protected least significant difference among varieties ($\alpha = 0.05$).
[t]CV = coefficient of variance.
[NS],*,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

water content was generally lower. Thus, dry matter production in the form of an ear was greater, and this influenced nutrient removal values, which were measured and calculated on a dry matter basis. Consequently, nutrient removal values were generally greater for the sweet corn produced in 2004 on the silt loam soil as compared with the crop produced on the sandy loam soil in 2003. In Table 2, the nutrient removal values are averaged across years as the best practical solution available for the purpose of writing nutrient management plans.

Differences in ear size were associated with different varieties. As expected, the early maturing variety, 'Early Choice', had the smallest ear size. Varieties 'Temptation' and 'Double Choice' represented the midseason varieties, and 'Sensor', 'Brocade', 'Silver King', 'Argent', 'Terrific', and 'Brilliance' represented the late-season varieties. The different maturity groups were tabulated separately for the purpose of providing data to support the writing of nutrient management plans that include early, mid-, and late-season varieties (Table 2). Although significant differences in ear size occurred among late-season varieties, nutrient removal values were averaged across varieties to represent late-season varieties as a category. The rationale for this grouping, despite differences in ear size, is that breeding programs will continue to develop new varieties of varying ear size; grouping them represents the best practical solution available for nutrient management.

Depending on whether sweet corn is grown for direct marketing, wholesale, or processing, growers will likely use different units to express crop yield. Thus, the nutrient removal values determined from this study are expressed in Table 2 in both units of ear number and weight. In the mid-Atlantic region, a crate, which consists of 50 ears of a late-season variety, is a popular market unit. Whether expressed as 1000 ears, hundredweight, or crates, nutrient management planners can scale nutrient removal values up to a yield goal per unit land area by multiplication.

Using the nutrient removal data obtained in this study and based on a typical sweet corn yield of 150 cwt/acre (or about 18,396 ears/acre, or about 368 crates), a full-season hybrid would be projected to remove 51 lb/acre N, 9.1 lb/acre P, and 34 lb/acre K. These mean values in the present study for late-season sweet corn obtained for N, P, and K removal agree fairly well with the "nutrient absorption" values of 55 lb/acre N, 8 lb/acre P, and 30 lb/acre K, in *Knott's Handbook for Vegetable Growers* (Maynard and Hochmuth, 1997). A late-season variety at the 150 cwt/acre yield level would also be projected to remove (in lb/acre) 3.7 S, 2.0 Ca, 3.9 Mg, 0.024 B, 0.014 Cu, 0.09 Fe, 0.044 Mn, and 0.072 Zn.

With only 9.1 lb/acre of P or 20.8 lb/acre of phosphate (P_2O_5) removed by a typical sweet corn ear harvest, it is apparent that it may take many harvest years to draw down a very high soil test P level to the optimum range. A long-term study with field corn in North Carolina (Kamprath, 1999) found that more than 13 years of grain harvest may be required to draw a very high soil test P level down to the range where the crop would respond to P fertilization. The application of high rates of P-containing starter fertilizers for early plantings of sweet corn on very high P testing soils will slow the rate of P withdrawal from the soil P reserve. Thus, on soils where it is desirable to draw down soil test P levels, starter fertilizers should supply either none or substantially less than 20.8 lb/acre of P_2O_5. However, when the soil test P level is in the optimum range, and it is desired to maintain this fertility level, a typical starter fertilizer application of 20 lb/acre of P_2O_5 should supply enough P for maintenance.

Use of the data in Table 3 enables nutrient uptake calculations to be made for sweet corn plant residue, or stover, after harvest of the upper fresh ear. Occasionally, after harvest of marketable ears, the remaining sweet corn crop residue is harvested for livestock feed. The data on nutrient removal by harvesting the plant residue (assuming 23,231 plants/acre) in 2004 showed that the remaining sweet corn biomass for the average full-season hybrid contained (in lb/acre) 126 N, 13.4 P, 173 K, 11.6 S, 20.6 Ca, 13.6 Mg, 0.05 B, 0.37 Fe, 0.30 Mn, 0.05 Cu, and 0.13 Zn. Alternatively, the data show that when fresh sweet corn crop residue is tilled into the soil, a significant quantity of nutrients is returned; this has been shown to provide some available N to subsequent crops (Heckman et al., 2002).

This study provides nutrient removal values for just one crop, but data are needed for a fuller range of field-grown horticultural crops than is currently available. Determining nutrient removal values, as a part of conducting crop variety trials, affords an opportunity to gather additional useful data for nutrient management.

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