Fertility Influence of the U.S. Midwestern Soils on Yellow Shoulder Disorder in Processing Tomatoes

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Abstract. The economics of processing tomato production are driven by soluble solids content, viscosity, color, and color uniformity of the fruit. Ripening disorders that affect color are a major limitation to the economic success of processing whole-peel and diced products. The causes of ripening disorders are not completely understood, although it is clear that soil nutritional status, weather, plant genetics, and interactions among these variables are important factors. We sampled both soil and fruit from fields in Michigan, Ohio, and Indiana and were able to correlate soil fertility properties and fruit color. The correlation between soil properties and fruit color was different for fine- and coarse-textured soils. Fine-textured soils presented more frequent, but weaker, correlations with absolute color and within-fruit color differences when compared with coarse-textured soils. For fine-textured soils, exchangeable K correlated with a measure of within-fruit variation, L^* difference (L^*_{diff} ; $r = -0.21$, $P < 0.01$). Other measurements of K nutrition, $K:Mg^{-1/2}$ ratio, K_{act} , and $K\%CEC$, all correlated to the same extent ($r = -0.29$, $P < 0.01$). The highest correlations were identified between soil-available P and L^* ($r = -0.33$, $P < 0.01$) and L^*_{diff} ($r = -0.31$, $P < 0.01$). In coarse-textured soils, exchangeable K correlated with L^* ($r = -0.373$, $P < 0.05$), b^* ($r = -0.49$, $P < 0.01$) and Hue° ($r = -0.37$, $P < 0.05$). $K:Mg^{-1/2}$ ratio and K_{act} yielded higher correlation coefficients with absolute color measurements when compared with fine-textured soils. Soil-available P was correlated with L^* ($r = -0.375$, $P < 0.05$), a^* ($r = 0.49$, $P < 0.01$), Hue° ($r = -0.46$, $P < 0.01$), and C^* ($r = 0.40$, $P < 0.01$). For coarse soils, $K:Mg^{-1/2}$ ratio, K_{act} , and available P were important properties when the color of tomato fruit is of value. In all cases, higher exchangeable K and P nutrient status had a positive correlation with fruit color. Our sampling could not detect interactions among weather, genetics, and soil, and further work will be necessary to clearly describe the role of interactions in determining fruit quality in tomatoes.

Ripening disorders that affect the color of the fruit are a major limitation to the economic success of the tomato processing industry, especially for whole-peel and diced products. Yellow Shoulder Disorder (YSD) is characterized by discolored yellow or green sectors under the peel, near the shoulder of

the fruit. Internal white tissue is considered a less severe expression of YSD (Francis et al., 2000). Negative economic consequences of YSD affect growers through contract incentives and processors through increased costs of peeling (Barrett et al., 2006) and lower product grades (USDA, 1983). Ripening disorders also lower the nutritional potential of the fruit resulting from a reduction of lycopene and beta-carotene in affected tissue (Darrigues et al., 2007).

The causes of ripening disorders are not completely understood, although evidence suggests that soil nutritional status, weather, plant genetics, and their interactions are important factors (Hartz et al., 1999; Sacks and Francis, 2001). Variance partitioning

indicated that 20% to 30% of the color variability of tomato fruits was attributable to location effects. Year-to-year differences attributed to weather accounted for 5% to 10%, and variety differences accounted for 18% to 27% (Sacks and Francis, 2001). The majority of the variability was the result of unknown causes or interactions between variables (25% to 50%). We postulated that location differences are closely tied to soil properties and soil fertility status. Variability of fruit color resulting from soil fertility, in particular soil-exchangeable potassium and magnesium status, had been demonstrated (Hartz et al., 1999). A relationship between soil nutrient status and fruit quality is not surprising; in the greenhouse environment, there was a direct relationship between higher K nutrition and lower incidence of color disorders (Ozgun et al., 1967; Picha, 1987; Picha and Hall, 1981; Van Lune and Van Goor, 1977). The incidence of color disorders had also been linked to high temperature of the pericarp of the fruit and high relative environmental humidity (Picha, 1987).

Nutritional status of soil is influenced by management history, including crop rotation, tillage systems, and application of fertilizers (Brady and Weil, 2002). Intrinsic properties of soils such as mineralogy and texture also influence the level and availability of nutrients (Newman, 1984). Soil nutritional properties that affect YSD had been described for processing tomatoes in California (Hartz et al., 1999). Tomatoes for processing are cultivated in a diverse variety of soils in the Great Lakes region of the United States, ranging in location from the south of Michigan and north of Ohio and spread over the entire state of Indiana. This region encompasses the Major Land Resource Area (MLRA) 111, 98, and 99 (USDA, 1981). These three MLRAs are dominated by Udalfs, Aqualfs, and Aquepts soils. The soils in the area have a mesic soil temperature regime (mean annual soil temperature of 8 °C), and a humid (aquic or udic) soil moisture regime. They are very deep and generally very poorly drained to somewhat poorly drained. Illitic and mixed mineralogy are predominantly associated with these soils. In contrast, soils in central California are dominated by Xeralfs, Xererts, and Xerolls. These soils have a thermic temperature regime (mean annual soil temperature = 15 °C), a dry Mediterranean-like (xeric) soil moisture regime, and mixed or smectitic mineralogy. They generally are very deep, somewhat excessively drained to somewhat poorly drained, and have loamy or clayey texture.

Studies relating the fertility level of soils in the Great Lakes region of the United States with fruit color for processing tomatoes have not yet been reported. Our objective was to combine extensive sampling of soil and tomato fruit in Michigan, Ohio, and Indiana to determine the role of soil fertility properties in determining the color quality of tomatoes in this region.

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Materials and Methods

Selection of sites and soil texture. Fields were originally selected based on grower supplied soil-test data that allowed us to focus on fields that represented regional diversity. We reviewed soil tests from 41 grower fields and a total of 643 soil samples. These samples revealed significant regional variation, and we selected 24 field locations spread over Indiana, Michigan, and Ohio such that the wide range of soil characteristics was represented. Our own sampling also revealed significant within-field variation. We therefore collected and analyzed 241 soil and fruit samples from the 24 fields.

The number of samples per field varied according to its size, ranging from two to 20 samples per field. Each soil sample comprised two adjacent cores separated by 3 m of planted row, an area that we considered a plot for fruit harvest and analysis. Soil surface samples (0 to 30 cm deep) were collected adjacent to the plants (usually within 20 cm), using a soil auger of 5-cm i.d.. The location of each core sample was flagged to delimit plots for later harvesting of fruit.

Soil samples were air-dried and ground for standard fertility analysis. All samples were analyzed by the Service Testing and Research Laboratory (STAR Laboratory) at the Ohio State University, OARDC. Standard analysis was performed according to the most usual method of soil analysis used in the region (Brown, 1998), i.e., Bray P1 extraction to determine available P and ammonium acetate extraction to determine exchangeable K, Ca, and Mg. Cation exchange capacity (CEC) and percent base saturation were estimated from the mineral analysis results. Indices of K activity ($K_{act} = [K]/[Ca + Mg]^{-1/2}$), percentage of CEC occupied by K ($K_{\%CEC}$), and the ratio of $K:Mg^{-1/2}$ were estimated on the basis of $cmol \cdot kg^{-1}$. Organic matter was determined by loss on ignition (Brown, 1998). Soil texture was determined using the hydrometer method (Gee and Bauder, 1986). A composite sample for each location was used for the textural analysis.

Analysis of potassium fixation was performed for 23 composite samples of coarse-textured soils and 39 samples of fine-textured soils representing all fields and geographic regions in this study. The methodology used to determine percent of potassium fixed is described in Hartz et al. (2002).

Fruit sampling and analysis. At least 24 fruit were harvested and analyzed for color from each 3-M plot. Fruit were harvested when fields reached 80% red ripe. A thin (2 to 3 mm) transversal section of the stem end of each fruit was cut, and objective measurements of color were made on the exposed tissue using a CR-300 colorimeter (Minolta, Ramsey, NJ). The CR-300 colorimeter uses an 8-mm diameter measuring area, a $d/0^\circ$ illuminating and viewing geometry and was set to illuminate C. Objective measures of color were collected in the CIELAB color space, where $+a^*$ is the red direction, $-a^*$ is the green direction, $+b^*$ is the yellow direction,

and $-b^*$ is the blue direction. Lightness of color is measured on the L^* axis from 0 (black) to 100 (white). Hue° angle in degrees is a measure of an object's color based on the a^* and b^* coordinates and calculated as $[(180/\pi) \cos^{-1} (a^*/(a^{*2} + b^{*2})^{1/2})]$. Chroma (C^*), a measure of color saturation, was estimated by $(a^{*2} + b^{*2})^{1/2}$ (Sacks and Francis, 2001). Absolute color was estimated from the average of two measurements per fruit. The difference between two color measurements within fruit was used as an estimate of color uniformity and is indicated by the subscript "diff" (e.g., Hue°_{diff}). Large differences in color or high values of Hue° and L^* indicate the presence of YSD.

Scanned pictures of tomatoes were analyzed visually for color. We established empirical cutoff values of L^* at 48 or lower and Hue° of 48° or lower for fruit that are acceptable. A fruit was considered free of yellow shoulder if all four values (two measurements each for L^* and Hue°) were below 48. The percentage of fruit that were free of YSD was then calculated for each plot ($\%YSD_{free}$).

Statistical analysis. The presence of outliers was verified using studentized residual plots against predictor variable. The data set for each soil textural group was composed of 196 plots for fine-textured soil and 45 plots for coarse-textured soils. Analysis of variance followed by a t test was used for mean comparison between soil and fruit variables within textural classes. Linear correlation and Pearson's correlation coefficients (r) were used to detect relationships between soil and fruit color variables. Statistical analysis was performed using STATISTICA 6.0 software (StatSoft, Tulsa, OK).

Results and Discussion

Exploratory statistical analysis suggested that the data set could be divided into two main groups according to textural classes,

fine- and coarse-textured soils. Textural classes were based on the percentage of clay, silt, and sand present in the sample. As a result of its high specific surface area and usually negatively charged surface, only a small percentage of clay (20%) in the soil is required to influence soil fertility and soil structure (Newman, 1984). Fine-textured soils contained more than 20% of clay and a wide range of sand and silt content and included the following classifications in the USDA textural triangle: sandy clay loam, clay loam, silty clay loam, clay, silt loam, and loam. Coarse soils were dominated by sand and silt and included the following soil textures: loamy sand and sandy loam, with sand content ranging from 50% to 100%, and clay content below 20%. Although a wide range of soil texture can be found in Indiana, Michigan, and Ohio, coarse-textured soils were mainly found in southern Michigan and southwest Indiana, hence the small percentage of coarse-textured soils (19%) found in this study with a total of 45 samples of soil and fruit color. The central regions of Indiana and Ohio were dominated by fine-textured soils and correspond to 81% (196 of 241) of the samples. The textural classification adopted in this work also overlaps the mineralogical description of the region, where coarse soils tend to have a mixed mineralogy and fine soils are dominated by illitic mineralogy. We believe that by classifying soils of different textures, we can better evaluate the influence of fertility and certain physical properties, in this case texture, that are easily identified by growers.

Characterization of the soils into fine and coarse was supported by objective data (Table 1). Soil properties were significantly different in all instances, with the exception of pH. Fine soils had higher levels of exchangeable K, Ca, and Mg, percent organic matter, and K fixation. However K_{act} , Ca/Mg, and $K:Mg^{-1/2}$ ratios were higher in coarse soils. Soil texture, clay content, and organic matter content are linked with cation fixation,

Table 1. Mean values and SD for soil properties in fine and coarse soils.²

	Mean	SD	Mean	SD	
	Fine soil		Coarse soil		P value
Sand ^y	31.91	13.87	69.34	8.65	0.000
Clay ^y	32.19	5.00	15.47	3.27	0.000
Silt ^y	35.90	14.11	15.19	5.95	0.000
pH	6.40	0.53	6.37	0.72	0.701
OM ^y	3.12	0.85	2.17	0.90	0.000
CEC ^x	15.31	5.33	7.64	3.83	0.000
K ^y	0.52	0.20	0.42	0.17	0.001
K fixed ^w	16.20	12.18	6.15	3.65	0.000
Ca ^x	9.57	3.12	4.94	2.98	0.000
Mg ^x	2.56	1.07	0.90	0.65	0.000
$K:Mg^{-1/2}$ ratio	0.34	0.11	0.49	0.20	0.000
K_{act}	0.15	0.05	0.18	0.07	0.000
Ca/Mg ratio	4.02	1.22	6.76	3.51	0.000
$K_{\%CEC}^w$	3.76	1.68	6.26	2.87	0.000
p^x	64.08	26.84	84.56	47.08	0.001

²P values refer to t test for mean comparison between fine- and coarse-textured soils.

^yPercent basis.

^x $cmol \cdot kg^{-1}$ basis.

^w $ug \cdot g^{-1}$ basis.

OM = organic matter; CEC = cation exchange capacity.

CEC, leaching of mobile nutrients and transport of ions, hence the higher K fixation of fine-textured soils (Brady and Weil, 2002; Newman, 1984). On average, tomatoes grown in soils with fine texture had darker color (lower L* and Hue° values), and a higher percentage of fruits free of YSD. Intensity of color (C*) and within-fruit differences in C* measurements were not significantly different between the two soil groups. However, fruits grown in fine soils had more uniform color as indicated by lower Hue°_{diff} within fruit relative to coarse-textured soils. These results (Tables 1 and 2) showed that soil properties and fruit color for the fine and coarse groups were significantly different and suggested that the two textural classifications might be appropriate for separate statistical analysis. More importantly, the results suggested that soil texture should be considered when managing the color quality of tomato fruit.

Linear regression and Pearson's correlation coefficients were used to evaluate the

relationship between color traits and soil fertility properties within each soil group (Table 3). For fine-textured soils, pH correlated with L*_{diff}, whereas for coarse-textured soils, pH was not significantly correlated with any of the color traits. Soil pH will affect the availability of soil nutrients essential to plant growth, having an optimum range between 5.5 and 7.5 (Wienhold et al., 2004). Both soil management groups identified in this study had pH values well within the optimum range, with the exception of one field that showed an average pH value of 4.87.

Percent organic matter correlated with L*, b*_{diff}, and C*_{diff} for fine-textured soils, but showed no correlation with color traits for coarse-textured soils. The influence of organic matter in fruit color for these soils was not clear. Although organic matter (OM) showed a negative correlation with L*, suggesting that fruit were darker (lower L*) as OM increased, color differences within fruit, expressed by b*_{diff} and C*_{diff}, increased as OM increased. The fact that OM had ambig-

uous effects on color in fine-textured soils, improving L* while also increasing C*_{diff}, might be linked with organic matter functions in the soil. Soil organic matter affects nutrient availability, water retention, soil aggregation, CEC, and nutrient availability (Brady and Weil, 2002). For this study, levels of organic matter correlated with calcium ($r = 0.74$, $P < 0.01$ for fine soils and $r = 0.78$, $P < 0.01$ for coarse soils) and magnesium content ($r = 0.68$, $P < 0.01$ for fine soils and $r = 0.61$, $P < 0.01$ for coarse soils) but showed poor correlation with exchangeable K, cation indices, and available P for both soils (data not shown). Organic matter content was previously found to have a detrimental effect on tomato fruit quality (soluble solids, titratable acidity, and color) as a result of increased water availability at the ripening stage (Colla et al., 2000). A more comprehensive study of soil physical, chemical, and biological properties affected by soil organic matter is necessary to understand its relationship with fruit quality.

Levels of Ca and Mg did not correlate with any absolute color trait in both soil groups considered. Calcium and Mg showed weak correlations with color differences in fine-textured soils; Ca correlated with C*_{diff} and Mg correlated with a*_{diff} and C*_{diff} (Table 3). For California conditions, soil Ca did not influence the color of tomato fruit; however, Mg content presented a positive correlation with color disorders with correlation coefficients ranging from 0.30 to 0.36 (Hartz et al., 1999). In our sample, both Ca and Mg content correlated positively with C*_{diff}, meaning that increases in either of these two minerals in the soil tended to increase C* differences within fruits. The same trend was valid for Mg and a*_{diff}, a tendency also observed in California (Hartz et al., 1999). The role of calcium and

Table 2. Mean values and SD for fruit color traits in fine and coarse soils.*

	Mean	SD	Mean	SD	
	Fine soil		Coarse soil		P value
%YSD _{free} ^y	65.73	22.76	48.76	27.92	0.000
L*	42.50	3.22	45.78	3.36	0.000
a*	26.84	3.80	25.76	5.63	0.118
b*	26.06	2.17	26.93	1.89	0.013
Hue°	44.59	5.61	47.25	7.75	0.008
C*	38.10	2.46	38.34	2.87	0.570
L* _{diff}	4.07	1.48	4.35	1.68	0.292
a* _{diff}	4.23	1.87	5.04	2.56	0.016
b* _{diff}	3.21	1.02	2.73	0.94	0.005
Hue° _{diff}	6.62	3.33	8.08	4.41	0.015
C* _{diff}	2.89	0.70	2.57	0.73	0.009

*P values refer to *t* test for mean comparison between fine- and coarse-textured soils.

^yPercentage of fruits free of YSD.

YSD = Yellow Shoulder Disorder.

Table 3. Pearson's correlation coefficients for soil properties and fruit color traits in fine- and coarse-textured soil.

	pH	OM	K	Ca	Mg	K·Mg ^{-1/2}	K _{ACT}	K% CEC	P
Fine soils									
%YSD _{free}	0.131	0.020	0.078	-0.035	-0.084	0.140	0.133	0.144*	0.218*
L*	-0.126	-0.201*	-0.089	0.039	-0.067	-0.032	-0.126	-0.146*	-0.325**
a*	0.113	0.051	0.123	-0.100	-0.126	0.225**	0.202**	0.161	0.208
b*	-0.105	-0.007	-0.040	-0.076	0.014	-0.053	-0.027	-0.070	-0.122
Hue°	-0.124	-0.040	-0.102	0.052	0.114	-0.189**	-0.160*	-0.148*	-0.213**
C*	0.041	0.050	0.080	-0.122	-0.089	0.152*	0.148*	-0.087	0.079
L* _{diff}	-0.140*	0.104	-0.209**	0.106	-0.072	-0.291**	-0.285**	-0.290**	-0.310*
a* _{diff}	-0.070	0.033	-0.139	0.130	0.165*	-0.256**	-0.227**	-0.218**	-0.263**
b* _{diff}	-0.028	0.210**	-0.142*	0.076	-0.120	-0.263**	-0.200*	-0.211**	-0.219**
Hue° _{diff}	-0.062	-0.011	-0.106	0.103	0.137	-0.202**	-0.176*	-0.180**	-0.276**
C* _{diff}	-0.023	0.243**	-0.160*	0.170*	0.207*	-0.330**	-0.271**	-0.226**	-0.056
Coarse soils									
%YSD _{free}	-0.072	0.134	0.284	-0.121	-0.196	0.396**	0.367*	0.142	0.479**
L*	0.126	-0.190	-0.373*	0.085	0.160	-0.454**	-0.486**	-0.188	-0.375*
a*	0.002	0.118	0.281	-0.010	-0.096	0.360*	0.288	0.096	0.488**
b*	0.214	-0.111	-0.489**	0.017	0.009	-0.444**	-0.503**	-0.230	-0.269
Hue°	0.080	-0.122	-0.369*	0.005	0.066	-0.407**	-0.372*	-0.130	-0.458**
C*	0.153	0.060	-0.021	-0.054	-0.163	0.141	-0.002	-0.048	0.395**
L* _{diff}	0.115	-0.183	0.010	-0.032	0.170	-0.098	0.012	0.273	-0.212
a* _{diff}	0.050	-0.129	-0.043	0.063	0.205	-0.157	-0.061	0.087	-0.162
b* _{diff}	0.143	-0.194	-0.095	-0.109	0.067	-0.103	-0.047	0.280	-0.254
Hue° _{diff}	0.065	-0.127	-0.057	0.050	0.185	-0.133	-0.057	0.118	-0.216
C* _{diff}	0.145	-0.126	-0.185	-0.039	0.050	-0.297	-0.222	0.025	-0.182

*,**Significant at $P \leq 0.05$ and 0.01 , respectively.

OM = organic matter; YSD = Yellow Shoulder Disorder; CEC = cation exchange capacity.

magnesium in color disorders might be related to potassium–calcium–magnesium interactions in the soil and tissue composition of the plant (Syedomar and Sumner, 1991; Wilkinson et al., 2000). The ratio of nutrients K, N, P, and Ca was shown to correlate with the incidence of ripening disorders in greenhouse tomatoes (Winsor et al., 1961). Similarly, Collin and Cline (1966) reported that increase in Ca content in the nutrient solution increased ripening disorders of greenhouse tomatoes.

Soil-exchangeable potassium was reported to have significant influence on color disorders (Hartz et al., 1999; Picha, 1987; Picha and Hall, 1981). We found a strong relationship between exchangeable K and fruit color for coarse soils with significant correlations for L^* , b^* , and Hue° (Table 3). Correlation coefficients were higher than those identified in California (Hartz et al., 1999). However, for fine-textured soil, exchangeable K did not correlate with any absolute color measurement and was only weakly correlated with L^*_{diff} , b^*_{diff} , and C^*_{diff} . In both textural types, higher exchangeable K had a positive effect on color and color differences in the fruit. Individual soil cations did not correlate with %YSD_{free} fruit for either textural group. Because %YSD_{free} is based on L^* and Hue° cutoff values, it is possible that the correlations of exchangeable K and L^* and Hue° for coarse soils were not strong enough to translate into significant correlation with %YSD_{free}. Although not statistically significant, there was a tendency of %YSD_{free} fruits to be positively influenced by soil K and negatively influenced by increases of Ca and Mg in the soil.

Stronger correlations of soil nutrients and fruit color were found when the ratio of cations in the soil, expressed by the indices $K:Mg^{-1/2}$, $K\%_{CEC}$, and K_{act} , were used instead of individual nutrients (Table 3). All three indices correlated similarly to absolute color and color differences in fine-textured soils with stronger correlations for color differences within the fruit. An increase of the indices, corresponding to a relative increase in soil-exchangeable K compared with Ca or Mg, improved absolute color, expressed by negative correlations with L^* , b^* , and Hue° , and positive correlations with a^* and C^* . $K:Mg^{-1/2}$ showed the highest correlation among all indices, agreeing with previous work (Hartz et al., 1999). Correlations were more frequent but weaker (maximum $r = -0.330$) for fine soils relative to coarse soils (Table 3). Absolute color and %YSD_{free} fruit were strongly correlated with $K:Mg^{-1/2}$ ratio and K_{act} (maximum $r = -0.503$) in coarse-textured soils. However, $K\%_{CEC}$ was not correlated with any color traits for coarse soils (Table 3). The apparent importance of mineral ratios may be the result of strong chemical interactions among cations and clay minerals in the soil, regulating release and availability of nutrients to the plants, as well as plant nutrient uptake (Newman, 1984). Greenhouse experiments also indicated the

importance K/Ca ratio in culture solution on ripening disorders of tomatoes (Van Lune and Van Goor, 1977). Cation indices, especially $K:Mg^{-1/2}$ ratio and K_{act} , appeared to be a more sensitive tool than the absolute values of individual nutrients to describe the complex interaction of nutrients in the soil.

Soil-available phosphorus correlated with all color traits, except a^* , b^* , C^* , and C^*_{diff} in coarse-textured soils (Table 3). Soil P showed the highest correlations among all soil properties in fine-textured soils with L^* and L^*_{diff} ($r = -0.325$ and $r = -0.310$). The relationship between soil-available P and color traits was not expected based on previous work in the field. Soil-available P had been reported in the literature as having no influence on YSD (Hartz et al., 1999). In all instances, higher soil P was positively correlated with color, increasing the percentage of fruit free from YSD and decreasing L^* and Hue° . Increased P was also correlated with decreased color differences for fine-textured soils, including a significant decrease in L differences in the fruit (Table 3).

There is some evidence in the literature for a potential role of phosphorus nutrition in color disorders, although the physiological role is not clear. Greenhouse experiments showed that high P nutrition significantly decreased the incidence of green back, a type of ripening disorder (Winsor and Long, 1967). However, the same study indicated that high P concentrations could have negative effects relative to other ripening disorders (Winsor and Long, 1967). There are indications that fruit tissue affected by color disorders contains less than half the P and K levels when compared with red tissue (Picha, 1987), suggesting a role for both nutrients.

Soil-available P correlated with every soil property for fine-textured soil, with the exception of %OM, ranging from $r = 0.65$ for $K\%_{CEC}$ to $r = -0.21$ for Ca/Mg ratio. Available P did not correlate with Ca, Mg, $K:Mg^{-1/2}$ ratio, or K_{act} for coarse-textured soils (data not shown). The inconsistent correlations among available P and other soil properties in both soil types suggested that the role of phosphorus in tomato color is not an indirect consequence of other soil properties. Soil-available P correlated poorly with cation indices yet still had a positive correlation with the color of fruit in coarse-textured soils (Table 3). The role of soil-available P remains to be clarified by experimentation under both controlled and field conditions.

Results of linear correlation indicated that management of yellow shoulder and fruit color at the field level should be a function of the overall fertility and quality of the soil. The influence of potassium, either in nutrient solution or soil conditions, on reducing the incidence of ripening disorder is well documented (Hartz et al., 1999, 2005; Ozbun et al., 1967; Picha, 1987; Winsor and Long, 1967). Our results also suggested an important role for soil-available phosphorus in absolute and color differences. Future recommendations on soil fertility targeting YSD in processing tomatoes for different soil types

should take into consideration the interaction of cations and the role of available P. The correlation between soil fertility and color of the fruit may be used as a predictive tool to identify soil prone to YSD. In addition, the results of this study suggested that management strategies to optimize fruit quality should differ for coarse soils and fine-textured soils.

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