The Influence of Mineral Nutrition and Fungicides on Russeting of 'Goldspur' Apple Fruit[1]

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Abstract. Altering the elemental content of 'Goldspur'/M.26 apple tree leaves and fruits affected fruit russet but did not reduce it to acceptable levels. Multiple regression analyses indicated that fruit size and elemental content variables accounted for 57.5% of the russeting variance. Fruit size had a greater negative correlation with fruit russeting than any element. Fruits collected from 'Goldspur'/MM.106 apple trees growing beneath plastic canopies and treated with different fungicides had a higher finish than those from trees outside the canopies. Dodine-treated fruits were more russeted than fruits receiving metiram or no fungicides.

The value of 'Golden Delicious' apples grown in humid environments is reduced by russet. Although russet was once acceptable, today's consumer will select and pay more for a russet-free 'Golden Delicious' apple than for one marred by russet. Fruit growers, aware of the change in consumer preference, are anxious to have the russeting problem solved.

The russeting phenomenon received considerable attention long before it became directly important to the consumer. It was and is considered to be an important limiting factor in the storage life of fruit (8). Since 1897, numerous studies have been conducted to determine the cause of 'Golden Delicious' russet in humid climates (5, 12). Those review articles point out that the problem still remains unsolved. However, most researchers consider 1 characteristic of the fruit cuticle to be important in russet development. The cuticle is comprised of a grossly cracked, amorphous wax which exposes the epidermis. This characteristic is peculiar to this cultivar regardless of where it is grown (4, 7, 8).

Of the various russeting factors investigated, 3 may account for the higher russeting incidence in PA than in the northwestern United States. These are nutrition, fungicides, and precipitation. Relative humidity, per se, is considered unimportant because 'Golden Delicious' fruit growing on dwarf trees in a local greenhouse were smooth and nearly russet-free. The small amount of russet was limited to lenticels.

This study was conducted to test the hypothesis that nutrition and fungicides are important factors in "normal" 'Golden Delicious' fruit russeting. "Normal" russet as used here refers to russet arising in orchards where there has been no frost, elemental deficiencies, powdery mildew, or mechanical injury to the fruit.

Materials and Methods

Mineral nutrition. In the spring of 1970, 2-year old 'Goldspur'/M.26 apple trees were planted in 114-liter drums lined with a 247-liter plastic bag and filled with pure quartz sand. Approximately 30 drainage holes 1.27-cm in diam were punched through the bottom of the liner and drum using a pointed rod. Prior to planting the trees, each drum was placed in a hole in the soil where it rested on a gravel layer surrounding a tile drainage ditch. Nine drums were placed 1.8 m apart in each of 6 rows that were 3.6 m apart. This provided a randomized complete block statistical design of 9 treatments with 6 replications. Each drum was fitted with a lid to keep out rainwater. The lid was removed at the end of each growing season and replaced in the spring.

The first 3 growing seasons were required to establish the proper nutrient concn and to stabilize the trees to the different treatments. Table 1 lists the concd nutrient solutions established as optimum and used during the 1973 growing season. N, P, K, and Mg were selected as the nutrient variables based on a report by Eggert and Mitchell (2). The nutrient solutions were injected into 9 separate trickle irrigation systems at the rate of 1 liter per hr beginning 2 weeks before anticipated bloom and ending at harvest. The pH of the nutrient solutions ranged between 6.2 and 6.8. After the concd nutrient solution was pumped into the irrigation water, the water entered a header where six 0.193-cm (I.D.) supply lines were attached.[3] A supply line went to a tree in each row designated to receive that nutrient treatment. The discharge rate of 2.3 liters per tree was regulated by cutting the proper length of 0.091-cm (I.D.) tubing and inserting it into the end of the supply line. The minor nutrient elements in each solution concentrate were $MnCl_2$, $ZnSO_4$, $CuSO_4$, H_3BO_3, FeEDTA, and Na_2MoO_4 at .025, .012, .032, .198, .228, and .0011 mM, respectively.

The trickle irrigation and nutrient injection systems were automated. Each day the trickle irrigation systems were activated 15 min before the nutrient solution pumps started and deactivated 30 min after the pumps had stopped. This allowed the pressure in the systems to stabilize before nutrient injection began and flushed the lines after injection stopped. The injection systems were designated to operate 4 hr a day, 5 days a week, after which the concd solutions were renewed. Electric stirrers were activated for 20 min before solution injection began the first 3 days following the mixing of each new concentrate solution. This successfully prevented the accumulation of nutrient precipitates. While the nutrient injection pump operated 5 days a week, the irrigation system operated an additional 2 days to leach excess salts. Periodic tests indicated that there was no salt accumulation in the sand during the experiment.

The trees were not pruned, except for removing dead or diseased limbs. After fruiting began in 1971, each tree was thinned to a maximum of 30 fruits. The standard disease and pest control practices for high-finish fruit were followed.

In 1973, 30 leaves were collected from the middle of random shoots around each tree on July 20 and August 20. The leaves were dried, ground, and 1 g of sample ashed overnight at 396°C. P, K, Ca, Mg, Mn, Fe, Cu, B, Zn, and Na were determined by an electrical arc emission spectrophotometer. Total N was determined by the standard Kjeldahl method.

Twenty harvested fruits were selected to be measured for circumference and degree of russeting. The amount of russet on each fruit was estimated using a scale of 1 to 10; 1 representing no russeting. Six apples were taken at random for elemental analysis of the peel and flesh. They were immersed briefly in tap and distilled water, respectively. The peel was removed from the fruit with a razor and composited. The flesh samples consisted of a ½-inch longitudinal wedge-shaped portion along the full length of the fruit. Portions from the 6 apples were composited. The peel samples were dried for 72 hr and the flesh samples for 2 weeks at 70°C before grinding. After grinding, 1 g of peel sample and 3 g of flesh sample were ashed and

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analyzed following the same procedures used for the leaf samples.

Analysis of variance of the 1973 data and mean separations were done according to Duncan's Modified (Bayesian) Least Significant Difference (DLSD) Test (k = 100) (11). The correlation and step-down multiple regression coefficients comparing fruit russet to fruit circumference and elemental content of leaves, peel, and flesh were determined also.

Plastic canopy. Clear 4-mil, conical plastic canopies, 2.5 m in diam by 2.1 m high, were placed over nine 6-year old 'Goldspur'/MM.106 apple trees growing in an orchard. The canopies were positioned over the trees at petal fall and left until after fruit harvest. The canopies protected the fruit from precipitation wetting and routine spray contamination. Air temperature differences inside and outside were minimized by raising the canopy 60 cm above the ground and having a 45 cm diam ventilation hole in the top. A small roof was placed 25 cm above the ventilation hole to exclude rain. Monitoring of the relative humidity and temperature using hygro-thermographs located inside and outside of the canopies showed that the maximum temperature differences ranged from 0.5 to 1.5°C during the 2 warmest hr of the day. Both temperatures were the same the remainder of the day. Except for rainy days, the relative humidity between 1:00 and 6:00 P.M. would drop to 40% outside while only to 70% inside the canopies.

Three fungicide spray treatments with 3 replications were each applied to trees beneath the canopies. Dodine (*n*-dodecylguanidine acetate at 0.33 g per liter and metiram (ethylene bis (dithiocarbamate) zinc 80%) at 1.92 g per liter were each applied spearately to the same 3 trees every week for 13 weeks beginning 1 week after petal fall. The remaining 3 canopied trees received no fungicide application. Carbaryl (1-naphthyl methylcarbamate) plus dicofol (4,4'-dichloro-*a*-(tricholoromethyl) benzhydrol) at 1.20 and 0.42 g per liter, respectively, were applied every 14 days to all trees beneath the canopies to control insects. Three noncanopied trees served as checks and received the regular orchard sprayings with captan (*n*-((trichloromethyl) thio)-4-cyclohexene-1,2-dicarboximide). A clear plastic covering was placed beneath each of the non-canopied trees about 45 cm above the ground to maintain the same soil moisture content. Emitters in a trickle irrigation system were calibrated to deliver the same amount of water to each tree.

The fruit from each tree was observed continuously for russet development. At harvest, 20 apples were taken randomly from each tree and measured for circumference and rated for russeting. The russet ratings varied from 1 to 10: 1 meant no russeting; 2 represented lenticular russeting; 3 to 9 indicated increasing amounts of interlenticular russeting; and fruits that were completely russeted were rated 10. Two sets of 6 fruits each were selected from lots of nonrusseted and heavily-russeted fruits. Peel and flesh samples were collected and analyzed for elemental content.

The fruit russet and circumference data from each treatment were analyzed statistically by analysis of variance and means were separated by the DLSD Test. Data from the peel and flesh elemental analysis were analyzed using the Student's t-test since only 2 treatment means were involved for each element.

Results and Discussion

Mineral nutrition. Preliminary tests in 1972 indicated that fruit russeting and elemental content of leaves collected June 15 and July 28 were not related. There were no significant differences between treatment means of any of the elements, yet there were fruits with varying degrees of russet.

The 1973 leaf analyses indicated that treatments successfully stratified the N, P, K, and Mg levels within the ranges desired (Table 2). The nutrient treatments effectively varied the amount of russet and circumference of the fruit (Table 3). Although there were significant differences in fruit russet, the lowest amount with a value of 6.1 was not commercially acceptable.

The high N treatment produced trees with short terminal growth, small fruit, and depressed leaf Ca levels (Tables 2 and 3). Prior to 1973, $NaNO_3$ had been used rather than NH_4NO_3 with opposing results. The $NaNO_3$ usage was discontinued following peel and flesh analysis in 1972 showing 'Golden Delicious' fruits grown in the west

Table 1. Concn of the nutrient elements in each solution concentrate injected into the trickle irrigation system and the final nutrient concn delivered to each 4-year old 'Goldspur'/M.26 apple tree growing in sand.

Treatment	Molarity (mM)						
	$Ca(NO_3)_2$	$CaCl_2$	KH_2PO_4	KCl	$MgSO_4$	KNO_3	NH_4NO_3
Control	32.8 (4.0)	5.4 (0.7)	6.6 (0.8)	22.0 (2.7)	8.5 (1.0)	0 (0)	0 (0)
Low N	7.4 (0.9)	29.2 (3.6)	6.6 (0.8)	22.0 (2.7)	8.5 (1.0)	0 (0)	0 (0)
High N	36.0 (4.4)	0 (0)	6.6 (0.8)	0 (0)	8.5 (1.0)	21.7 (2.7)	78.7 (9.7)
Low P	31.7 (4.0)	5.4 (0.7)	2.2 (0.3)	26.1 (3.2)	8.5 (1.0)	0 (0)	0 (0)
High P	31.7 (4.0)	5.4 (0.7)	20.2 (2.5)	8.2 (1.0)	8.5 (1.0)	0 (0)	0 (0)
Low K	29.6 (4.0)	5.4 (0.7)	6.6 (0.8)	2.4 (0.3)	8.5 (1.0)	0 (0)	0 (0)
High K	31.7 (4.0)	5.4 (0.7)	6.6 (0.8)	77.4 (9.5)	8.5 (1.0)	0 (0)	0 (0)
Low Mg	32.8 (4.0)	5.4 (0.7)	6.6 (0.8)	22.0 (2.7)	2.8 (0.3)	0 (0)	0 (0)
High Mg	31.7 (4.0)	5.4 (0.7)	6.6 (0.8)	22.0 (2.7)	25.5 (3.0)	0 (0)	0 (0)

Table 2. The effect of different fertilizer treatments on the elemental comparison of leaves collected July 20, 1973 from 4-year old 'Goldspur'/M.26 apple trees growing in sand.[z, y]

Treatment	Major elements (%)					Minor elements (ppm)					
	N	P	K	Ca	Mg	Mn	Fe	Cu	B	Zn	Na
Control	2.84bc	.23abc	1.38d	.90c	.28d	55ab	97a	6a	24ab	88a	59a
Low N	2.63a	.22ab	1.56e	.77bc	.23b	54ab	117a	8b	30d	127b	74a
High N	3.27e	.26c	1.06c	.25a	.25c	62b	123a	7ab	23a	122b	62a
Low P	2.70ab	.21a	1.55e	.82bc	.27cd	53ab	94a	7ab	23a	105ab	58a
High P	3.08d	.34d	.76b	.70b	.27cd	45a	101a	7ab	26bc	90a	62a
Low K	2.89c	.25c	.62a	.76bc	.36e	54ab	94a	6a	26c	94a	58a
High K	2.83bc	.24bc	2.01f	.69ab	.22b	55ab	91a	8b	23a	87a	59a
Low Mg	2.89c	.23abc	1.56e	.75bc	.16a	62b	110a	7ab	27c	83a	64a
High Mg	2.81bc	.26c	1.37b	.83bc	.40f	52ab	89a	7ab	23a	95a	62a

[z] Mean separation, within columns, by Duncan's modified (Bayesian) least significant difference test (DLSD) at the 5% level.
[y] Averages of 6 replications.

Table 3. The effect of different fertilizer treatments on shoot length, fruit russet, and fruit size of 'Goldspur'/M.26 apple trees growing in sand.[z]

Treatment	Shoot length (cm)[y]	Fruit russet[x, w]	Fruit circumference (cm)[x]
Control	24.0d	6.1a	7.68c
Low N	19.5b	6.1a	7.39c
High N	18.0a	9.6e	6.46a
Low P	25.0de	7.0abcd	7.50c
High P	22.5c	7.9d	7.00b
Low K	26.0e	7.8cd	6.82b
High K	25.5e	6.6abc	7.62c
Low Mg	24.0d	6.2ab	7.66c
High Mg	22.5c	7.4bcd	7.56c

[z] Mean separation, within columns, by DLSD at the 5% level.
[y] Average of 6 replications with 6 shoots per subsample.
[x] Average of 5 replications with 20 fruits per subsample.
[w] Values represent a rating of 1 to 10, where 1 indicates no russeting and 10 indicates no epidermis remaining on the fruit.

higher in Na than those grown in the east. Similar responses to NH_4-NO_3 have recently been reported by other scientists (1, 3, 13). Since the high N treatment produced results unexpected for high levels of N, it was excluded from the simple correlation (*r*) and multiple regression analyses.

The simple correlations indicated that fruit size was the most important variable influencing fruit russet (Table 4). Larger fruit were less russeted than smaller fruit in agreement with some reports but not others (12). There were no significant *r* values between fruit russet and the elemental content of the fruit peel and flesh. Leaf K and Mg, and perhaps P and Fe, appeared to separately influence russeting. The positive Mg and negative K correlations to increasing amounts of russeting are similar to those reported by Eggert and Mitchell (2).

Although there were statistically significant *r* values, the accumulative effect of all combined in a multiple regression analysis accounted for only 57.5% of the explained variance (Table 5). These results suggest that nutrition is not the principal factor influencing "normal" russet.

Plastic canopy. Fruit from check trees were more russeted than dodine-treated fruits with the highest finish occurring on fruits from the metiram and no fungicide treatments (Table 6). This agrees with other reports (9).

It is important to note that precipitation alone increased the amount of russet. Dodine is known to produce considerably more russet than captan[4]. However, the rain plus captan induced more russeting than dodine alone. Rain may wash spray materials into the cuticle cracks or it may alone, upon entering the cracks, increase the cell turgor pressure sufficiently to rupture the cells (5). Reducing the amount of time the cells are exposed to water may reduce russet and may explain why fruit grown on hillsides under good drying conditions have less russet than fruit grown in low spots (12). It is equally important to know that smooth fruit can be obtained in spite of high humidity (10), by protecting the fruit from precipitation and harmful fungicides (9). Inter-lenticular russeting on fruit from the check and dodine-treated trees was visible approximately 4 weeks after petal fall. Lenticular russeting was not clearly visible on the untreated and meritam-treated fruit until the fruit began to lose its green color.

Elemental analysis of the peel and flesh of russeted and non-russeted fruit revealed no significant differences. This information coupled with that from the nutritional studies provide a convincing argument that nutrition has little effect on "normal" russeting.

It would appear that future russet research should be directed towards modifying the wax structure of the 'Golden Delicious' fruit cuticle to eliminate the cracks that appear. This might be done through a breeding program or altering the structure chemically (5, 6). Elimination of the cracks would keep precipitation and spray materials from coming in contact with the epidermis and causing injury. The importance of these cracks is emphasized by the fact that most of the russeting on the untreated trees under the canopies was limited to the lenticels.

[4] Tree Fruit Production Recommendations for PA, The PA Cooperative Extension Service, The Pennsylvania State University, University Park, PA 100 pp.

Table 4. Simple correlations (*r*) between fruit russet and fruit size and between fruit russet and individual elements in fruit and leaf samples taken from 4-year old 'Goldspur'/M.26 apple trees growing in sand.

Variable	Fruit sample		Leaf sample	
	Apple peel	Apple flesh	July	August
Fruit size	−.650**	−.650**	−.650**	−.650**
N	.022	.114	.253	−.182
P	.234	.257	.347**	.250
K	−.178	−.451	−.467**	−.549**
Ca	.212	.102	−.017	.122
Mg	−.209	−.044	.450**	.426**
Mn	−.191	−.190	−.203	−.078
Fe	−.058	−.180	−.002	−.383*
Cu	−.024	−.031	−.101	−.213
B	.184	.196	−.146	−.247
Zn	.092	−.079	−.001	−.066
Na	.137	−.075	.049	−.022

* Significant 5% level
** Significant 1% level

Table 5. Multiple correlation coefficients (*R*) comparing fruit size and content of 11 elements in apple flesh and peel and in leaves collected during July and August on incidence of fruit russeting. Samples were taken from 4-year old 'Goldspur'/M.26 apple trees growing in sand.

Source	Multiple correlation coefficient (*R*)	Percent of explained variance (R^2)
Apple peel sample	.737	54.4
Apple flesh sample	.712	50.7
July leaf sample	.758	57.5
August leaf sample	.751	56.3

Table 6. The effect of fungicides and exposure to environmental conditions on 'Goldspur' apple fruit finish.[z, y]

Treatment	Fruit Russet[x]	Fruit Size (cm)
Check[w]	6.2c	7.50a
Dodine	3.5b	7.80b
Meritam	2.3a	7.85b
No Fungicide	2.2a	7.78b

[z] Mean separation, within columns, by DLSD at the 5% level.
[y] Average of 3 replications with 20 fruit subsamples per replication.
[x] Values represent a rating on a scale of 1 to 10 where 1 indicates no russeting and 10 indicates all surface russeted remaining on the fruit.
[w] Fruit from trees not under a plastic canopy and receiving captan as a fungicide.

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Effect of Delays between Harvesting and Drying on Kernel Quality of Walnuts[1]

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Abstract. During 2 successive seasons, and several experiments, trees of *Juglans regia* cvs. Payne and Hartley were shaken and the walnuts were allowed to remain on the ground in sun or shade up to 72 hr before drying. Kernel temperature exceeded air temperature, sometimes by more than 10°C in those walnuts which were exposed to the sun, while those in the shade remained below air temperature. When the ambient air temperatures exceeded 35°C, extensive kernel quality loss occurred in shaded walnuts. At lower air temperature the market value of sun-exposed walnuts was decreased. Under high air temperature sun-exposed walnuts with hulls lost more market value than walnuts without hulls. Moisture content of the hull at time of exposure had no major effect on kernel quality. The greatest loss of kernel quality occurred when walnuts were exposed to midday sun.

In establishing the market value of walnut kernels, quality of the edible product, as determined by the pelicle color and insect damage, is of primary importance. While the CA walnut crop was of higher quality in 1973 than in other years, the average quality of walnut kernels was considerably below its potential (2). Among the factors which affect kernel quality are climate, cultivar, pruning, pest control, irrigation, and harvest procedures. However, little is known on the effect of delay of walnut drying after harvest on kernel quality as determined by pelicle color.

California walnuts are mechanically shaken to the ground, windrowed, picked up, hulled, and dried. The grower normally begins harvest when about 80% of the walnuts are removable. We evaluated the effect of delays between harvest and drying on kernel quality, comparing the following: 1) sun or shade exposure with walnuts laying on the ground for 3, 6, 9, 24, 48, and 72 hr; 2) presence or absence of hulls on sun-exposed walnuts; 3) hull moisture content on sun-exposed walnuts; 4) correlation between air temperature and kernel temperature both in the sun and shade, and on the tree or ground; and 5) time of day when the walnuts were placed in the sun or shade.

Materials and Methods

In 1972 and 1973 mature trees of walnut cvs. Payne and Hartley were selected for this study in Visalia, CA, with 8 replicates of 2 trees per cultivar. When 80% of the walnuts were judged removable, they were shaken onto a canvas with a conventional mechanical shaker and then dumped at the base of the tree. For each treatment 80 random walnuts with and without hulls were taken from the paired trees, 40 from each tree, and placed in a nylon mesh bag.

Control samples were immediately hulled and taken to the drier while all other samples were placed as specified in either sun or shade for various exposure time periods, then hulled and dried at 40°. Subsequent to drying, the walnut kernels from all samples were evaluated by the Diamond Walnut Growers, Inc. for quality, including kernel color and insect damage, using USDA standard procedures (1). These standards placed descreasing value on the following color categories: Light, Light Amber, Amber and Offgrade. The value of kernels was calculated from a 5-year average received in California.

In the 1972 test air temperature during the experiment was monitored with a standard thermograph located in the shade of the test area. Hull and kernel temperatures were measured periodically with a Telethermometer having a hypodermic probe. In 1973, to more closely monitor kernel temperature, a 24-point constant temperature recorder was utilized with copper-constantan thermocouples inserted into kernels via the stem end of the walnut.

Identical procedures were followed 2 weeks later for the second harvest from the same trees, to account for the remaining 20% of the crop. In 1973, the second harvest was eliminated as air temperature was judged too mild to induce quality loss.

Two additional tests were conducted with 'Payne' in 1973. The effect of the time of day was evaluated by placing sample walnuts in the sunlight hourly, starting at 0800 and continuing until 1600. After 3 hr exposure, sample walnuts were hulled and dried and kernel quality was determined. In the other test, walnuts with tight non-dehiscent hulls (46% moisture), dehiscent hulls (33% moisture), and no hulls were placed in the sunlight or shade. Moisture percent was determined by weighing random samples before and after oven drying. After 3 or 6 hr, the walnuts were hulled and dried, and kernel quality determined. In a related test with 'Hartley', walnuts with and without hulls were exposed to the sun for 3, 6, 9, and 24 hr, then pulled and dried, and kernel quality was determined as in 1973 tests.

Results

Drying delays of walnuts exposed to sun or shade. In 1972, first harvest (Sept. 6) 'Payne' walnuts held in sunlight for only 3 hr exhibited a reduction in quality, judged by percent Light kernels (Fig.

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